European Commission

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

Final Study Report

Phase 2: Preparatory study

Main report

30 October 2025

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

EUROPEAN COMMISSION

Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs
Directorate Directorate I: Mobility & Energy intensive industries
Unit Unit I.3 – Green and Circular Economy

Contact: Davide Polverini
E-mail: davide.polverini@ec.europa.eu
European Commission
B-1049 Brussels

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

Final Study Report

Phase 2: Preparatory study

Main report

30 October 2025

<u>Contract Manager:</u>

Tatiana Pasquel Garcia, VITO

<u>Authors:</u>

Viegand Maagøe, Van Holsteijn en Kemna (VHK) and Fraunhofer ISI

Contents

Tables

Figures

Acronyms

ABS	Acrylonitrile Butadiene Styrene
BC	Base Case
CEAP	Circular Economy Action Plan
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardisation
CL	Colour Laser
CRM	Critical Raw Material
DG GROW	Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs
ED	Ecodesign Directive
EN	European Norm
ERT	EcoReport Tool
ESPR	Ecodesign for Sustainable Products Regulation
EU	European Union
GWP	Global Warming Potential
ICT	Information and Communication Technology
JTC	Joint Technical Committee
MEErP	Methodology for Ecodesign of Energy-related Products
PCR	Post-Consumer Recycled
PJ	Petajoule
PP	Polypropylene
PS	Polystyrene
RE	Reference Equipment
RoHS	Restriction of Hazardous Substances
SPI	Sustainable Products Initiative
SRM	Strategic Raw Material
TWh	Terawatt-hour
WEEE	Waste Electrical and Electronic Equipment

1. EXECUTIVE SUMMARY

1.1. Background, aim and political context

The Ecodesign Materials study was commissioned by the European Commission to assess material efficiency requirements in ecodesign and energy labelling policy. The aim was 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 the Ecodesign for Sustainable Products Regulation (ESPR) legal frameworks and/or the Energy Labelling Regulation.

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]

1.2. Scope and Methodology

The product scope for the study is energy related products covered by the Ecodesign Directive 2009/125[4] or the Ecodesign for Sustainable Products Regulation[6] with a focus on products that are already comprised by implementing ecodesign measures[5]. 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.

The five products selected are:

---

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

[5] 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

- Computers (currently reviewed under the Ecodesign Directive)
- Imaging equipment (currently undergoing a preparatory study under the Ecodesign Directive)
- Household refrigerating appliances (currently reviewed under the Ecodesign for Sustainable Products Regulation)
- Household washing machines (currently reviewed under the Ecodesign for Sustainable Products Regulation)
- Electric motors (currently reviewed under the Ecodesign for Sustainable Products Regulation)

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.

The typology of main requirements analysed in the studies were:

- Information requirements (on material weight, weight range, recycled raw material content)
- Requirements setting a minimum level of content of recycled raw materials
- Requirements based on the definition of product specific indexes on product recyclability

The work was carried out via two phases:

- Phase 1: Screening analyses of products and materials and prioritisation of products and materials for analyses in phase 2.
- Phase 2: Mini-preparatory studies using via the MEErP, Methodology of Ecodesign of Energy related Products, focusing on the parts of the methodology relevant for materials assessment and design and policy options.

A broad range of stakeholders were actively enganged in following the study and providing much input that we appreciated high. Four stakeholder meetings were carried out with about 150-200 participants online and physically at each meeting. After all stakeholder meetings, stakeholders were given an opportunity to provide written comments. Additionally, several meetings were held with individual organisations, who also were helpful in providing relevant data and information.

1.3. Horizontal Assessments

As a basis for the prioritisation in phase 1 and the product case studies in phase 2, the study team performed horizontal assessments of topics:

- Standards and standardisation activities related to recycled content, recyclability and material efficiency including the EN 4555x series developed by CEN-CENELEC Joint Technical Committee 10 on Energy-related products - Material Efficiency Aspects for Ecodesign (CEN-CLC/JTC 10)
- Recyclability and use of recycled content for relevant material types: plastics, biobased plastics, ferrous and non-ferrous materials and CRMs (Critical Raw Materials)
- Recycling technologies (mechanical and chemical)

- Market aspects, availability and prices
- Verification

1.4. Product Case Studies

The product case studies have been summarised in this report describing scope, Bill-of-materials for selected base cases, Environmental impacts for the baseline models, Critical Raw Materials, Design and policy options, Estimates of Magnitude of Impacts, and the Timeline of the review / preparatory study.

The complete reports are available at https://www.ecodesignmaterials.eu/documents.

2. Introduction

2.1. 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.

It is supplemented with these reports:

- Ecodesign materials and recycled content Phase 1 (screening and selecting five product case studies)
- Product case studies:
  - Ecodesign materials and recycled content Phase 2 Refrigeration appliances
  - Ecodesign materials and recycled content Phase 2 Washing machines
  - Ecodesign materials and recycled content Phase 2 Electric motors
  - Ecodesign materials and recycled content Phase 2 Personal Computers
  - Ecodesign materials and recycled content Phase 2 Imaging Equipment

The product case studies are summarised in Section 4 of the current report.

All reports are available at https://www.ecodesignmaterials.eu/documents

2.2. About the study

The purpose of the study was 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 were:

- 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 considered 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 should also provide inputs for the draft working documents on these implementing measures.

The study consisted 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. The input is used for the parallel preparatory and online studies taking place currently.

Four stakeholder meetings took place, each followed by a possibility to provide written comments and feedback to the consultants and the European Commission.

The consultations were supported by a study website (www.ecodesignmaterials.eu) with published documents, presentations and minutes from the meetings and basic information on the study and news. Registration for updates and for meetings took also place via the website.

2.3. 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[6] 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)[7]
- European Critical Raw Materials Act (CRMA)[8]

The Ecodesign Directive required 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

[6] 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

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

[8] 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

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[9] announces a sustainable product policy legislative initiative to make products fit 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) was 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[6] substituting the Ecodesign directive, though with a transition period for a limited amount of products.

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.

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

2.4. Scope

2.4.1. Product scope

The product scope for the study is energy related products covered by the Ecodesign Directive 2009/125[10] or the Ecodesign for Sustainable Products Regulation[6] with a focus on products that are already comprised by implementing ecodesign measures[11]. 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.

The five products selected are:

- Computers (currently reviewed under the Ecodesign Directive)
- Imaging equipment (currently undergoing a preparatory study under the Ecodesign Directive)
- Household refrigerating appliances (currently reviewed under the Ecodesign for Sustainable Products Regulation)
- Household washing machines (currently reviewed under the Ecodesign for Sustainable Products Regulation)
- Electric motors (currently reviewed under the Ecodesign for Sustainable Products Regulation)

2.4.2. 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.

2.4.3. 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

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

[11] 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

- Requirements based on the definition of product specific indexes on product recyclability
- Other requirement on recyclability and product reusability

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

2.5.1. 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 sub-stantial 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).

2.5.2. Critical Raw Materials

The most recent list of CRMs[12] contains 34 CRMs. The CRM list consists of raw materials meeting the requirements according to the published EU criticality methodology[13]. 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 outstipping supply and expected difficulties in increasing supply to compensate for the lack of CRMs and SRMs. SRMs are considered CRMs 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.

[12] 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
[13] https://data.europa.eu/doi/10.2873/769526

2.5.3. 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 2.4.3) include:

- 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.[14]

2.6. 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).[15] It is

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

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

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 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.[16]

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. This may be the only fraction of pre-consumer recycled content that can be considered as recycled material.

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

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

- Recycled content from any 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.

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.[17,18] By reaching this goal, the EU will attain an almost 20 % success rate of recycled plastics uptake into new products for all applications.[19]

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.[20]

2.7. 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

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

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

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

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

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 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.

A study on the development of recyclability indexes for photovoltaic products (PV modules and inverters) has recently been finalised.[21] Outcome of this study provided a useful source of information for the current project.

2.8. 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: 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

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

for two case studies, i.e. domestic computers and imaging equipment, and the cross-cutting assessments of topics relevant for all five case studies.

- 1 July 2025: 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 three case studies, i.e. refrigerating appliances, washing machines and electric motors.

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

3. HORIZONTAL ASSESSMENTS

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

3.1. 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[22]

3.2. Recyclability and use of recycled content

3.2.1. Plastic

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.

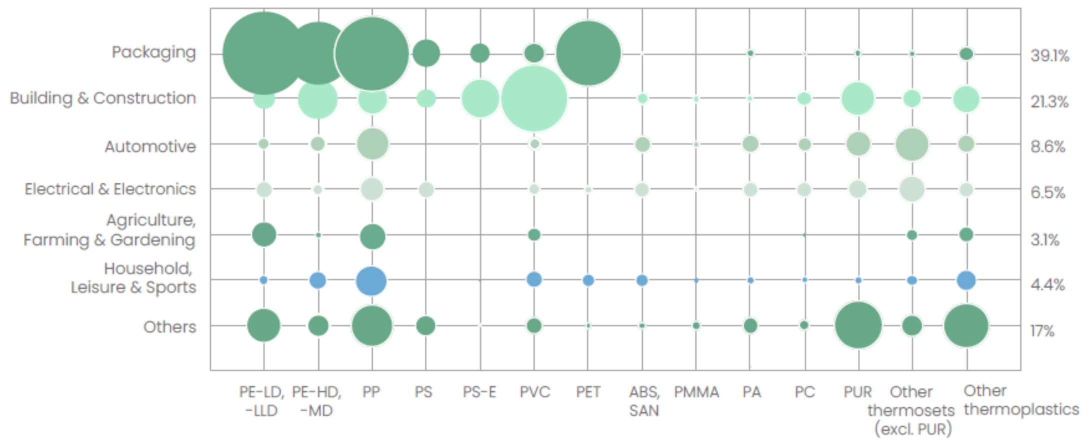

Figure 1: European plastics converters' demand by application and type[23]

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

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

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[24] 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%).

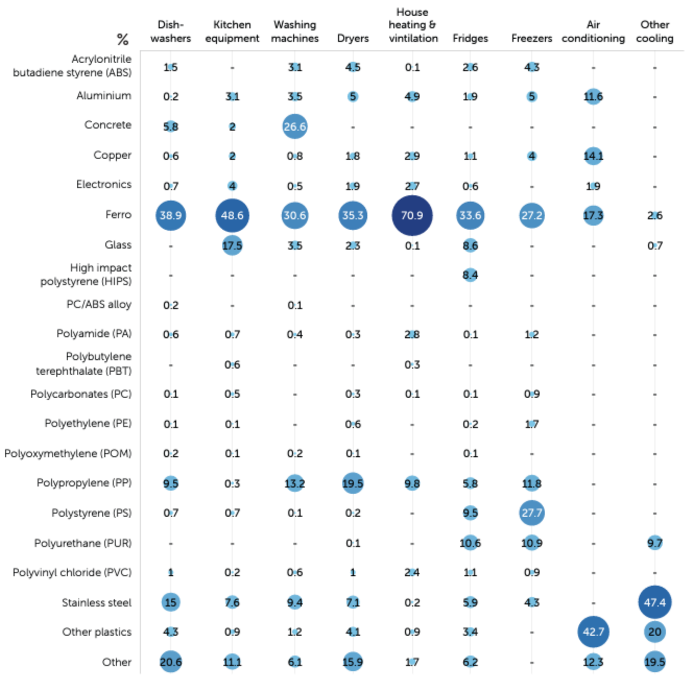

Figure 2: The average material composition of large home appliances. Source APPLiA

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.

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

[24] Home | APPLiA statistical report 2022-2023

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.

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.

<u>Types of biobased plastics</u>

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[25]. 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.

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 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

[25] 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

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.[26]

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.

<u>Mechanical recycling</u>

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[27].

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.

<u>Chemical recycling</u>

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[28], 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.
- 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.

---

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

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

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

- 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, plasticisers, 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 e.g. for safety reasons.

Market aspects

According to the Preparatory study for the Ecodesign and Energy Labelling Working Plan 2020-2024[29] 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.

3.2.2. Critical Raw Materials

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 once collected for recycling[30,31]. Table 1 presents a summary of the

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

[30] 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.

recycling rates used in the latest EU criticality study for all critical and strategic raw materials[32]. 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[33]. 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.

Table 1: Summary of recycling rates used in the latest criticality exercise[34] 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[35] and references in European Commission 2023[36] 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

[31] 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).

[32] 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.

[33] 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.

[34] 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.

[35] 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.

[36] 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.

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 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[37] 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[38]; Nb is not recovered in its pure form[39]. 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[40].
    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[41], 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[42]) and the design and economics of the recycling plant itself.

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

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

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

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

[41] 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.

[42] 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

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 metal tools and PGMs used in catalytic converters for vehicles with internal combustion engines[43]. The recycling of PGM is also favored by their electrochemical properties[44]. 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[45], both leading to higher EoL recycling rates within the respective focal systems compared to the overall recycling of the same raw materials.

[43] 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.

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

[45] 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.

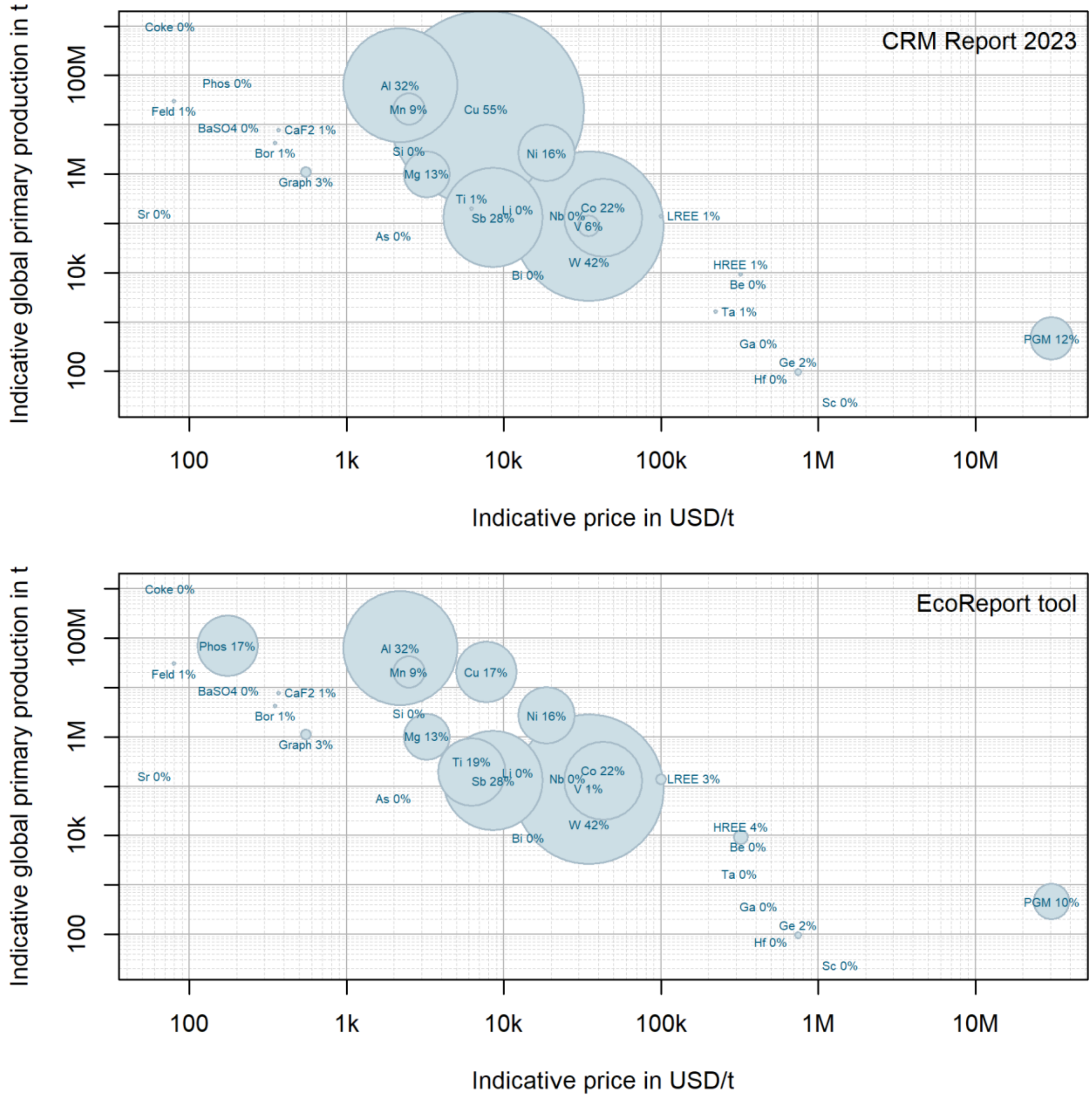

Figure 3: (Top) Recycling rates of critical and strategic raw materials as used in the latest EU criticality exercise[46]. Indicative prices retrieved from the SCRREEN (2023) and DERA (2024). (Coke = coking coal; Phos = phosphate rock; Feld = feldspar; Bor = Boron/borate; Graph = natural graphite, LREE/HREE = 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)[47], ideally following the definitions set out by Talens Peiró et al. (2018-10)[48]. However, given data limitations, this is not possible for all raw materials shown, see Tercero Espinoza (2021)[49] for a discussion and overview of this issue[50]. (See bottom Figure:)

[46] 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.

[47] 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.

[48] 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.

[49] 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.

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.

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 (Nd), 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%)[51]. 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%[52] .

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[53]. 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[54]. 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[55]. 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[56].

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

[50] 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.

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

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

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

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

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

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

the EU, but the EU holds a share of 1.1% worldwide. The EoL recycling rate of tantalum is at 13%[57].

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%[58].

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%[59].

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[60, 61]. 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[62]. On an applied level however, only Palladium is commonly recovered from PCBs, alongside the copper recovery process.

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.

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

---

57 RMIS - Raw materials' profiles

58 RMIS - Raw materials' profiles

59 RMIS - Raw materials' profiles

60 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.

61 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.

62 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.

current output products' market value of tantalum and quantity produced[63,64]. Efficient recycling of neodymium is also still challenging and costly due to the scattered distribution of neodymium in various products[65][66]

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[67]. 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[68].

3.2.3. Ferrous and non-ferrous materials

Material types

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

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 surplus was exported. The proportion of steel scrap used in relation to crude steel production in the EU is 56%[69]. 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.

[63] 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.

[64] 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).

65 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.

[67] 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.

[68] 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.

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

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%.[70]

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 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.

3.3. 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 manufacturers 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. The Commission is exploring this topic further.

4. Summary of product cases

In the following, we summarise the five product case studies:

- Computers
- Imaging Equipment
- Household refrigerating appliances
- Household washing machines
- Electric motors

All reports are available at https://www.ecodesignmaterials.eu/documents.

4.1. Computers

4.1.1. Scope

The product scope for the Computers mini-study study is aligned with the scope proposed in the draft Impact Assessment of Personal Computers that is on-going at this time. The following products, powered both directly from the mains alternating current (AC) including via an external or internal power supply or by batteries (i.e. both desktops and portable computers):

- Desktop computers;
- Integrated desktop computers;
- Notebook computers (including tablet computers);
- Workstations;
- Thin clients;
- Small-scale servers

4.1.2. Bill-of-materials for selected base cases

In the separate report containing the Computers mini-study, two product types were selected for analysis – desktop computers and notebook computers. For this summary, only notebook computers are presented. The definition of a notebook computer is provided below:

> **Notebook computer** means a computer designed specifically for portability and to be operated for extended periods of time either with or without a direct connection to an AC power source. Notebook computers utilise an integrated display, with a viewable diagonal screen size of at least 22.86 cm (9 inches) and are capable of operation on an integrated battery or other portable power source.

As shown in the figure below, for the notebook (laptop) computer (BC2), the total weight of the computer is 2.9 kg, excluding packaging material used in shipping. Breaking down the computer into groups of material types, metals represent 50% of the mass (1.4 kg), electronics are 33% (0.9 kg), plastics are 15% (0.4 kg) and other materials are 2% (0.06 kg).

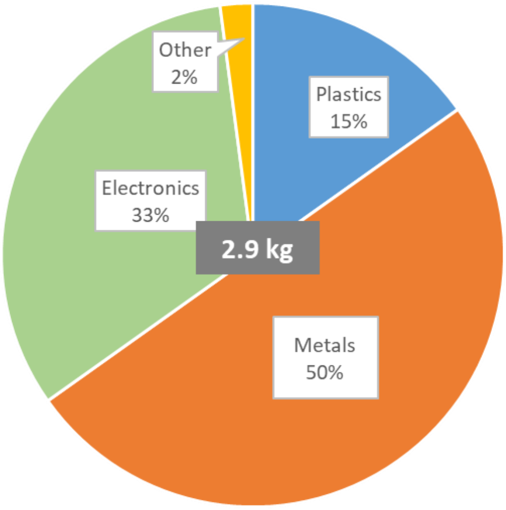

Figure 3. Materials weight allocation for the notebook computer base case model. Electronics may also include plastics and metals.

4.1.3. Environmental impacts for the baseline models

The baseline environmental impacts for the base case notebook (laptop) computer (BC2) are given below. These results have been calculated using the 2024 EcoReportTool version 1.7. Only impacts from raw materials and end-of-life impacts and credits have been considered.

Figure 4 provides the shares of each material category in the environmental impacts for raw materials and end-of-life impacts and credits for the reference scenario. Although electronic components (PCBs, cables, LED) represent approximately one-third of the weight of the laptop computer, they have the highest environmental impact shares for most parameters (green shaded bars). The two exceptions are ‘ozone depletion’ (primarily from other, which is glass), and ‘land use’ (primarily from metals). For ‘land use’ the impact from electronics is reported as negative which is considered an error, so it has been zeroed out.

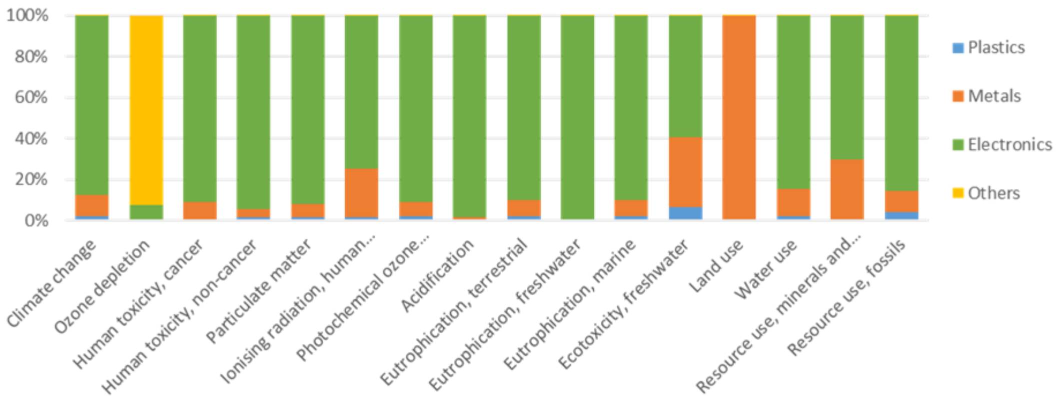

Figure 4. Shares of environmental impacts by material category for Notebook Computer (BC2)

4.1.4. Critical Raw Materials

The prioritisation scores for environmental impacts were examined for all materials together and separately per material category (plastics, ferrous metals, non-ferrous metals, coating / plating, electronics and miscellaneous). For personal computers, the Phase 1 analysis identified the top five CRMs are: Tantalum, Cobalt, Palladium, Bauxite/Aluminium and Magnesium.

Computers have most of their CRMs contained in the materials used on printed circuit boards (PCBs) inside the machines. However, PCBs are challenging to recycle because of the variety of materials they contain, including precious metals (e.g., gold, silver, and palladium), base metals (e.g., copper, aluminum, and tin), and hazardous substances (e.g., lead, mercury, epoxy resin containing brominated flame retardants). Corroborating these findings. Other researchers found that PCBs contain the following:

- Antimony: found in some lead-containing solders;
- Beryllium: small amounts found in connectors using as a copper-beryllium alloy (typically 98% copper, 2% beryllium);
- Cadmium: small amounts used in plated contacts and switches;
- Chlorine and/or Bromine: brominated and inorganic flame retardants may be in the PCBs; and
- Lead: found in solder and some electronic components.

Researchers found that mechanical treatment and separation of PCBs is essential for effective resource recovery and recycling, for both economic viability and environmental protection. According to a study that looked at material composition, waste PCBs contained approximately 30% metallic material, 40% organic resin materials and about 30% glass fibers used to reinforce the boards. Of these, the metallic material consists of metals bound up in the circuitry (mainly copper), solder and lead frames (tin, iron and lead) and integrated circuits (gold, silver and palladium). As an illustration of this, one paper found that a waste PCB from a computer contains 20% copper as well as 250 grams of gold and 110 grams of palladium per ton of waste PCBs.

4.1.5. Design and policy options

In the following, we describe the design and policy options that have been presented and discussed. These may be considered in the process of elaborating the forthcoming ecodesign regulation on computers.

The design options considered for computers in this mini-study included the following:

- Recycled plastic content in personal computers;
- Recyclability of personal computers at end of life; and
- Critical Raw Materials used in personal computers

Regarding recycled plastic content, there were four possible approaches that were considered which would establish requirements around the use of recycled plastic in personal computers:

1. Based on the total mass of the finished product;
2. Based on the total mass of plastic in the finished product;
3. Based on the total mass of plastic in a specific component or part in the product; or
4. Based on specific type(s) of plastic used in the finished product.

For recyclability, the design options considered were intended to facilitate the recovery of materials at the end of life – including critical raw materials (CRMs) – and thereby achieve the targets modelled in in the EcoReport Tool for the assumed recyclability rates. Measures for consideration included:

1. Design for disassembly – enable the separation of different material types used in a single part or component;
2. Require marking the different types of plastic to facilitate sorting (similar to what is done for packaging);
3. PCBs larger than 10 cm² and boards containing batteries or wet capacitors should be easily removable for recyclers; and
4. Forbid the use of halogenated flame retardants, and require a marking for plastics containing flame retardants, like the regulation for electronic displays.

For CRMs, no recycled content requirements for CRMs and SRMs were proposed. For copper and aluminium such requirements are not necessary, these two CRMs are already recovered and recycled as much as economically justified.

Additionally, recyclability requirements for CRMs and SRMs are proposed. Recyclability of CRMs and SRMs from depends on collection rates (which are beyond the scope of the mini-study), and to a lesser extent on the recycling rate of printed circuit boards. Recyclers state that the latter is already high.

Considering the lack of information on the types and quantities of CRMs and SRMs, setting information requirements could be relevant, however, considering the expected small quantities, and the considerable traceability effort for recyclers, it requires further evaluation.

4.1.6. Estimates of Magnitude of Impacts

Recycled content and recyclability

Calculations have been made for reduction of environmental impacts compared to the baseline, when using 10% and 30% recycled content in input to the production for plastics for laptop computer (BC2) and for recyclability, when 10% or 30% of the material contained in the finished product at end of life is recovered for reuse.

Figure 5 presents the results for two of the fifteen environmental indicators, Climate change and Ecotoxicity, Freshwater. Plastic only constitutes 15% of the total mass of the laptop, therefore the impacts of increasing recycled content and recyclability have a limited effect on the overall environmental impact of the materials used in this laptop.

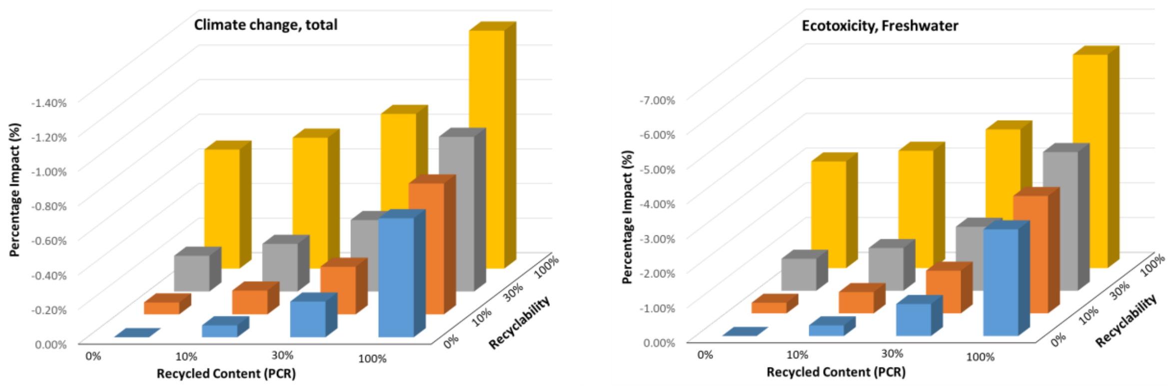

Figure 5: Impact Improvement of Climate Change and Ecotoxicity (Freshwater) for increasing recycled content and recyclability of the basecase laptop computer (BC2)

GHG and virgin plastic savings

This section provides an estimate of the environmental benefit for the measures considered in recycled plastic and recyclability of plastic for the sales and stock of laptop computers in 2030. The results consider two combinations: 10% recycled plastic content with 10% recyclability at end of life, and 30% recycled plastic content with 30% recyclability at end of life. The benefits calculated for the representative base case model laptop (BC2) are then multiplied by the projected sales and stock in 2030 to estimate the magnitude of the savings potential overall from these two measures.

Table 2: CO2 savings estimates in 2030 for notebook (laptop) basecase computer (BC2)

Policy Scenario	**GHG Savings / unit** *[kg CO_2 eq]*	**2030 Sales** *[tonnes CO_2 eq]*	**2030 Stock** *[tonnes CO_2 eq]*
Laptop: 10% PCR plastic content & 10% recyclability at end of life	0.13	9,521	43,664
Laptop: 30% PCR plastic content & 30% recyclability at end of life	0.40	28,564	130,991

Combining these laptop computer savings with the desktop savings presented in the mini-study report, it was estimated that approximately 20,000 metric tonnes of CO2 would be saved for the 10%/10% scenario if all sales in 2030 incorporated those requirements. If (hypothetically) the entire stock of laptops and desktops switched overnight to comply with this measure, the combined savings would be approximately 110,000 metric tonnes of CO2. It is recognised, however, that the in reality the stock conversion would happen gradually over time as the models are replaced, also taking into account the possibility of over-compliance (i.e., products designed to contain more recycled content than required).

The values for the 30% / 30% scenario are approximately triple those of the estimates for 10% / 10%, with approximately 60,000 metric tonnes of CO2 savings for the 2030 sales and approximately 330,000 metric tonnes of CO2 savings for the 2030 stock.

Table 3: Estimates of Virgin Plastic Avoided through use of PCR Plastic

Policy Scenario	Virgin Plastic avoided per Annum in 2030 *[kilotonnes]*	Virgin Plastic avoided in Stock in 2030 if 100% converted *[kilotonnes]*
10% PCR plastic content for notebook computers (BC2) and desktop computers (BC5)	6.6	34.9
30% PCR plastic content for notebook computers (BC2) and desktop computers (BC5)	19.8	104.7

4.1.7. Timeline of the review study

This mini study on recycled content, recyclability and CRM for personal computers had a limited schedule and budget, therefore it relied primarily on interviews with stakeholders, preliminary data collection and EcoReport Tool analyses that will be handed over to the review study team working on personal computers for DG Energy. It is expected that the review study team will conduct further investigations into these and other policy options, conduct additional data collection and analysis, and address any comments received from this stakeholder consultation, incorporating the final recommendations into the Commission's Working Document for a new regulation on personal computers.

The review study of Personal Computers (Lot 3) is on-going at this time, with a stakeholder meeting scheduled for 15 September 2025 and additional work on the Impact Assessment in the months that follow. The Commission is planning to finalise its analysis in 2026 and publish the requirements for personal computers (both ecodesign and energy labelling) by the end of 2026.

4.2. Imaging equipment

4.2.1. Scope

The product scope for the Imaging Equipment mini-study is aligned with the scope proposed in the 2024 JRC Preparatory Study on Imaging Equipment, however consumables were excluded from the analysis. In other words, the scope of this study of critical raw materials (CRMs), recycled content and recyclability is only on the equipment itself, not the cartridges, containers, drums or other consumables associated with imaging equipment.

Table 4. Scope of coverage of this CRM and Recycled Content Study

Device	In Scope	Out of Scope
General	Devices intended for household and office use	Devices intended for professional use or other than household and office use
Printers, multi-function printers and copiers	Standard format (up to A3)	Large format Devices designed to operate on three-phase power
Scanner	All scanners	
Fax Machine	All fax machines	
Digital duplicators		All digital duplicators
Mailing Machine		All mailing machines
Consumables		All consumables

4.2.2. Bill-of-materials for selected base cases

In the Commission's full review of imaging equipment, seven basecase representative models are being developed for analysis:

- BC1: Small Office, Laser A4 colour printer, 26 ipm
- BC2: Small Office, Laser A4 mono printer, 42 ipm
- BC3: Large Office, Laser A4 colour printer, 52 ipm
- BC4: Large Office, Laser A4 mono printer, 70 ipm
- BC5: Large Office, Laser A3 colour printer, 80 ipm
- BC6: Large Office, Laser A3 mono printer, 90 ipm
- BC7: Household, Inkjet A4 colour printer, 15 ipm

For the CRM and recycled content mini-study, the team selected two of base case models for analysis. These two models were selected in order to represent a popular model used in the professional environment and a popular model used in the household setting. For the professional (office) environment, the base case model BC5 – Large Office, Laser A3 colour printer, 80 ipm was selected. For the household (domestic) setting, the only base case model from this sector was used, base case model BC7 – Household, Inkjet A4 colour printer, 15 ipm. In this chapter of the Phase 2 main report, we only present the findings from the BC5, the large office A3 colour laser printer.

For the large office A3 colour laser printer (BC5), the total weight of the printer is 85.8 kg, excluding packaging material used in shipping. Breaking down the printer into groups of material types, metals represent 61% of the mass (52.6 kg), plastics are 32% (27.2 kg), electronics are 5% (4.4 kg), and other materials are 2% (1.6 kg).

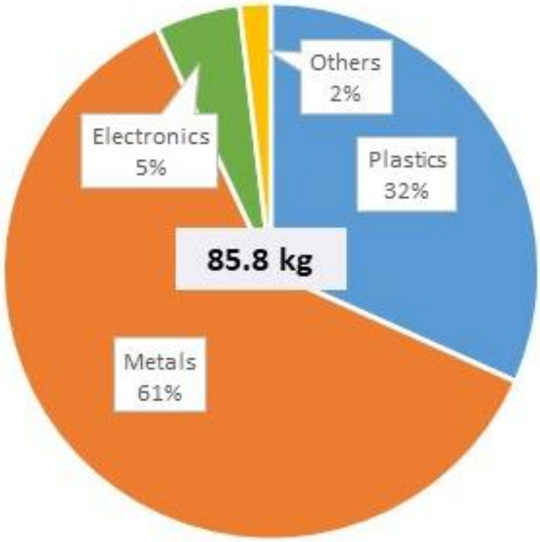

Figure 6. Materials Weight Allocation for the A3 Colour Laser Printer Base Case Model

4.2.3. Environmental impacts for the baseline models

The baseline environmental impacts for the base case A3 colour laser printer (BC5) have been computed using the 2024 EcoReportTool version 1.7. They are based on the BoM and factors R1, R2 and A of Table 8. Only impacts from raw materials and end-of-life impacts and credits have been considered .

Figure 10 gives the shares of each material category in the environmental impacts for raw materials and end-of-life impacts and credits for the reference scenario. Although electronic components (PCBs, cables, LED) represent only 5% of the weight of the laser printer, they have the highest environmental impact shares for most parameters (green shaded bars). The two exceptions are ‘ozone depletion’ (primarily from other, which is glass), and ‘land use’ (primarily from metals). For ‘land use’ the impact from electronics is reported as negative which is considered an error, so it has been zeroed out.

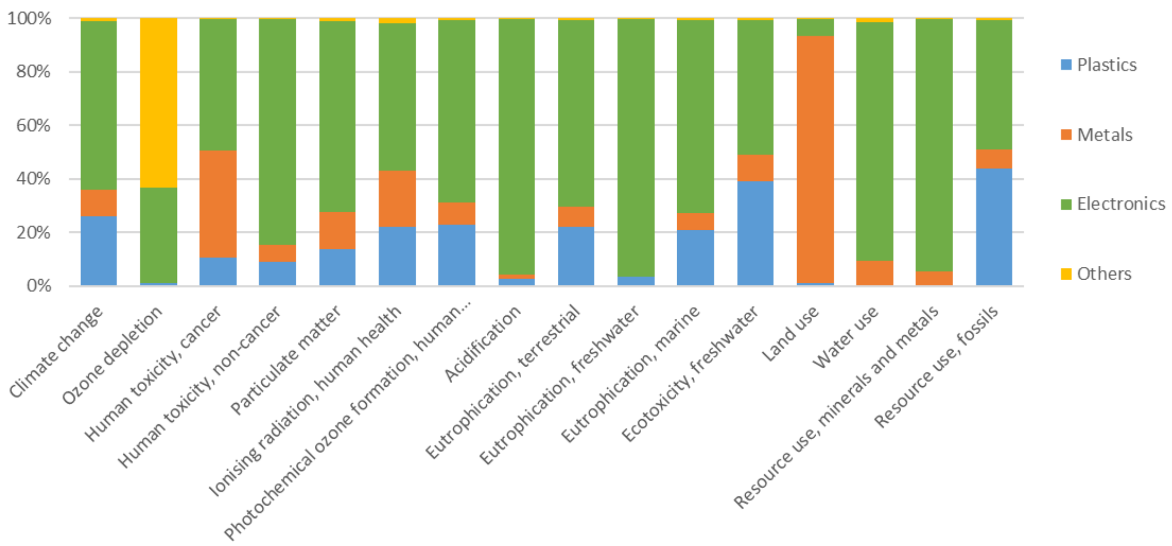

Figure 7. Shares of environmental impacts by material category for A3 colour laser printer (BC5)

4.2.4. Critical Raw Materials

The prioritisation scores for environmental impacts have been examined for all materials together and separately per material category (plastics, ferrous metals, non-ferrous metals, coating / plating, electronics and miscellaneous).

For imaging equipment, the Phase 1 analysis identified the top five CRMs in this order: (1) Palladium; (2) Tin; (3) Bismuth; (4) Bauxite/Aluminum; and (5) Antimony. Imaging equipment have most of their CRMs contained in the materials used on printed circuit boards (PCBs) inside the machines. However, PCBs are challenging to recycle because of the variety of materials they contain, including precious metals (e.g., gold, silver, and palladium), base metals (e.g., copper, aluminum, and tin), and hazardous substances (e.g., lead, mercury, epoxy resin containing brominated flame retardants) Corroborating these findings. Other researchers found that PCBs contain the following:

- Antimony: found in some lead-containing solders;
- Beryllium: small amounts found in connectors using as a copper-beryllium alloy (typically 98% copper, 2% beryllium);
- Cadmium: small amounts used in plated contacts and switches;
- Chlorine and/or Bromine: brominated and inorganic flame retardants may be in the PCBs; and
- Lead: found in solder and some electronic components.

Researchers found that mechanical treatment and separation of PCBs is essential for effective resource recovery and recycling, for both economic viability and environmental protection. According to one study that looked at material composition, waste PCBs contained approximately 30% metallic material, 40% organic resin materials and about 30% glass fibers used to reinforce the boards. Of these, the metallic material consists of metals bound up in the circuitry (mainly copper), solder and lead frames (tin, iron and lead) and integrated circuits (gold, silver and palladium). As an illustration of this, one paper found that a waste PCB from a computer contains 20% copper as well as 250 grams of gold and 110 grams of palladium per ton of waste PCBs.

4.2.5. Design and policy options

In the following, we describe the design and policy options that have been presented and discussed. These may be considered in the process of elaborating the forthcoming ecodesign regulation on imaging equipment.

The design options considered for imaging equipment in this mini-study included the following:

- Recycled plastic content in imaging equipment;
- Recyclability of imaging equipment at end of life; and
- Critical Raw Materials used in imaging equipment.

Regarding recycled plastic content, there were four possible approaches that were considered which would establish requirements around the use of recycled plastic:

1. Based on the total mass of the finished product;
2. Based on the total mass of plastic in the finished product;
3. Based on the total mass of plastic in a specific component or part in the product; or
4. Based on specific type(s) of plastic used in the finished product.

For recyclability, the design options considered were intended to facilitate the recovery of materials at the end of life – including critical raw materials (CRMs) – and thereby achieve the targets modelled in in the EcoReport Tool for the assumed recyclability rates. Measures for consideration included:

1. Design for disassembly – enable the separation of different material types used in a single part or component;
2. Require marking the different types of plastic to facilitate sorting (similar to what is done for packaging);
3. PCBs larger than 10 cm² and boards containing batteries or wet capacitors should be easily removable for recyclers; and
4. Forbid the use of halogenated flame retardants, and require a marking for plastics containing flame retardants, like the regulation for electronic displays.

For CRMs, no recycled content requirements for CRMs and SRMs were proposed. For copper and aluminium such requirements are not necessary, these two CRMs are already recovered and recycled as much as economically justified.

Additionally, recyclability requirements for CRMs and SRMs are proposed. Recyclability of CRMs and SRMs from depends on collection rates (which are beyond the scope of the mini-study), and to a lesser extent on the recycling rate of printed circuit boards. Recyclers state that the latter is already high.

Considering the lack of information on the types and quantities of CRMs and SRMs, setting information requirements could be relevant, however, considering the expected small quantities, and the considerable traceability effort for recyclers, it requires further evaluation.

4.2.6. Estimates of Magnitude of Impacts

Recycled content and recyclability

Calculations have been made for reduction of environmental impacts compared to the baseline, when using 10% and 30% recycled content in input to the production for plastics for laptop computer (BC2) and for recyclability, when 10% or 30% of the material contained in the finished product at end of life is recovered for reuse.

Figure 5 presents the results for two of the sixteen environmental indicators, Climate change and Ecotoxicity Freshwater. Plastic constitutes 32% of the total mass of the printer, therefore the impacts of increasing recycled content and recyclability have a measurable effect on the overall environmental impact of the materials used in this laser printer.

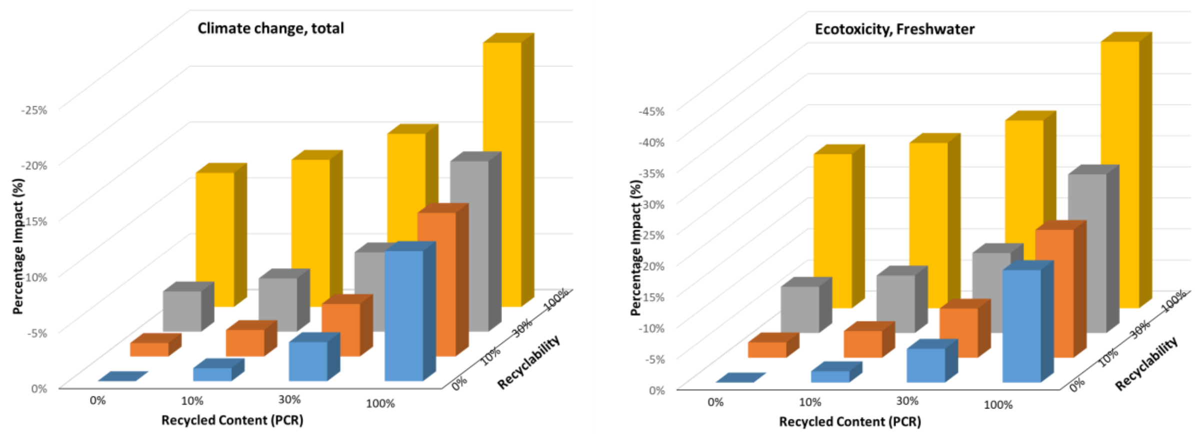

Figure 8: Impact Improvement of Climate Change and Ecotoxicity (Freshwater) for increasing recycled content and recyclability of the basecase A3 colour laser printer (BC5)

GHG and virgin plastic savings

An estimate was prepared of the environmental benefit for the measures considered in recycled plastic and recyclability of plastic for the sales and stock of the A3 colour laser printer in 2030. The results consider two combinations: 10% recycled plastic content with 10% recyclability at end of life, and 30% recycled plastic content with 30% recyclability at end of life. The benefits calculated for the representative base case model A3 colour laser printer (BC5) are then multiplied by the projected sales and stock in 2030 to estimate the magnitude of the savings potential overall from these two measures.

Table 5: CO2 savings estimates in 2030 for the A3 colour laser basecase printer

Policy Scenario	**GHG Savings / unit** *[kg CO_2 eq]*	**2030 Sales** *[tonnes CO_2 eq]*	**2030 Stock** *[tonnes CO_2 eq]*
A3 Laser: 10% PCR plastic content & 10% recyclability at end of life	7.84	27,598	165,157
A3 Laser: 30% PCR plastic content & 30% recyclability at end of life	23.51	82,794	495,470

Combining the savings from both the A3 colour laser printer base case (BC5) and the A4 colour inkjet printer (BC7), approximately 33,000 metric tonnes of CO_2 would be saved for the 10%/10% scenario if all sales in 2030 incorporated those requirements. If (hypothetically) the entire stock of inkjet and laser printers switched overnight to incorporate this measure, the combined savings would be approximately 190,000 metric tonnes of CO_2 savings. It is recognised, however, that the in reality the change in stock would happen gradually over time as the models are replaced, also taking into account the possibility of over-compliance (i.e., products designed to contain more recycled content than required).

The values for the 30% / 30% scenario approximately triple those estimates for 10% / 10% scenario, with approximately 99,000 metric tonnes of CO_2 savings for the 2030 sales and approximately 580,000 metric tonnes of CO_2 savings for the 2030 stock.

Table 6: Estimates of Virgin Plastic Avoided through use of PCR Plastic

Policy Scenario	**Virgin Plastic avoided per Annum in 2030** *[kilotonnes]*	**Virgin Plastic avoided in Stock in 2030 if 100% converted** *[kilotonnes]*
10% PCR plastic content for A4 colour inkjet and A3 colour laser printers	11.5	66.9
30% PCR plastic content for A4 colour inkjet and A3 colour laser printers	34.4	200.7

4.2.7. Timeline of the preparatory study

This mini study on recycled content, recyclability and CRM for imaging equipment had a limited schedule and budget, therefore it relied primarily on interviews with stakeholders, preliminary data collection and EcoReport Tool analyses that will be handed over to the review study team working on imaging equipment for DG Environment. It is expected that the parallel study team will conduct further investigations into these and other policy options, conduct additional data collection and analysis, and address any comments received from this stakeholder consultation, incorporating the final recommendations into the Commission's Working Document for a new regulation on imaging equipment.

The preparatory study of Imaging Equipment is on-going at this time, with work currently being conducted on the Impact Assessment. The Commission is planning to finalise its analysis in 2026 and publish the requirements for imaging equipment (both ecodesign and energy labelling) by the end of 2026.

4.3. Household refrigerating appliances

4.3.1. Scope

The product scope for the fridge mini-study is the same as the scope of the 2019 Ecodesign and Energy Labelling regulations for (household) refrigerating appliances.

4.3.2. Bill-of-materials for selected base cases

The impact analysis of the mini-study is based on a Bill-of-Materials (BoM) for a refrigerator-freezer combi of a major European manufacturer, for a model still on the market in January

2025. Combis represent more than 50% of the annual fridge sales, and the percentual material distribution for the specific BoM is similar to the one for the average refrigerator in APPLiA statistical reports. Hence, analysis results are retained representative.

As shown in the graph, 41% of the fridge mass is plastic, 45% ferrous metal, 3.4% non-ferrous metal (2.1% aluminium, 1.3% copper), 9.6% glass, 0.5% electronic components, and 0.7% others (adhesives, refrigerant, lubrication oil).

More specifically for the plastics, 23% of the fridge mass is polystyrene (high-impact HIPS or general purpose GPPS), 11% polyurethane foam (PU), 4% polypropylene (PP), 1% polyvinylchloride (PVC), 0.6% acrylonitrile butadiene styrene (ABS) and 0.8% other plastics.

Viewing the mass distribution from the point of view of fridge components, 55% is in the body and the doors, 20% is in internal components (shelves, drawers, baskets, accessories), 11% is in the hermetic compressor, 10% is in the rest of the cooling system (condenser, evaporator), and the rest are airflow components (fans, ducts, covers) and electronics.

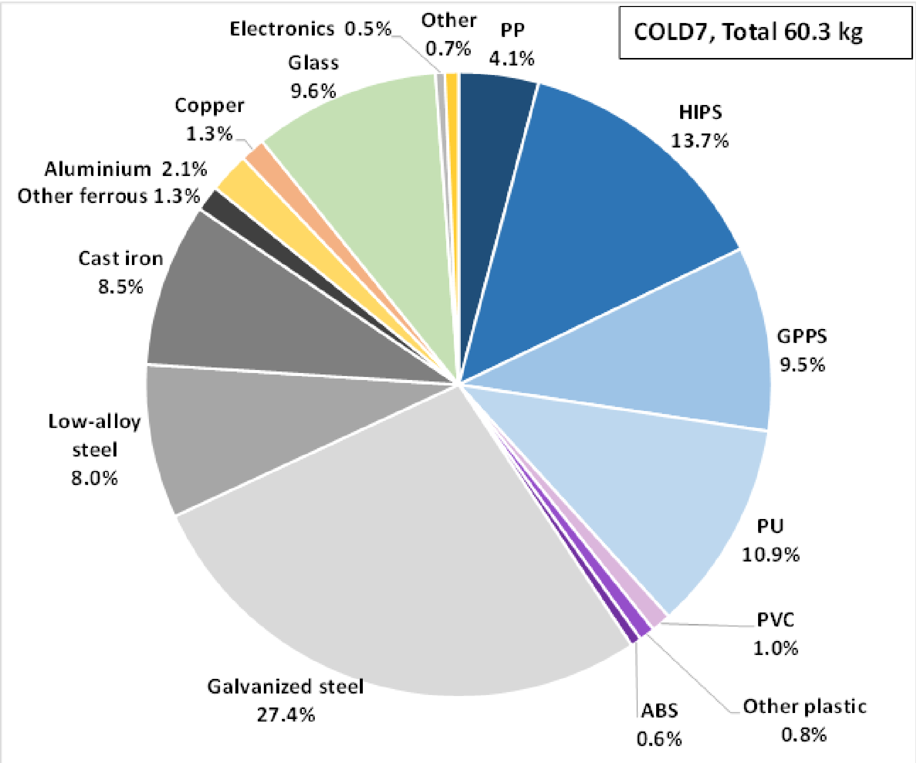

Figure 9: Material distribution for the reference refrigerator-freezer combi

4.3.3. Environmental impacts for the baseline models

For the reference refrigerator-freezer combi, environmental impacts have been calculated using the 2024 EcoReportTool v1.7.2. Impacts from materials and from end-of-life (EoL, impacts and benefits) have been considered and compared to those from lifetime electricity consumption (for 235 kWh/year, 15.7 years lifetime, electricity grid mix dataset 243 of the EcoReportTool v1.7.2)

A large share of material and EoL impacts comes from plastics (purple bars). For most environmental categories, material and EoL impacts are small compared to lifetime use-phase impacts from electricity consumption. The main exceptions are ‘resource use, minerals and metals’, and ‘ozone depletion’.

For plastics, the largest environmental impacts come from HIPS, GPPS, and PP (grey and cyan bars). For this reason, these plastic types have been targeted for recycled content requirements. Impacts from rigid PU foam (purple) are also high, but recycling of PU is currently not economically viable (recommended to reassess in 2030).

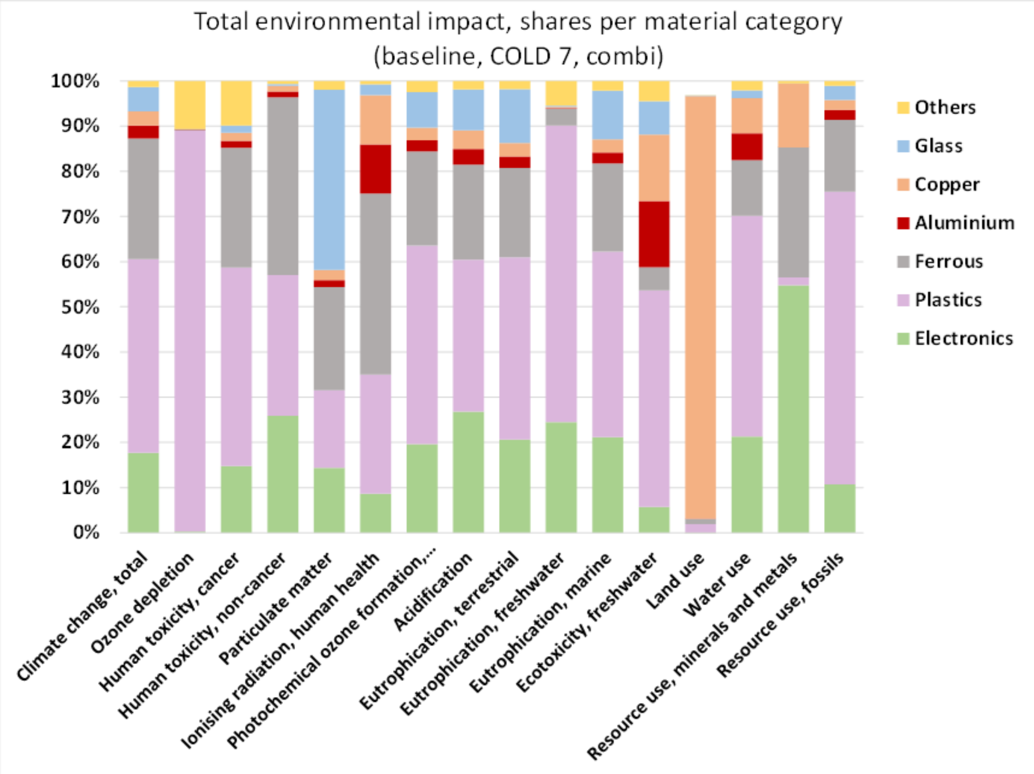

Figure 10: Shares per material category in the total environmental impacts from materials and end-of-life, per environmental impact category, for base case COLD 7 (combis), for the baseline scenario.

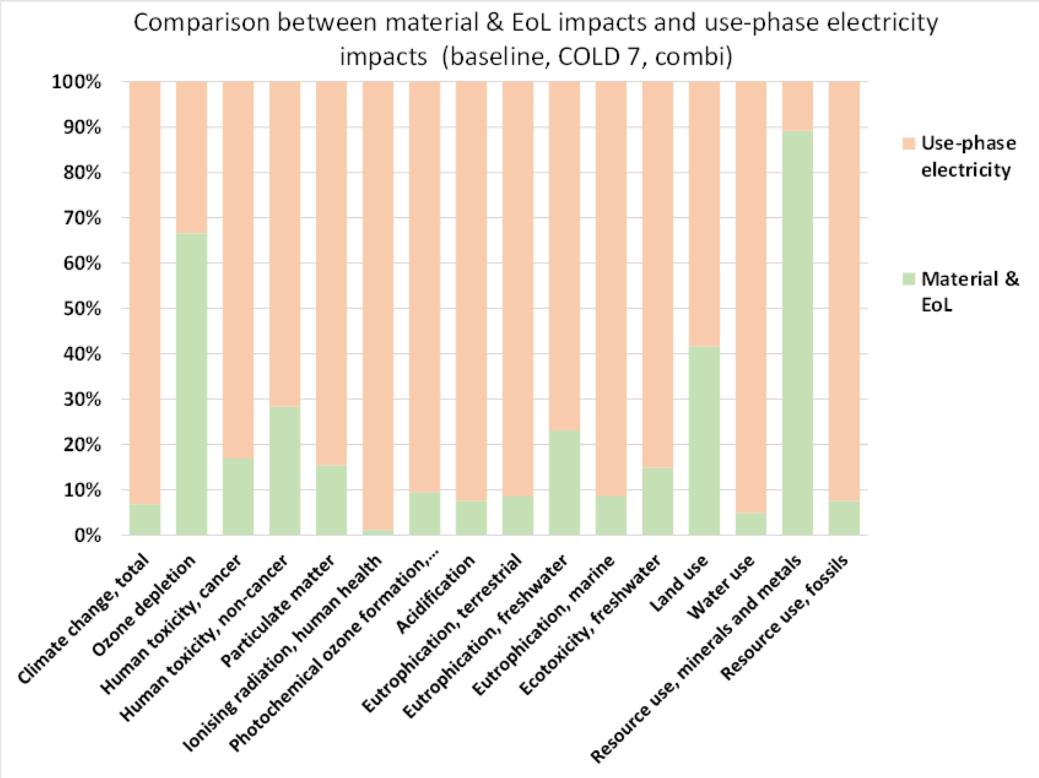

Figure 11: Impact shares from materials & end-of-life (green) and from lifetime use-phase electricity consumption (orange), per environmental impact category, for base case COLD 7 (combis), for the baseline.

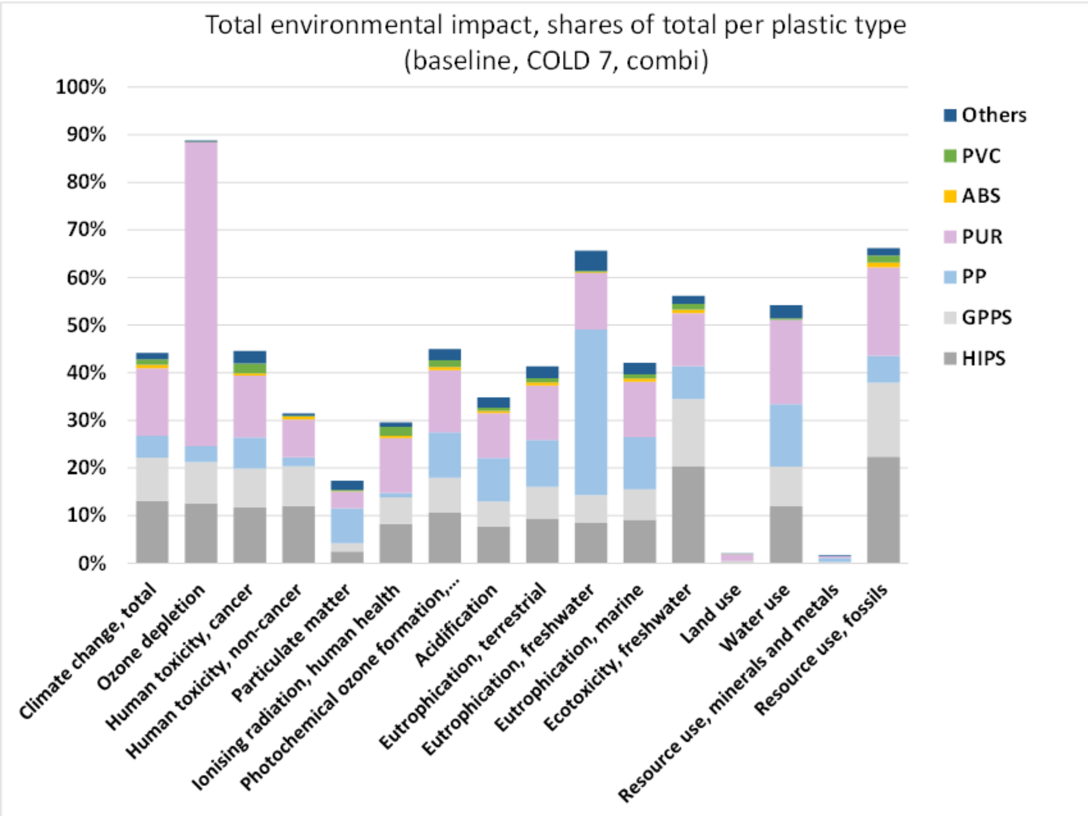

Figure 12: Shares per plastic type in the total environmental impacts from materials and end-of-life, per environmental impact category, for base case COLD 7 (combis), for the baseline scenario.

4.3.4. Critical Raw Materials

Amounts of CRMs in fridges are low and mainly found in the hermetic compressors, copper and aluminium parts of the cooling circuits, and in electric and electronic components.

In the current fridge recycling practice, hermetic compressors and power cables are removed before shredding and recycled by specialized companies. If they contain CRMs, the hermetic compressors are also in scope of article 28 of the CRM act.

Copper and aluminium parts are shredded with the fridge structure, but recovered in following separation processes.

Electronic boards and other small CRM-containing parts of fridges are of relatively low value and therefore often not removed by recyclers before shredding (not economically viable). A large part of the board flakes is anyway recovered in successive separation processes and send to specialized recyclers. More CRMs could be recovered from the boards if they would be separated before shredding.

4.3.5. Design and policy options

In the following, we describe the design and policy options that have been presented and discussed. These may be considered in the process of elaborating the forthcoming ESPR regulation on household refrigerating appliances.

The table presents a survey of potential recycling-related requirements on fridges. The sections of the dedicated fridge report where these requirements are further discussed are indicated, and a first judgement is provided whether to continue considering the requirement or not.

Main stakeholder comments on the potential requirements:

- Organizations of home appliance manufacturers judge the setting of minimum recycled content requirements as premature. They prefer to start with information requirements on recycled material content. Recycler organizations and environmental NGOs are in general in favor of setting minimum recycled content requirements, considering only post-consumer recyclates.
- There is wide support from stakeholders for measures like 2.7.1 and 2.7.2 that require the removal of electronic boards (and other CRM-containing parts) before shredding.
- Chemical industry organizations and organizations of home appliance manufacturers are not in favor of a ban on halogenated flame retardants.
- Stakeholders generally agree not to set recycled content requirements for CRMs.

Table 7: Survey of potential requirements on fridges

	Potential requirement	**reference**	**recommendation**
1	**Recycled content requirements**		
1.1	Minimum recycled content for entire fridge. > 25% in 2030, > 45% in 2033	6.2.1.4, option 1	no
1.2	Minimum recycled content for entire plastics fridge mass. > 10% in 2030, > 30% in 2033	6.2.1.4, option 2	YES
1.3	Minimum recycled content for sum of PS, PP, ABS mass in fridge. > 20% in 2030, > 40% in 2033	6.2.1.4, option 3	Alternative to 1.2
1.4.1	Minimum recycled content per type of plastic in a fridge. PS > 30% in 2030, > 50% in 2033	6.2.1.4, option 4	Alternative to 1.2

	PP > 20% in 2030, > 40% in 2033 ABS > 20% in 2030, > 40% in 2033		
1.4.2	Minimum recycled content per type of plastic in a fridge PUR > X% in 2033	6.2.1.4, option 4	To be decided in 2030.
1.5	Minimum recycled content per (plastic) fridge component. Body inner liner > 30% in 2030, > 50% in 2033 Door inner liner > 30% in 2030, > 50% in 2033 Shelves, drawers, etc. > 30% in 2030, > 50% in 2033	6.2.1.4, option 5	no
1.6	Minimum recycled content for ferrous metals in fridges	6.2.2	no
1.7	Minimum recycled content for aluminium in fridges	6.2.2	no
1.8	Minimum recycled content for copper in fridges	6.2.2	no
1.9	Minimum recycled content for flat glass in fridges > 15% in 2030, > 35% in 2033	6.2.3	YES
1.10	Minimum recycled content for electronics in fridges	6.2.4	no
1.11	Minimum recycled content for other fridge materials	6.2.5	no
2	**Recyclability requirements**		
2.1	Main structure: marking for the presence or not of vacuum insulation panels, and of the type of core material used	6.3.4.1	YES
2.2	Transparent doors: design for ease of separation of glass from other door materials (e.g. spacers, frames)	6.3.4.2	YES, but needs further study
2.3	Shelves, drawers, etc.: require a marking on the shelves, drawers, baskets and accessories that indicates the type of plastic, like what is done for packaging.	6.3.4.3	YES
2.4	Shelves, drawers, etc.: design for ease of separation of different material types used in a single component.		YES, but needs further study
2.4	Hermetic compressor: require separation before shredding and separate processing by specialists	6.3.4.4	no
2.5	Cooling system: no potential requirements identified	6.3.4.5	void
2.6	Internal air flow: require spare parts availability for fans, fan motors, and controls	6.3.4.6	YES, but needs further study
2.7.1	Electronics: boards larger than 10 cm² and boards containing batteries or wet capacitors should be easily removable for recyclers, without the use of screwdrivers	6.3.4.7	YES, but needs further study
2.7.2	Electronics: position all printed circuit boards in a box on top of the fridge, or if that is not possible use a standardized marking, recognizable from 2-meter distance, to indicate the location of the box	6.3.4.7	YES, but needs further study
2.7.3	Electronics, for printed circuit boards in fridges, use any of the four types of plastics that are recycled from fridges today (GPPS, HIPS, PP, ABS), as bare board material	6.3.4.7	no
2.8	Other components: require a label indicating the type of refrigerant being used in the fridge, clearly visible from a distance during the recycling process	6.3.4.8	no
2.9.1	Additives and fillers: forbid the use of halogenated flame retardants, and require a marking for plastics containing flame retardants, like the regulation for electronic displays	6.3.5	Needs further study
2.9.2	Additives and fillers: set a maximum 10% mass content for chalk, talcum, or fibre glass filler in polypropylene	6.3.5	maybe
2.9.3	Plastics with additives or fillers giving recycling problems: require density 1.2 g/cm3 or higher to facilitate separation	6.3.5	maybe
2.10	Recyclability index: develop a recyclability index for fridges	6.3.6	Needs further study
3	**Requirements for CRMs**		
3.1	Recycled content requirements	6.4	no
3.2	Recyclability requirements	6.4	Needs further study
3.3	Information requirements	6.4	Needs further study

4.3.6. Estimates of Magnitude of Impacts

The analysis of the reduction of impacts compared to the baseline has been performed for the following minimum post-consumer recycled content (RC) requirements:

PS > 30% in 2030, > 50% in 2033

PP > 20% in 2030, > 40% in 2033

ABS > 20% in 2030, > 40% in 2033

Flat glass > 15% in 2030, > 35% in 2033

The results of the analysis are shown in the table below for the tier 2 requirements of 2033, for refrigerating appliances projected to be sold in 2033 (17.4 million units).

The table is split in two parts, covering different environmental impact categories. The top four rows show the baseline materials and end-of-life impacts, for plastics only, for glass only, and for all fridge materials, and the latter when adding impacts from use phase electricity consumption over the product lifetime. The bottom four rows show the impact reduction shares versus the baseline impacts. For some categories, the EU27 total impact in 2020 is also shown for reference.

Table 8: Reduction of material and end-of-life impacts compared to the baseline, for fridges projected to be sold in 2033, when using 2033 minimum proposed recycled content percentages for PS, PP, ABS and flat glass, for base case COLD 7 (combi).

RF sales in 2033 Tier 2, 2033	Virgin Mass in input [kton]	Climate change, total [kton CO2 eq]	Ozone depletion [kg CFC-11 eq]	Human toxicity, cancer [CTUh]	Human toxicity, non-cancer [CTUh]	Particulate matter [disease incidence]	Ionising radiation, human health [ton Bq U235 eq]	Photo-chemical ozone formation, human health [ton NMVOC eq]	Acidifi-cation [k mol H+ eq]
Baseline impact Material & EoL									
Plastics only	427	868	17.6	0.4	11.2	26.9	37985	2063	2330
Glass only	96	109	0.0	0.0	0.1	62.9	3539	368	627
All materials	890	1964	19.9	0.9	35.5	155.3	128335	4583	6688
All materials & Electricity use		28821	29.8	5.4	125.4	1011.6	11540810	48567	88412
EU27 total 2020		3311000							
Impact reduction									
PP (R1=40%)	17.3	18.1	1.7E-01	1.3E-02	1.6E-01	2.1E+00	285	105.8	139.3
HIPS (R1=50%)	72.0	56.2	-2.5E+00	3.4E-02	1.4E+00	2.2E-02	-636	80.9	20.8
GPPS (R1=50%)	50.0	39.1	-1.8E+00	2.4E-02	9.7E-01	1.5E-02	-442	56.2	14.5
ABS (R1=40%)	2.3	3.2	3.3E-05	1.2E-03	4.9E-02	4.3E-02	59	6.5	6.5
Glass (R1=35%)	30.2	3.2	1.8E-04	-7.5E-04	2.9E-03	4.5E+00	248	4.0	1.1
Sum reduction	**172**	**119.8**	**-4.1**	**0.1**	**2.6**	**6.7**	**-487**	**253**	**182**
Share reduction vs. baseline									
Plastics only	33%	13.4%	-23.3%	17.7%	23.0%	8.1%	-1.9%	12.1%	7.8%

Glass only	32%	3.0%	6.9%	-5.0%	2.1%	7.2%	7.0%	1.1%	0.2%
All materials	19%	6.1%	-20.7%	7.8%	7.2%	4.3%	-0.4%	5.5%	2.7%
All materials & Electricity use		0.4%	-13.8%	1.3%	2.1%	0.7%	0.0%	0.5%	0.2%
Share EU27 total 2020		0.004%							

RF sales in 2033 Tier 2, 2033	Eutrophi-cation, terrestrial [k mol N eq]	Eutrophi-cation, freshwater [kg P eq]	Eutrophi-cation, marine [ton N eq]	Ecotoxicity, freshwater [k CTUe]	Land use [k pt]	Water use [Mm3 water eq. of deprived water]	Resource use, minerals and metals [kg Sb eq]]	Resource use, fossils [TJ]
Baseline impact Material & EoL								
Plastics only	6348	10.8	609	11978	1696	241	949	25440
Glass only	1868	0.04	160	1839	86	9	6	1196
All materials	15354	16.4	1445	21327	82427	464	56327	38427
All materials & Electricity use	179676	71.2	16945	143625	198076	9633	63168	505537
EU27 total 2020						158640		(51749000)
Impact reduction								
PP (R1=40%)	364	1.4	38.5	376	-10.5	14.7	115.8	540
HIPS (R1=50%)	141	-0.7	15.3	1325	20.6	6.1	16.4	2262
GPPS (R1=50%)	98	-0.5	10.6	921	14.3	4.2	11.4	1572
ABS (R1=40%)	24	0.0	2.3	44	4.9	-2.9	0.5	91
Glass (R1=35%)	23	0.0	1.3	138	1.2	0.2	0.4	17
Sum reduction	**650**	**0.2**	**68.1**	**2803**	**30.4**	**22.2**	**144**	**4483**
Share reduction vs. baseline								
Plastics only	9.9%	1.6%	11.0%	22.3%	1.7%	9.1%	15.2%	17.6%
Glass only	1.2%	6.8%	0.8%	7.5%	1.4%	2.2%	5.9%	1.5%
All materials	4.2%	1.1%	4.7%	13.1%	0.0%	4.8%	0.3%	11.7%
All materials & Electricity use	0.4%	0.3%	0.4%	2.0%	0.0%	0.2%	0.2%	0.9%
Share EU27 total 2020						0.014%		(0.009%)

4.3.7. Timeline of the review / preparatory study

The “Review Study, Evaluation and Impact Assessment support study for Refrigerating appliances” started in December 2024 and is expected to be completed in Spring 2027. The findings of the mini-study on fridges will feed into that study and be further discussed there.

4.4. Household washing machines

4.4.1. Scope

The product scope for this mini-study is aligned with the scope proposed in the 'Review study and support to evaluation and impact assessment for Ecodesign and EU Energy Labelling for the product group "household washing machines and household washer-dryers"',[71] which is currently on-going.

4.4.2. Bill-of-materials for selected base cases

This mini study considers the same baseline cases (BCs) as the Review Study:

- BC 1 washing machine (8 kg nominal capacity)
- BC 2 washing machine (10 kg nominal capacity)
- BC 3 washer-dryer (9 kg nominal capacity)

The BOMs of the BCs are shown in Table 9:

Table 9: Currently available aggregated BoMs, from the on-going Review Study

Component / material	**BC1**	**BC2**	**BC3**
ABS Plastics	1.51	1.65	1.63
Aluminium	2.41	3.04	5.07
Cables	0.58	0.66	0.59
Concrete	21.40	22.00	14.00
Copper	1.14	1.18	1.35
Elastomer	2.64	2.67	2.76
Ferrite magnet	0.04	0.07	0.07
Heatsink (Aluminium)	0.16	0.16	0.13
PA (polyamide)	0.40	0.60	0.40
Other technical and non-technical plastics	0.85	0.90	0.85
PP (polypropylene)	7.09	9.11	8.13
Glass fibre	1.67	2.12	2.10
Powder paint	0.60	0.60	0.60
Printed wire boards	0.77	0.92	0.86
Glass	2.20	2.20	2.20
Silicone	0.03	0.03	0.03
Stainless steel	4.11	4.69	4.30
Steel	24.09	28.06	27.44
Sum	71.71	80.66	72.49

As the BOMs of the base cases are similar, with total weights ranging from 71.1 kg to 80.7 kg and comparable materials and BC1 accounts for 79% of EU-sales, the LCA carried out for the mini-study focussed on BC1.

The amount of virgin material, of recycled material in input and output are shown Figure 13 and Figure 14. In the baseline, 14% of the input mass is recycled content (all from metals)

[71] See: https://ecodesign-washing-machines.eu/

and 38% of the input mass is recycled at end-of-life (most from metals, but also from PP, PS, ABS, and some electronics).

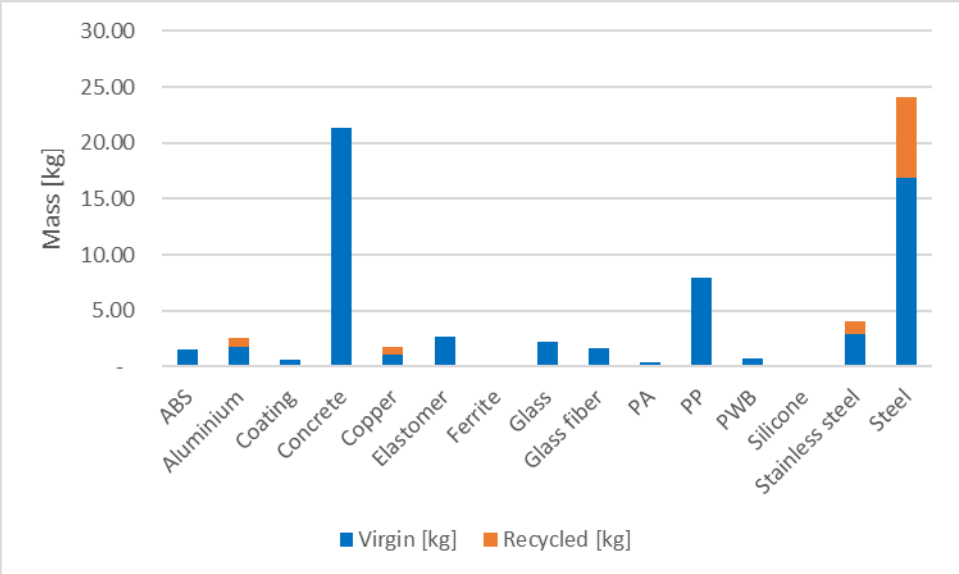

Figure 13: Virgin and recycled material in input, baseline, base case 1

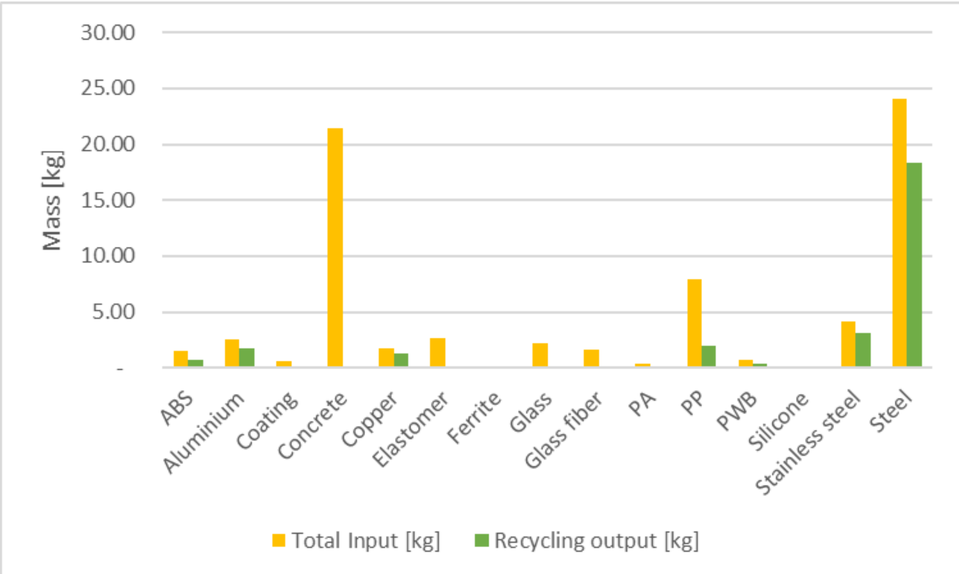

Figure 14: Total material input and recycled material output, baseline, base case 1

4.4.3. Environmental impacts for the baseline models

A LCA was conducted using the latest version of the EcoReport Tool. According to the LCA result (see Figure 15), the use phase is the most relevant stage in the overall life cycle of a typical household washing machine.[72]

---

[72] Assumptions: 183 cycles/a and 12.5 years per washing machine. In terms of consumption: 135 kWh/a (0.739 kWh/cycle) of electricity, 11.39 m³/a (62 l/cycle) of water and 10.4 kg/a (57 gr/cycle) of detergent

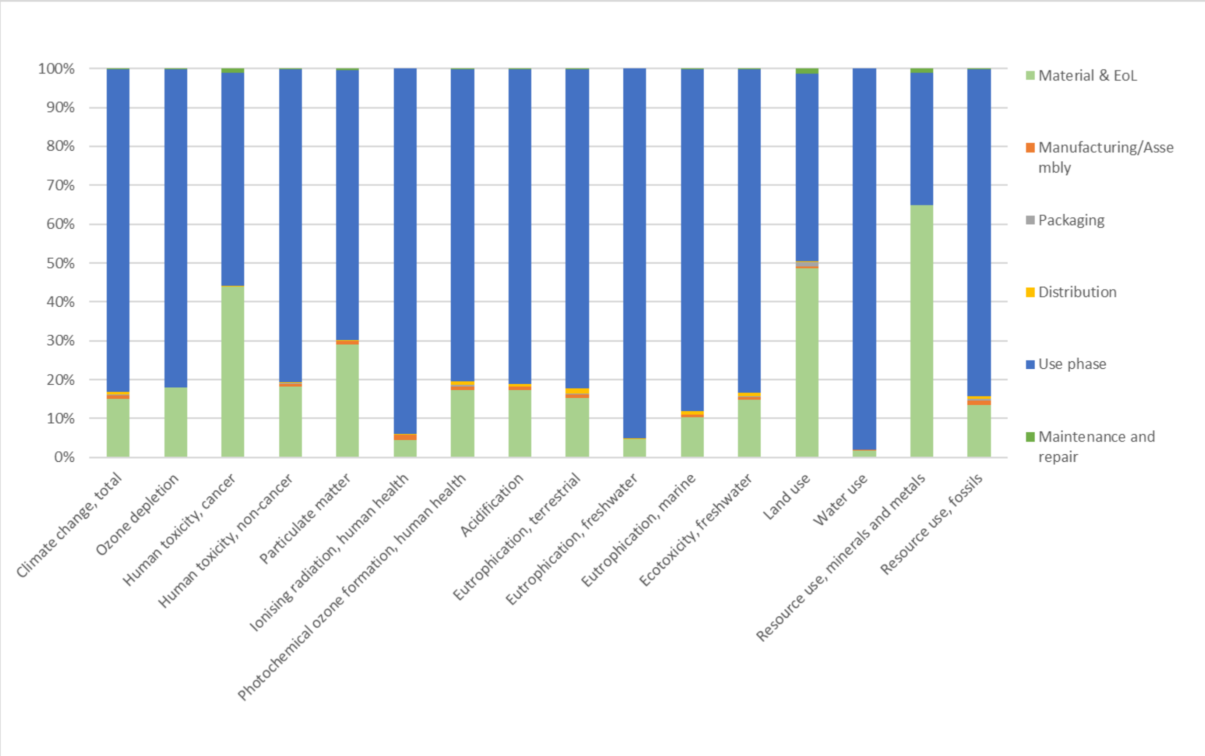

Figure 15: Impact shares from materials & end-of-life and from use-phase electricity consumption, per environmental impact category, for base case 1, for the baseline.

4.4.4. Critical Raw Materials

Automatic washing machines and tumble driers are explicitly in the scope of Article 28[73] of the CRM Act. However, not all washing machines utilize rare earth-based permanent magnets; some may contain rare-earthbased permanent magnets (averaging far below 100 grams in total) spread across a few components, which are not present in all models. Assuming that NdFeB[74] is used for the rare earth permanent magnets, this implies that there is significantly less than 30 grams of Nd per washing machine, and often much less for many models, if any. At least one manufacturer declared to use exclusively ferrite-based PM, even for its high-end models. All together, 10 gr. of NdFeB magnet (3 gr. of Nd) per washing machine might be a realistic figure for an average washing machine on the EU market.

4.4.5. Design and policy options

In the following, we describe the design and policy options that have been presented and discussed. These may be considered in the process of elaborating the forthcoming ESPR regulation on household washing machines and household washer-dryers.

Table 10 summarize the design and policy options.

[73] Recyclability of permanent magnets

[74] *NdFeB alloy is typically composed of 30% of neodymium (Nd), 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%)*

Table 10: Overview of potential requirements on washing machines

	Potential requirement	**Recommendation**
1	**Recycled content requirements**	
1.1	Minimum recycled content (all materials) for entire WM. > 18% in 2029, > 22% in 2032	No
1.2	Minimum recycled content for entire plastics WM mass. > 30% in 2029, > 60% in 2032	Likely, thresholds to be further checked
1.3	Minimum recycled content for sum of, PP, ABS, and elastomer mass in WM. > 30% in 2029, > 60% in 2032	Alternative to 1.2
1.4	Minimum recycled content per type of plastic in a WM. - PP > 30% in 2029, > 60% in 2032 - ABS > 30% in 2029, > 60% in 2032 - Elastomer > 10% in 2029, 20% in 2032	Alternative to 1.2
1.5	Minimum recycled content per (plastic) WM component. - Washer tub (outer drum) > 30% in 2029, > 60% in 2032 - Gasket: > 10% in 2029, > 20% in 2032 - Visible parts: > 30% in 2029, > 60% in 2032 - Other non-visible parts (back panel,…): > 40% in 2029, > 80% in 2032	No
1.6	Minimum recycled content for ferrous metals in WM	No
1.7	Minimum recycled content for aluminium in WM	No
1.8	Minimum recycled content for copper in WM	No
1.9	Minimum recycled content for glass in WM	No
1.10	Minimum recycled content for concrete in WM	No
1.11	Minimum recycled content for electronics in WM	No
1.12	Minimum recycled content for CRM	No (covered by CRM Act)
1.12	Recycled content on the label	Maybe, but needs further study
2	**Recyclability requirements**	
2.1	Top panel containing woody material: require a marking and design for ease of separation of top panel from the WM (e.g. spacers, frames)	Maybe, needs further study
2.2	Door with tempered glass: design for ease of separation of glass from the WM (e.g. spacers, frames)	Maybe, needs further study
2.3	PP washer tub: information requirement if > 10% filler	maybe
2.4	Dispensers/trays/hoses, drums, etc.: require a marking on the components and accessories that indicates the type of plastic, like what is done for packaging.	Maybe, needs further investigation
2.5	Dispensers/trays/hoses, drums, etc.: design for ease of separation of different material types used in a single component.	Maybe, but needs further study
2.6	Printed circuit boards containing batteries should be easy to identify and to remove for recyclers (without the use of screwdrivers)	Maybe, but needs further study
2.7	Additives and fillers: set a maximum 10% mass content for chalk, talcum, or fibre glass filler in polypropylene	Maybe, but needs further study
2.8	Additives and fillers: forbid the use of halogenated flame retardants, and require a marking for plastics containing flame retardants, like the regulation for electronic displays	Maybe
2.9	Recyclability index: develop a recyclability index for washing machines	No
2.10	Adhesives and glue…: limit the amount on plastic parts	No, indirectly addressed in case of reparability requirements
2.11	Recyclability requirements for CRM	No (partly covered by CRM Act)
2.12	Standardized marking for permanent magnets based on NdFeB, SmCo, and AlNiCo	Yes
2.13	Disassembly requirements for parts containing permanent magnets based on NdFeB, SmCo, and AlNiCo	Yes

Both recycled pre-consumer material (also named post-industrial recyclates (PIR)) and post-consumer recyclates (PCR) would be considered, accordingly, the suggested recycled content requirements were ambitious.

4.4.6. Estimates of Magnitude of Impacts

4.4.6.1. Impact reduction on product level

Table 11 shows the environmental impacts of a washing machine (Base Case 1) according to different levels of requirements: BAU (business-as-usual, i.e. no requirement), Tier 1, and Tier 2. The table also presents the recycled content: +31% in Tier 1 and +63% in Tier 2 compared to BAU.

Plastic recycled content requirements contribute to reducing the environmental impact of the product across all categories. However, the improvements achieved by Tier 2 are relatively limited and range from 0.00% (land use) to 15.95% (eutrophication, freshwater) - with 3.63% for climate change - when considering the material phase including end-of-life (EoL). When evaluating the entire life cycle of the product, the improvements range from 0.00% (land use) to 1.25% (eutrophication, freshwater), with 0.55% for climate change.[75]

Tier 1 achieves half the impact reduction of Tier 2, as Tier 2 is twice as ambitious.

[75] Important remark: the requirements are based on pre- and post-consumer recyclates. However, the ERT datasets for recycled plastics refer to post-consumer recyclates.

Table 11: Impact (on product level) of the washing machine according to the level of requirements

Level	Life stage	Recycled content [kg]	Climate change, total (kg CO2 eq)	Ozone depletion (kg CFC-11 eq)	Human toxicity, cancer (CTUh)	Human toxicity, non-cancer (CTUh)	Particulate matter (disease incidence)	Ionising radiation, human health (kBq U235 eq)	Photochemical ozone formation, human health (kg NMVOC eq)	Acidification (mol H+ eq)
BAU	Material (excl. EoL)	9.87	2.37E+02	3.15E-06	2.78E-06	5.33E-06	2.96E-05	1.07E+01	6.18E-01	1.22E+00
BAU	Other plases (use...)		1.11E+03	1.44E-05	1.35E-06	1.65E-05	5.92E-05	3.44E+02	2.34E+00	4.15E+00
BAU	EoL-i		3.22E+01	7.69E-09	4.00E-08	1.60E-07	1.91E-06	8.72E+00	4.85E-02	7.53E-02
BAU	EoL-c		-7.30E+01	-2.33E-08	-1.76E-06	-1.81E-06	-7.36E-06	-3.35E+00	-1.75E-01	-4.31E-01
BAU	**All stages**		**1.31E+03**	**1.75E-05**	**2.41E-06**	**2.02E-05**	**8.34E-05**	**3.60E+02**	**2.83E+00**	**5.01E+00**
BAU	**Material (incl. EoL)**		**1.96E+02**	**3.13E-06**	**1.06E-06**	**3.68E-06**	**2.42E-05**	**1.61E+01**	**4.91E-01**	**8.66E-01**
BAU	**Share material**		**15.0%**	**17.9%**	**43.9%**	**18.2%**	**29.0%**	**4.5%**	**17.4%**	**17.3%**
Tier 1	Material (excl. EoL)	12.98	2.34E+02	3.13E-06	2.77E-06	5.30E-06	2.93E-05	1.06E+01	6.01E-01	1.20E+00
Tier 1	Other plases (use...)		1.11E+03	1.44E-05	1.35E-06	1.65E-05	5.92E-05	3.44E+02	2.34E+00	4.15E+00
Tier 1	EoL-i		3.22E+01	7.69E-09	4.00E-08	1.60E-07	1.91E-06	8.72E+00	4.85E-02	7.53E-02
Tier 1	EoL-c		-7.30E+01	-2.33E-08	-1.76E-06	-1.81E-06	-7.36E-06	-3.35E+00	-1.75E-01	-4.31E-01
Tier 1	**All stages**		**1.31E+03**	**1.75E-05**	**2.40E-06**	**2.01E-05**	**8.31E-05**	**3.60E+02**	**2.82E+00**	**4.99E+00**
Tier 1	**Material (incl. EoL)**		**1.93E+02**	**3.11E-06**	**1.05E-06**	**3.65E-06**	**2.38E-05**	**1.60E+01**	**4.75E-01**	**8.45E-01**
Tier 1	**Share material**		**14.8%**	**17.8%**	**43.8%**	**18.1%**	**28.7%**	**4.4%**	**16.9%**	**16.9%**
Tier 2	Material (excl. EoL)	16.08	2.30E+02	3.10E-06	2.77E-06	5.27E-06	2.90E-05	1.05E+01	5.84E-01	1.18E+00
Tier 2	Other plases (use...)		1.11E+03	1.44E-05	1.35E-06	1.65E-05	5.92E-05	3.44E+02	2.34E+00	4.14E+00
Tier 2	EoL-i		3.22E+01	7.69E-09	4.00E-08	1.60E-07	1.91E-06	8.72E+00	4.85E-02	7.53E-02
Tier 2	EoL-c		-7.30E+01	-2.33E-08	-1.76E-06	-1.81E-06	-7.36E-06	-3.35E+00	-1.75E-01	-4.31E-01
Tier 2	**All stages**		**1.30E+03**	**1.75E-05**	**2.40E-06**	**2.01E-05**	**8.28E-05**	**3.60E+02**	**2.80E+00**	**4.97E+00**
Tier 2	**Material (incl. EoL)**		**1.89E+02**	**3.09E-06**	**1.05E-06**	**3.61E-06**	**2.35E-05**	**1.59E+01**	**4.58E-01**	**8.23E-01**
Tier 2	**Share material**		**14.5%**	**17.7%**	**43.8%**	**18.0%**	**28.4%**	**4.4%**	**16.4%**	**16.6%**
Tier1 vs BAU	**Material (incl. EoL)**	**31.51%**	**-1.82%**	**-0.77%**	**-0.20%**	**-0.89%**	**-1.26%**	**-0.54%**	**-3.40%**	**-2.47%**
Tier1 vs BAU	**All stages**		**-0.28%**	**-0.14%**	**-0.09%**	**-0.16%**	**-0.37%**	**-0.02%**	**-0.60%**	**-0.43%**
Tier 2 vs. BAU	**Material (incl. EoL)**	**62.92%**	**-3.63%**	**-1.54%**	**-0.40%**	**-1.78%**	**-2.53%**	**-1.09%**	**-6.79%**	**-4.95%**
Tier 2 vs. BAU	**All stages**		**-0.55%**	**-0.28%**	**-0.18%**	**-0.33%**	**-0.74%**	**-0.05%**	**-1.19%**	**-0.86%**

Level	Life stage	Eutrophication, terrestrial (mol N eq)	Eutrophication, freshwater (kg P eq)	Eutrophication, marine (kg N eq)	Ecotoxicity, freshwater (CTUe)	Land use (pt)	Water use (m3 water eq. of deprived water)	Resource use, minerals and metals (kg Sb eq)	Resource use, fossils (MJ)	Primary energy consumption (MJ)
BAU	Material (excl. EoL)	2.08	1.97E-01	2.69E-03	2.38E+03	2.95E+04	5.88E+01	1.24E-02	3.13E+03	3.13E+03
BAU	Other plases (use...)	9.390E+00	1.42E+00	5.14E-02	9.20E+03	1.11E+04	2.96E+03	4.36E-03	1.81E+04	1.85E+04
BAU	EoL-i	1.780E-01	1.66E-02	5.19E-05	1.06E+02	1.01E+02	7.11E+00	7.73E-06	5.11E+02	5.11E+02
BAU	EoL-c	-5.605E-01	-5.13E-02	-2.27E-04	-8.80E+02	-1.91E+04	-1.31E+01	-4.38E-03	-8.00E+02	-8.00E+02
BAU	**All stages**	**1.108E+01**	**1.58E+00**	**5.40E-02**	**1.08E+04**	**2.17E+04**	**3.01E+03**	**1.24E-02**	**2.09E+04**	**2.14E+04**
BAU	**Material (incl. EoL)**	**1.695E+00**	**1.63E-01**	**2.52E-03**	**1.61E+03**	**1.06E+04**	**5.29E+01**	**8.03E-03**	**2.84E+03**	**2.84E+03**
BAU	**Share material**	**15.3%**	**10.3%**	**4.7%**	**14.9%**	**48.7%**	**1.8%**	**64.8%**	**13.6%**	**13.3%**
Tier 1	Material (excl. EoL)	2.02	1.91E-01	2.49E-03	2.31E+03	2.95E+04	5.73E+01	1.24E-02	3.02E+03	3.02E+03
Tier 1	Other plases (use...)	9.389E+00	1.42E+00	5.14E-02	9.20E+03	1.11E+04	2.96E+03	4.36E-03	1.81E+04	1.85E+04
Tier 1	EoL-i	1.780E-01	1.66E-02	5.19E-05	1.06E+02	1.01E+02	7.11E+00	7.73E-06	5.11E+02	5.11E+02
Tier 1	EoL-c	-5.605E-01	-5.13E-02	-2.27E-04	-8.80E+02	-1.91E+04	-1.31E+01	-4.38E-03	-8.00E+02	-8.00E+02
Tier 1	**All stages**	**1.103E+01**	**1.57E+00**	**5.37E-02**	**1.07E+04**	**2.17E+04**	**3.01E+03**	**1.24E-02**	**2.08E+04**	**2.13E+04**
Tier 1	**Material (incl. EoL)**	**1.638E+00**	**1.57E-01**	**2.32E-03**	**1.54E+03**	**1.06E+04**	**5.13E+01**	**8.01E-03**	**2.73E+03**	**2.73E+03**
Tier 1	**Share material**	**14.9%**	**10.0%**	**4.3%**	**14.3%**	**48.7%**	**1.7%**	**64.7%**	**13.1%**	**12.9%**
Tier 2	Material (excl. EoL)	1.96	1.85E-01	2.29E-03	2.25E+03	2.95E+04	5.58E+01	1.24E-02	2.92E+03	2.92E+03
Tier 2	Other plases (use...)	9.389E+00	1.42E+00	5.14E-02	9.20E+03	1.11E+04	2.96E+03	4.36E-03	1.81E+04	1.85E+04
Tier 2	EoL-i	1.780E-01	1.66E-02	5.19E-05	1.06E+02	1.01E+02	7.11E+00	7.73E-06	5.11E+02	5.11E+02
Tier 2	EoL-c	-5.605E-01	-5.13E-02	-2.27E-04	-8.80E+02	-1.91E+04	-1.31E+01	-4.38E-03	-8.00E+02	-8.00E+02
Tier 2	**All stages**	**1.097E+01**	**1.57E+00**	**5.35E-02**	**1.07E+04**	**2.17E+04**	**3.01E+03**	**1.24E-02**	**2.07E+04**	**2.11E+04**
Tier 2	**Material (incl. EoL)**	**1.580E+00**	**1.51E-01**	**2.12E-03**	**1.47E+03**	**1.06E+04**	**4.98E+01**	**7.99E-03**	**2.63E+03**	**2.63E+03**
Tier 2	**Share material**	**14.4%**	**9.6%**	**4.0%**	**13.8%**	**48.7%**	**1.7%**	**64.7%**	**12.7%**	**12.4%**
Tier1 vs BAU	**Material (incl. EoL)**	**-3.37%**	**-3.68%**	**-7.97%**	**-4.15%**	**0.00%**	**-2.86%**	**-0.20%**	**-3.72%**	**-3.72%**
Tier1 vs BAU	**All stages**	**-0.52%**	**-0.38%**	**-0.38%**	**-0.62%**	**0.00%**	**-0.05%**	**-0.13%**	**-0.51%**	**-0.50%**
Tier 2 vs. BAU	**Material (incl. EoL)**	**-6.75%**	**-7.35%**	**-15.95%**	**-8.30%**	**0.00%**	**-5.72%**	**-0.41%**	**-7.45%**	**-7.45%**
Tier 2 vs. BAU	**All stages**	**-1.04%**	**-0.77%**	**-0.75%**	**-1.25%**	**0.00%**	**-0.10%**	**-0.27%**	**-1.02%**	**-1.00%**

4.4.6.2. Impact reduction on market level

Table 11 shows the environmental impacts of the washing machine market according to different levels of requirements: BAU (business-as-usual: no requirement), Tier 1 and Tier 2. To estimate the impact of the market, the environmental impacts of base case 1 have been multiplied by the whole EU market volume (12 Mio of units), considering all three base cases (BC1: WM 8 kg, BC2: WM 10 kg, BC3: WD 9 kg). As the BOMs of the base cases are similar (the total weights range from 71.1 kg to 80.7 kg and comparable materials) and BC1 accounts for 79% of EU-sales, this is a reasonable simplification for such a mini study. With Tier 1, 37 kt of virgin plastics could be saved per year; from 2022 (Tier 2), it would be even 74 kt.

4.4.7. Timeline of the review study

The “Review Study, Evaluation and Impact Assessment support study for Household Washing Machines and Household Washer-Dryers” started in June 2024 and is expected to be completed in November 2026. The Review Study itself is already well advanced, with the draft of Task 7 expected to be presented after summer 2025.

4.5. Electric motors

4.5.1. Scope

This study evaluates the potential for reducing environmental impacts in electric motors with a particular focus on critical raw materials (CRMs), recycled content, and recyclability. It serves as input for the ongoing review study on induction electric motors, variable speed drives (VSDs), and permanent magnet motors (PMMs). Motors for electric vehicle traction and those exceeding 1,000 kW are excluded. The study aims to assess design options for increasing recycled content and recyclability, particularly for CRMs like rare earth elements (REEs) and copper, while aligning with the EU’s broader circular economy and sustainability goals.

4.5.2. Bill-of-Materials for selected base cases

The detailed environmental analysis was carried out for two representative motor models: an IE4 Induction Motor (55 kW), and an IE4 Permanent Magnet Motor (PMM, 55 kW). Metals dominate the composition of both motors, with steel, cast iron, and copper being the primary materials. PMMs also include permanent magnets containing REEs, which account for 2.2% of the motor's mass. While copper and steel are assumed to have some recycled content (30–37%) in the base case, REEs are assumed to have none. The bill-of-materials (BoM) analysis highlights the material intensity of motors and the potential for improving circularity through targeted measures.

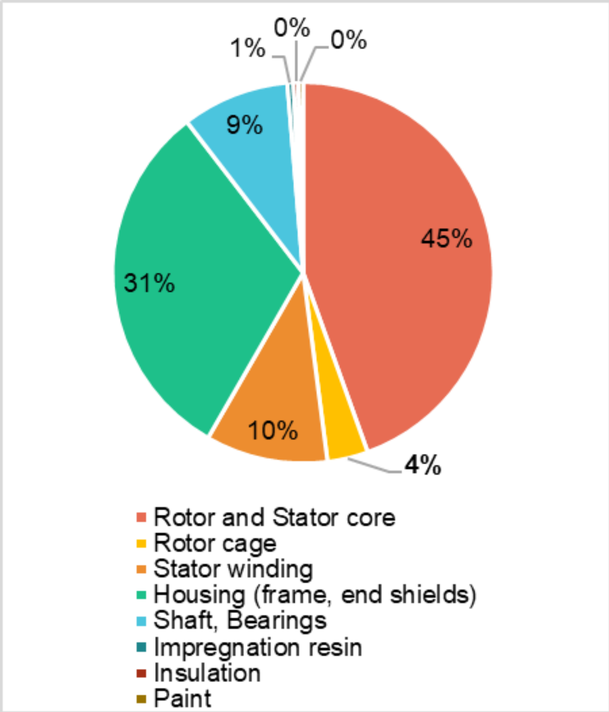

Figure 16: Mass distribution for SCIM IE4 55kW

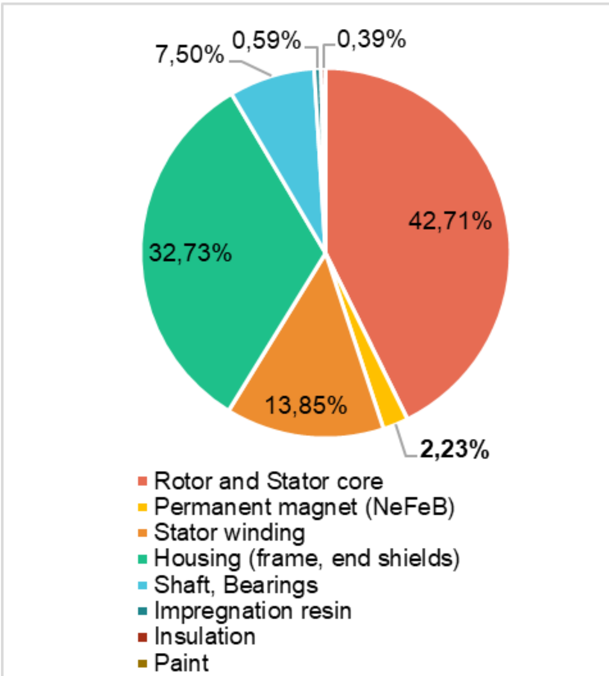

Figure 17: Mass distribution for PM IE4 55kW

4.5.3. Environmental Impacts for the baseline models

The environmental impacts of the motors were assessed across key categories, such as climate change, particulate matter, and resource use. The use phase dominates the overall environmental footprint due to energy consumption, but material-related impacts remain relevant because of a combination of strategic and environmental reasons. For PMMs, permanent magnets strongly influence water use, acidification, and particulate matter, while for induction motors, copper has a high impact on land use. Aluminum in induction motors contributes to ionizing radiation and freshwater ecotoxicity. These findings underscore the importance of addressing material impacts alongside energy efficiency improvements.

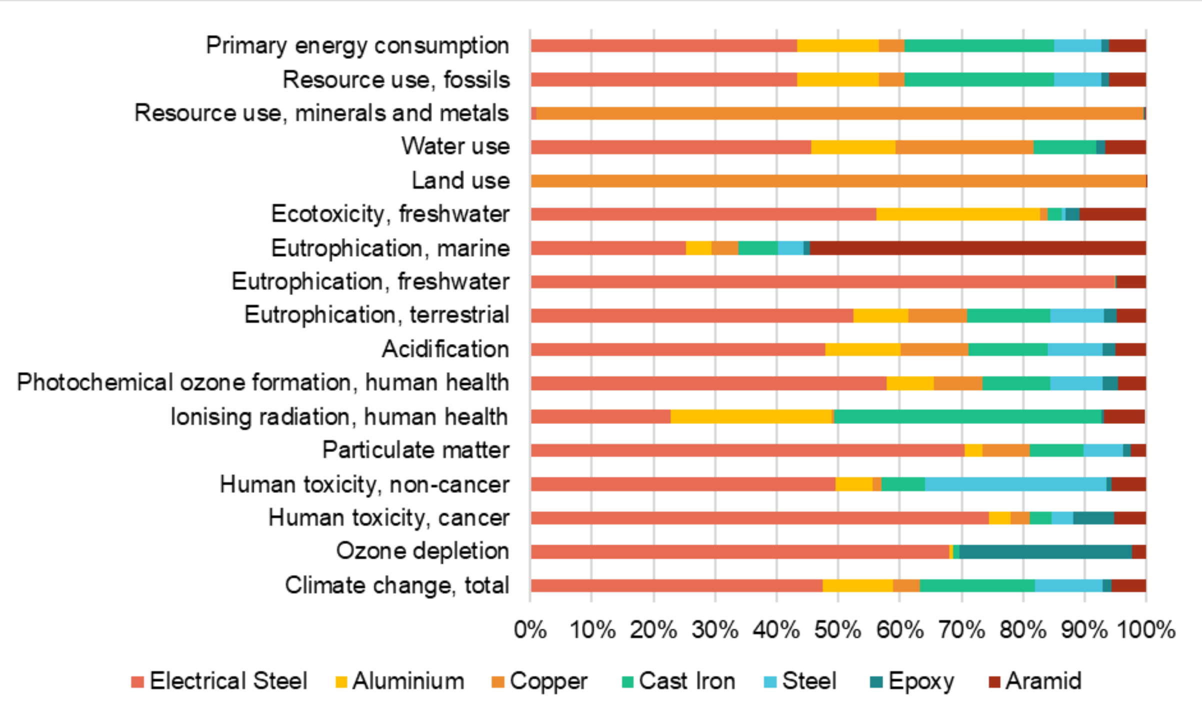

Figure 18: Shares of environmental impacts by material category, for SCIM IE4 55 kW

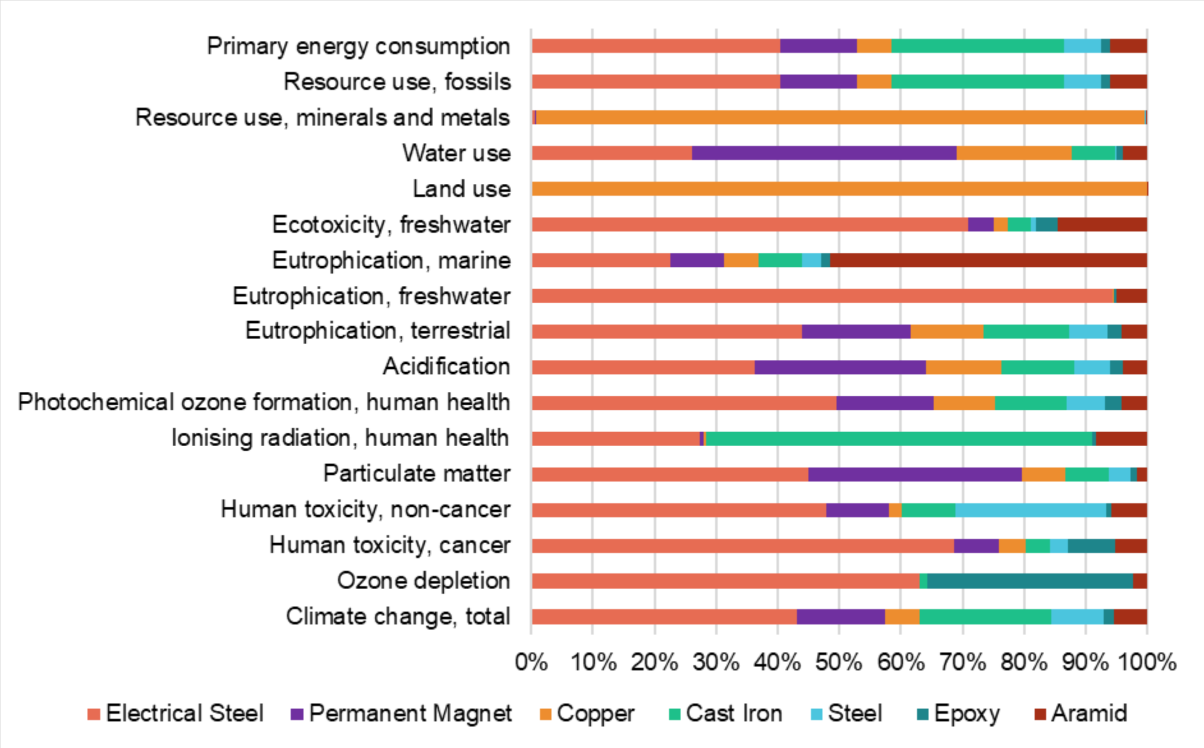

Figure 19: Shares of environmental impacts by material category, for PM IE4 55 kW

4.5.4. Critical Raw Materials

Permanent magnets in PMMs rely on REEs like neodymium and dysprosium, which are critical for motor performance but pose environmental and strategic risks. REE recycling is currently limited due to technical and economic barriers, such as complex separation processes and high costs. Copper, widely used in motor windings, is already extensively recycled due to its high economic value. Ensuring even higher quantities of high-purity recycled copper for motor applications remains a challenge. Both materials present opportunities for circularity but require tailored approaches to address their unique challenges.

4.5.5. Design and policy options

In the following, we describe the design and policy options that have been presented and discussed. These may be considered in the process of elaborating the forthcoming ESPR regulation on electric motors.

The study explored several design options to increase recycled content and recyclability. For copper, increasing recycled content to 60% could yield modest environmental benefits but faces significant challenges, including limited high-grade scrap availability, verification difficulties, and potential performance degradation. For REEs, introducing 10–30% recycled content in PMMs could reduce greenhouse gas (GHG) emissions by up to 547 tonnes CO_2 equivalent for motors sold in 2030 (considering the 30% target). However, prerequisites include ensuring material quality, scaling recycling infrastructure, and addressing economic viability. Improving REE recyclability to 30% could save over 2.000 tonnes CO_2 equivalent for motors sold in 2030, but this requires investments in advanced disassembly and separation technologies. Stakeholders emphasized the need for harmonization between the

Ecodesign for Sustainable Products Regulation (ESPR) and the CRM Act to avoid regulatory overlaps and streamline implementation.

4.5.6. Estimates of Magnitude of Impacts

The study estimates the environmental savings potential of the proposed design options. Increasing recycled copper content to 60% could save up to 17.261 tonnes CO_2 equivalent for induction motors in stock by 2030. Scaling recycled REE content to 30% could save 547 tonnes CO_2 equivalent for PMMs sold in 2030, while improving REE recyclability to 30% could save over 2.000 tonnes CO_2 equivalent. These findings highlight the significant potential of REE-focused measures, particularly in PMMs, which are strategically important for industrial applications. However, the study findings suggest to design timing and scope of the measures based on further feasibility analyis, and place an earlier focus on enhancing REE recyclability before mandating recycled content requirements. For copper, a more cautious approach is suggested and upstream measures such as directly targeting end-of-life collection rates seem to be the more effective and feasible options.

4.5.7. Timeline of the review study

The “evaluation and impact assessment for the review of the Commission regulation for electric motors and VSDs” started in December 2024, is currently in progress and is expected to be completed in April 2027.

Getting in touch with the EU

In person

All over the European Union there are hundreds of Europe Direct centres. You can find the address of the centre nearest you online (european-union.europa.eu/contact-eu/meet-us_en).

On the phone or in writing

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

– by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),
– at the following standard number: +32 22999696,
– via the following form: european-union.europa.eu/contact-eu/write-us_en.

Finding information about the EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website (european-union.europa.eu).

EU publications

You can view or order EU publications at op.europa.eu/en/publications. Multiple copies of free publications can be obtained by contacting Europe Direct or your local documentation centre (european-union.europa.eu/contact-eu/meet-us_en).

EU law and related documents

For access to legal information from the EU, including all EU law since 1951 in all the official language versions, go to EUR-Lex (eur-lex.europa.eu).

EU open data

The portal data.europa.eu provides access to open datasets from the EU institutions, bodies and agencies. These can be downloaded and reused for free, for both commercial and non-commercial purposes. The portal also provides access to a wealth of datasets from European countries.

[Catalogue number]

Publications Office
of the European Union