

# Support to implementation of 2024/1252 Critical Raw Materials Act Article 26: National Measures on Circularity

## Priority list of waste streams, evidence and methodology

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## Abstract

This JRC Science for Policy report provides scientific evidence for establishing the list of products, components and waste streams, rich in critical raw materials and with significant recovery potential, that Member States need to at least consider when establishing their national programmes containing circularity measures. Article 26 of the Critical Raw Material Act (Regulation (EU) 2024/1252) requires the establishment of a framework for ensuring a secure and sustainable supply of critical raw materials for the EU. Additionally, Article 26 (7) on National measures on circularity of which the Commission shall adopt implementing acts listing products, components, and waste streams deemed to have significant critical raw material recovery potential. This list will support actions to:

- promote waste prevention and the re-use/repair of critical raw material-rich items, and
- improve collection, sorting, and processing of critical raw material -containing waste, including metal scraps, for efficient recycling.

In developing the list, the Commission will consider Article 26 (7) sub-paragraphs *a* to *e*, such as, (a) the total recoverable critical raw material, (b) existing Union law coverage, (c) regulatory gaps, (d) challenges in collection and treatment, and (e) current systems for collection and treatment.

The list of products, components and waste streams contains in particular: batteries, electrical and electronic equipment, wind turbines and related infrastructure, motor vehicles, light means of transport, energy infrastructure and telecommunication infrastructure, industrial pumps, industrial catalysts, digestate and compost from separately collected biowaste, slag, sludges and ashes, and construction and demolition waste (particularly focusing on aluminium and copper alloys and cables in buildings).

This work also demonstrates that there is significant potential for improvement in recovery processes for strategic and critical raw materials for the analysed waste streams, such as for example Rare Earth Elements (REEs) in permanent magnets of wind turbines or aluminium parts in motor vehicles.

The work provides also opportunities for implementing provisions at EU and Members States levels through national programmes due to the identified gaps in current waste management and recovery processes for critical raw materials. This work highlights the importance of implementing circular economy strategies across EU Member States. This report represents also a valuable source of knowledge for implementing measures using existing and upcoming legislative documents, such as the Battery Regulation and the End-of-Life Vehicles Regulation Proposal, as well as Waste Electrical and Electronic Equipment Directive, that is under review.

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## **Executive summary**

### ***Policy context***

This JRC Science for Policy report provides scientific evidence for establishing the list of products, components and waste streams, rich in critical raw materials and with significant recovery potential, that Member States need to at least consider when establishing their national programmes containing circularity measures. It is required by the Article 26 (7) of the Regulation (EU) 2024/1252 (European Union 2024b) establishing a framework for ensuring a secure and sustainable supply of critical raw materials.

This work ultimately supports the transition towards a circular economy, strengthens EU economic security and competitiveness, and supports the objectives of the Clean Industrial Deal (CID) and the European Critical Raw Materials Act (CRMA).

Keeping strategic and critical raw materials in the EU will enhance the overall resilience of the EU economy as well as its twin transition.

### ***Key conclusions***

- This work demonstrates that there is significant potential for improvement in recovery processes for strategic and critical raw materials for the analysed waste streams, such as for example REEs in permanent magnets of wind turbines or aluminium parts in End-of-Life Vehicles.
- There is a need of implementing circular economy strategies and provisions at EU and Member States levels to overcome the identified gaps in current waste management and recovery processes for critical raw materials.
- In line with existing and emerging legislative instruments—such as the Battery Regulation, the ELV Regulation, and the WEEE Directive— Article 26 can serve as a reference for developing measures in other product categories, being the priority list herein developed intended to complement rather than duplicate the obligations already established under Union law.

### ***Methodology***

This work is developed to address specific legislation needs and mainly proposes and applies a consistent methodology to elaborate harmonised data on stock and flows of critical and strategic raw materials in waste streams, as well as prioritise them according to their recovery potential. The data are provided by the Horizon Europe project called “FutuRaM” and are further processed by the JRC. The data have high granularity, zooming in from the waste stream to the elements constituting the components and products. All the waste streams under the FutuRaM scope (see section of definitions) are consistently processed to provide a reproducible approach, accompanied by feasibility checks supported by expert judgment. Note that this work also includes relevant waste streams that do not have harmonised datasets available (e.g., in FutuRaM project), and their prioritisation will be based on specific analysis of existing information and literature research.

### ***Main findings: proposed list of products, components, and waste streams for Article 26 of the Regulation (EU) 2024/1252***

List of products, components and waste streams that are considered as having a relevant critical raw materials recovery potential:

- **Batteries**, with the following components, in particular:
  - (a) Cathode active materials\*;
  - (b) Anode active materials\*;
  - (c) Cathode current collectors\*;
  - (d) Anode current collectors\*;
  - (e) Battery management systems;
  - (f) Internal cables.
  
- **Electrical and electronic equipment**, with the following components, in particular:
  - (a) Permanent magnets;
  - (b) Hard disk drives;
  - (c) Compressors;
  - (d) Displays (cathode ray tube, liquid crystal, thin film, plasma);
  - (e) Printed circuit boards;
  - (f) Cables;
  - (g) Photovoltaic cells;
  - (h) Photovoltaic frames;
  - (i) Remaining fraction after specific dismantling in pre-treatment<sup>1</sup>.
  
- **Wind turbines and related infrastructure**, with the following components, in particular:
  - (a) Permanent magnets;
  - (b) Generators;
  - (c) Transformers;
  - (d) Converters and inverters;
  - (e) Cables.

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\* These components can also be found as main constituents in a mixed fraction after specific end-of-life-treatment, e.g. black mass.

<sup>1</sup> While not a component, the fraction of waste electrical and electronic equipment that remains after specific dismantling in pre-treatment typically contains high amounts of critical raw materials and may therefore be worth targeting in national circularity programmes.

- **Motor vehicles<sup>2</sup>** with the following components, in particular:
  - (a) Permanent magnet traction motors;
  - (b) Induction traction motors;
  - (c) Non-traction electric motors;
  - (d) Electrical and electronic components subject to re-use, recycling or any other form of recovery under relevant Union acts in their valid version;
  - (e) Converters and inverters;
  - (f) Main wiring harnesses;
  - (g) Fuel cells;
  - (h) Catalytic converters;
  - (i) Wrought aluminium components and/or parts;
  - (j) Cast aluminium components and/or parts;
  - (k) Magnesium components and/or parts.
- **Light means of transport.**
- **Energy infrastructure<sup>3</sup> and telecommunications infrastructure<sup>4</sup>.**
- **Industrial pumps.**
- **Industrial catalysts.**
- **Digestate and compost from separately collected biowaste.**
- **Sludges, and ashes**, in particular:

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<sup>2</sup> As defined in Regulation (EU) 2018/858 of the European Parliament and of the Council of 30 May 2018 on the approval and markets surveillance of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles, amending Regulations (EC) No 715/2007 and (EC) No 595/2009 and repealing Directive 2007/46/EC (OJ L 151, 14.6.2018, p. 1, ELI: <http://data.europa.eu/eli/reg/2018/858/oj>).

<sup>3</sup> As defined in Article 2, point (1), of Regulation (EU) 2022/869 of the European Parliament and of the Council of 30 May 2022 on guidelines for trans-European energy infrastructure, amending Regulations (EC) No 715/2009, (EU) 2019/942 and (EU) 2019/943 and Directives 2009/73/EC and (EU) 2019/944, and repealing Regulation (EU) No 347/2013 (OJ L 152, 3.6.2022, p. 45, ELI: <http://data.europa.eu/eli/reg/2022/869/oj>).

<sup>4</sup> Elements referred to in the definition of 'physical infrastructure as defined in Article 2, point (2) of Directive 2014/61/EU of the European Parliament and of the Council of 15 May 2014 on measures to reduce the cost of deploying high-speed electronic communications networks (OJ L 155, 23.5.2014, p. 1, ELI: <http://data.europa.eu/eli/dir/2014/61/oj>) and in Article 2, point (4) of Regulation (EU) 2024/1309 of the European Parliament and of the Council of 29 April 2024 on measures to reduce the cost of deploying gigabit electronic communications networks, amending Regulation (EU) 2015/2120 and repealing Directive 2014/61/EU (Gigabit Infrastructure Act) (OJ L, 2024/1309, 8.5.2024, ELI: <http://data.europa.eu/eli/reg/2024/1309/oj>).

Systems referred to in the definition of 'electronic communications network' as defined in Article 2, point (1) of Directive (EU) 2018/1972 of the European Parliament and of the Council of 11 December 2018 establishing the European Electronic Communications Code (OJ L 321, p. 36, ELI: <http://data.europa.eu/eli/dir/2018/1972/oj>).

- (a) Sewage sludge from urban wastewater<sup>5</sup> treatment;
- (b) Bottom and fly ashes resulting from the mono-incineration of sludges from the treatment of urban wastewater;
- (c) Bottom ashes from municipal solid waste incineration;
- (d) Bottom ashes from commercial or industrial waste incineration.

**- Construction and demolition waste, particularly focusing on aluminium, aluminium alloys, copper, copper alloys, and cables in buildings.**

The prioritisation of the above list is applied at the waste stream level, capturing the relevant components to be prioritised for the waste streams explored. It is important to note that each waste stream has several categories associated to it and not all the components need to be prioritised for each of these categories.

***Related and future JRC work***

This report provides direct input for the work of EC services in charge of CRM Act implementation, having a direct impact on national circularity programmes to be soon defined by EU Member States. Besides, it supports ongoing efforts related to the implementation of circularity measures of the CRM Act, such as Articles 28 and 29 as well as other EU legislation (e.g., WEEE Directive revision during 2026).

The methodology could be applied to revise the list in the future or to enlarge the scope of the study. Furthermore, the methodology and data published with this report could be utilised as input for future analyses also in other contexts, such as academia and research centres.

Based on this list, Member States could focus and strengthen their actions on dedicated production and design, thus decreasing waste generation, as well as actions to increase the waste collection, to improve the material recovery (particularly boosting the recovery of strategic and critical raw materials), to improve the technology development, and to expand the actions on not targeted yet product, components, and waste streams. Recyclers and waste management operators will benefit from the implementation of the Article 26 to target actions on the indicated waste streams of the list.

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<sup>5</sup> As defined in Article 2, point (1), of Directive (EU) 2024/3019 of the European Parliament and of the Council of 27 November 2024 concerning urban wastewater treatment (OJ L, 2024/3019, 12.12.2024, ELI: <http://data.europa.eu/eli/dir/2024/3019/oj> ).

# 1 Introduction

Within the Regulation (EU) 2024/1252 (European Union 2024b) establishing a framework for ensuring a secure and sustainable supply of critical raw materials, Article 26 (7) on National measures on circularity states that:

*“[...] the Commission shall adopt implementing acts specifying a list of products, components and waste streams that shall at least be considered as having a **relevant critical raw material recovery potential** within the meaning of paragraph 1, point b (promote waste prevention and increase re-use and repair of products and components with relevant critical raw materials recovery potential) and point c (increase the collection, sorting and processing of waste with relevant critical raw materials recovery potential, including metal scraps, and ensure their introduction into the appropriate recycling system, with a view to maximising the availability and quality of recyclable material as an input to critical raw material recycling facilities).*

*In drawing up that list, the Commission shall take account of:*

- (a) The total amount of critical raw materials recoverable from those products, components and waste streams;*
- (b) The extent to which those products, components and waste streams are covered by Union law;*
- (c) Regulatory gaps;*
- (d) Particular challenges affecting the collection and waste treatment of products, components and waste streams;*
- (e) Existing systems of collection and waste treatment applying to products, components and waste streams.”*

**The list in Article 26 (7) is binding and serves as a minimum list** that EU Member States (MSs) shall use when developing national programmes under points (b) and (c) of paragraph 1, though **they may include additional items**.

Practically, the list defines the minimum scope of critical raw materials (CRM)-rich products and waste to be addressed in national circularity programmes. It acts as a harmonisation tool, ensuring consistency across the EU and enabling comparable data, coordinated policies and experience sharing.

A key aspect of the Implementing Act (IA) list is that it is drafted in rigorous consideration of the 2023 list of Critical Raw Materials (CRMs) and Strategic Raw Materials (SRMs), as outlined in Annexes 1 and 2 of the EU Regulation 2024/1252. Since the lists of CRMs and SRMs are dynamic, the IA list may be updated to reflect any potential inclusions or exclusions from the revised Annexes. Additionally, the IA list considers the waste generated in 2022 and estimates for 2030 based on the currently available data. Therefore, updated data is needed in the coming years to replicate the analysis for 2035-2040, for example.

Note that, in this document, the terms “products” and “components” refer to items that have reached their end-of-life stage and thus the waste status (i.e. any substance or object which the holder discards or intends or is required to discard, according to the Waste Framework Directive (European Union 2008)) and subsequently must be treated as waste. Also note that, in general, components are within products.

**Critical raw materials** (CRMs) are raw materials that are evaluated as critical when they exceed defined thresholds in the following two dimensions, namely *Economic importance* (EI) and *Supply risk* (SR). EI represents the importance of the raw materials for the overall European Union's economy, and SR represents the risk of supply disruption for a raw material. Their evaluation is defined by an established EC methodology (see Annex 2 of the EU Regulation 2024/1252). The 2023 list of critical raw materials includes 34 raw materials out of the 87 screened individual materials (of which 67 are individual materials, and 3 grouped materials: 10 individual heavy (HREEs), 5 light (LREEs) rare earth elements, and 5 platinum-group metals (PGMs)).

**Strategic raw materials** (SRMs), on the other hand, are raw materials classified as such according to the criteria defined in the Annex 1 of the EU Regulation 2024/1252 based on:

- Their high strategic importance for the functioning of the internal market, considering their use in strategic technologies relevant for the green and digital transitions or for defence or aerospace applications.
- A potentially significant gap between global production and forecasted demand.
- Difficulty to increase their production.

The list of SRMs covers 17 raw materials out of the 34 identified as CRMs. The Regulation proposes to automatically add SRMs on the CRMs list. This means that all the SRMs are also, in turn, CRMs. It is important to highlight that copper (Cu) and nickel (Ni) do not meet the CRM threshold of supply risk but are included in the 2023 list of critical raw materials as SRMs (European Commission 2023). Copper is strategic because it is used in very large quantities for electrification across all strategic technologies. Nickel battery grade is strategic because used in strategic technologies, and its production capacity might be an issue in the future. Furthermore, some CRMs are also SRMs due to their specific quality grade or processing stage (lithium battery grade is both CRM and SRM, while lithium non-battery grade is only CRM).

Besides, being SRM differentiates CRM from others by providing an additional characteristic, which enables a focus on those critical raw materials used in strategic technologies that are essential for the European Union to tackle the green and digital transition and to enhance its strategic autonomy and competitiveness.

These aspects allow the identification of SRM as a criterion for prioritisation compared to the other CRMs that can be embedded in the analysed products and waste streams. Thus, within this research, the concept of strategic and critical raw materials (SCRMs when the reference is to both), will be extensively used to identify both materials under scope and to highlight that the strategic raw materials are important within the group of critical raw materials.

The Future Availability of Secondary Raw Materials (FutuRaM) project<sup>6</sup> seeks to develop knowledge on the availability and recoverability of secondary raw materials within the European Union (EU) up to the year 2050, with a special focus on CRMs, to enable fact-based decision making for their exploitation in the EU. FutuRaM is a four-year project funded by the Horizon Europe research and innovation programme that started in June 2022. The consortium of the FutuRaM project is

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<sup>6</sup> <https://cordis.europa.eu/project/id/101058522/reporting>

composed of 28 beneficiaries, affiliated entities and associated partners. The FutuRaM project contribution to this work is with interim datasets, and further insights on the feasibility check on the resulted prioritised list including the excluded waste streams. FutuRaM project focuses on six waste streams namely: Waste batteries (BATT), Waste Electrical and Electronic Equipment (WEEE), End-of-Life Vehicles (ELV), Mining waste (MINW), Slags, sludges, and Ashes (SLASH), and Construction and Demolition Waste (CDW). It is important to highlight that, in this work, MINW was not included, and wind turbines (WT) was included as a separate waste stream.

It is important to note that although Article 26 (3) states that *“programmes referred to in paragraph 1 shall cover in particular products and waste which are not subject to any specific requirement on collection, treatment, recycling or reuse under Union law. For other products and waste, the measures shall be implemented in accordance with Union law”* WEEE, BATT, and ELV—which are already covered by sector-specific legislation—are still considered for the priority list for future national programmes. This is because the focus of this list is specifically SCRM, which are not currently explicitly addressed in any other legislation, except in the 2023 Battery Regulation that specifically addresses CRMs such as lithium and cobalt. Their inclusion should not result in overlapping obligations/requirements but rather in complementary measures, implemented in line with existing Union law for these product and waste streams.

## 1.1 Objectives of the study

The main objective of this study is to support the implementation of the Article 26 of the Regulation (EU) 2024/1252. The following sub-objectives are included:

- **Develop a methodology to prioritise** products, components and waste streams that have a relevant critical and strategic raw material recovery potential, specifically in accordance with Article 26 (7) of the (EU) 2024/1252.
- Apply the methodology, using as much as possible **available harmonised data on secondary raw materials**, to **produce a list of products, components and waste streams with relevant critical and strategic raw material recovery potential**.
- **Provide evidence**, contextual factors and remarks to the prioritised list of products, components and waste streams.

## 2 Goal and scope

The main goal of this report is to develop a priority list of products, components and waste streams that have a relevant SCRM recovery potential, that will foster MSs to implement, through Article 26, meaningful and targeted national measures to increase circularity on them as shown in **Figure 1**, specifically reflecting the meaning of Article 26 paragraph 1, points (b) and (c). In **Figure 1** two parts can be identified. On the one hand, the upper part shows the situation “before” the Article 26, where the analysis for selected waste streams based on the Article 26 (7) sub-paragraphs *a* to *e* allows to account for the SCRMs in waste generated, potential losses, and potential recovery, considering the Union legislation coverage as well as the regulatory gaps. On the other hand, the lower part of the figure shows the situation “after” the Article 26, when national measures on circularity would ideally lead to less waste generated, more waste collected and more SCRMs recovered.

This section explains the scope of the study with a particular attention to the candidate waste streams, acknowledging that they fall into three distinct groups.

First, waste streams associated with specific flows identifiable as products placed on the market (PoM), (**waste stream group 1**) – these waste streams originate from final products and goods manufactured using materials and semi-finished products, both PoM. The products include: batteries (BATT), electrical and electronic equipment (WEEE), wind turbines (WT), and motor vehicles (considered as end-of-life vehicles (ELV)). These products are often complex in composition and multi-layered with components and sub-components, and, due to their intended relatively long lifetimes, they remain in use for extended periods, resulting in delayed waste generation. In this context, stock and flow modelling is applied to forecast future waste arisings and support extended waste monitoring, particularly for flows not captured in official waste statistics.

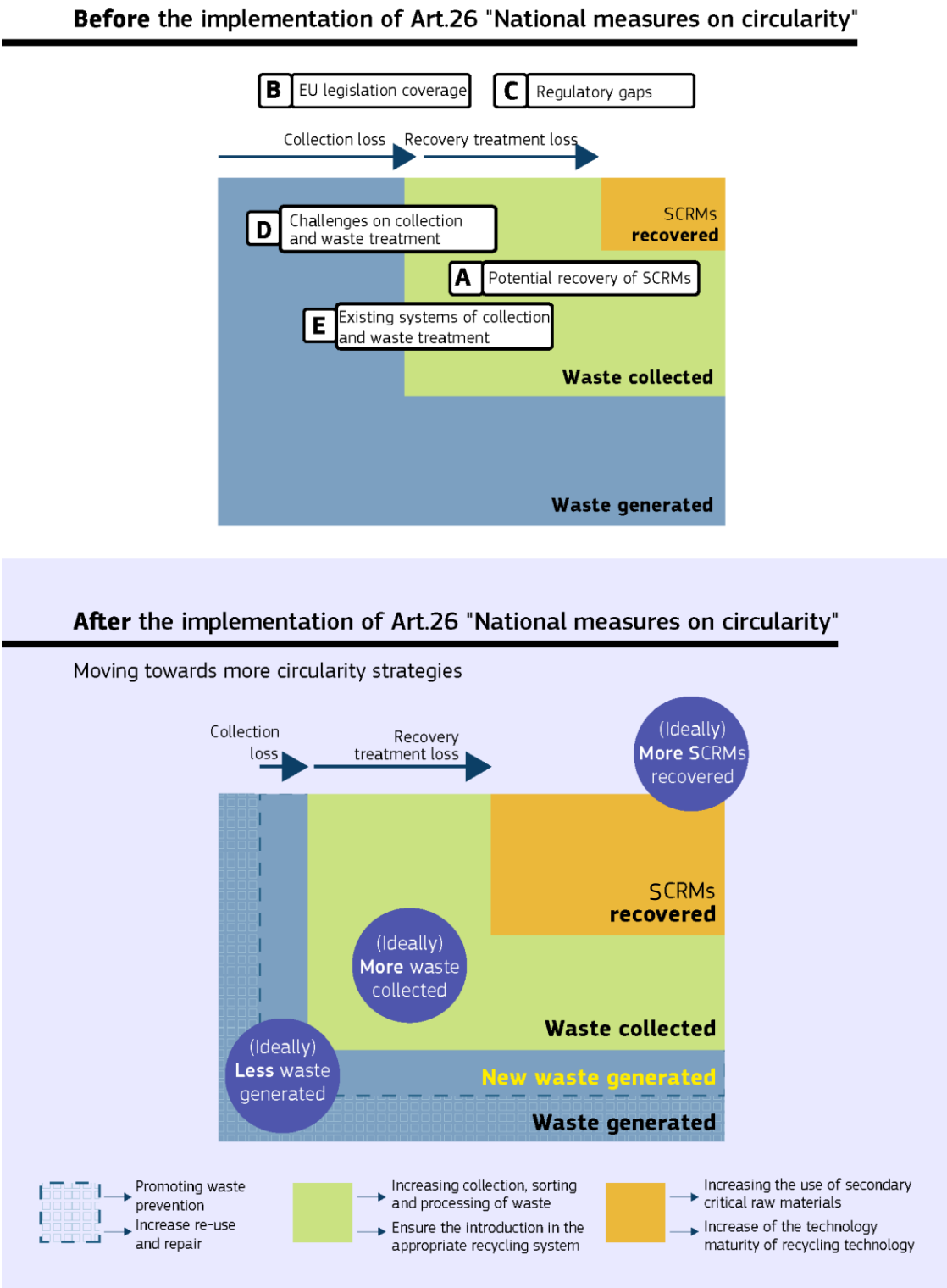
Secondly, waste streams related to flows not identifiable as PoM (**waste stream group 2**) – these waste streams involve waste where materials are aggregated and cannot be easily separated or identified as individual products or components. This means that the waste stream is generated from the disposal of materials that are mixed or aggregated, such as slag, sludges and ashes (SLASH), which stems from manufacturing of metals, and combustion processes such as coal, biomass, and waste incineration, and construction and demolition waste (CDW).

And finally, those waste streams for which only partial datasets, or no data are available (**waste stream group 3**).

As mentioned before, this study capitalises on input data on composition and stock and flow datasets provided by FutuRaM (see **Annex VI** for more information on the stock and flow model). FutuRaM chose waste streams and reported those under an appropriate list of waste (LoW) code, instead of investigating all wastes under particular LoW codes. Input data on composition and stock and flows provided by FutuRaM are based on observed data of the last decade and on estimations using business as usual (BAU) scenarios to extrapolate data for the coming years. The waste streams associated with flows identifiable as PoM – group 1 - (i.e., WEEE, BATT, ELV, and WT) have been mapped for PoM, waste generation, and waste collection, with a clear distinction between collection modes that comply with EU legislations (documented and reported) and others that do not. For these waste streams, there is an allocation of products/components to materials/elements. On the other hand, for waste streams related to flows not identifiable as PoM – group 2 - (i.e., CDW and SLASH), the materials cannot be allocated to products or components (further information in

section 2.1). Thus, the input data for CDW and SLASH require a slightly different elaboration and methodological approach due to their specific nature.

**Figure 1.** Graphical summary of the scope of the report, on how the waste stream prioritisation feeds into national circularity measures



Source: JRC elaboration.

Important data characteristics for this study are:

— Temporal scope:

- 2022 covering the recovery need of the current and in use products, including their design affecting the composition and the waste generation;
- 2030 covering the technology evolution of the near future, considering novel and changing market shares of products PoM. The lifespans and composition were adjusted in a business-as-usual scenario. The year 2030 serves as a reference point within the CRMA timeframe, making it relevant for anticipating potential critical and strategic raw materials (SCRMs when the reference is to both) needed for specific technology applications.

— Geographical scope:

- European Union 27 (EU-27) since the recovery potential of CRMs is for the purpose of EU MSs to adopt and implement circularity measures, within the meaning of paragraph 1 of Article 26.

— Raw materials classification (CRM, SRM, OTHER):

- Raw materials are classified based on whether they are included in the lists of SCRMs raw materials in Annexes I and II of the CRMA. All raw materials that are not classified as CRM or SRM fall into the category “OTHER”. This classification helps identify which raw materials within the waste stream datasets serve as a basis for the prioritisation process described in the methodology of this section. More details are available in the following sections.

## **2.1 Candidate waste streams (products, components, material, elements)**

A key aspect within FutuRaM datasets is the composition of the waste streams covered within the project. The covered waste streams are introduced in Section 2.1.1, and 2.1.2.

### **2.1.1 Waste streams associated with specific flows identifiable as products placed on the market – group 1**

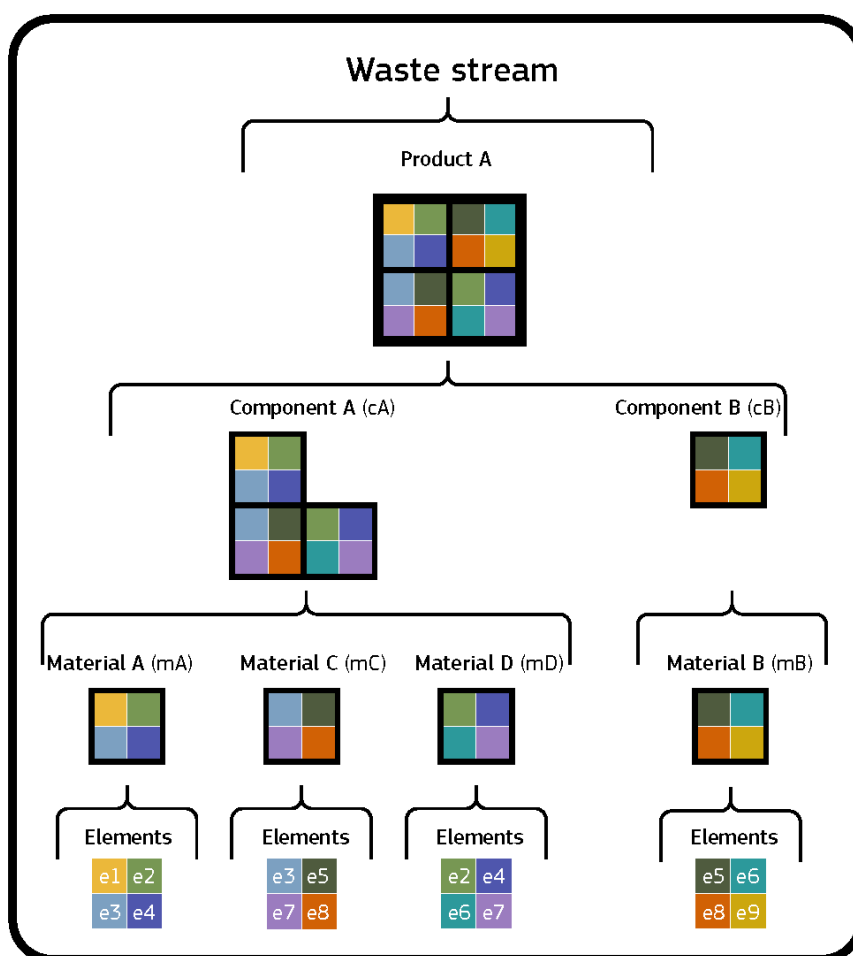
This group of waste streams is categorised by specific products or components that can be collected as they were PoM. This means that the waste stream is generated from their disposal. Examples of this group of waste streams include batteries (BATT), electric and electronic equipment (WEEE), wind turbines (WT), and motor vehicles (as ELV, end-of-life vehicles). These products are often complex in composition and multi-layered with components and sub-components, and, due to their intended relatively long lifetimes, they remain in use for extended periods, resulting in delayed waste generation. In this context, stock and flow modelling is applied to forecast future waste arisings and support extended waste monitoring, particularly for flows not captured in official waste statistics. In contrast to flows that are not identifiable as products PoM (see Section 2.1.2), waste streams associated with specific final products and goods manufactured using materials and semi-finished products have a layered structure, from waste stream to elements, allowing for a more detailed assessment of recoverability.

The FutuRaM approach establishes a hierarchical linkage among waste streams (ws), products (p), components (c), materials (m), and elements (e) for waste streams in group 1 as illustrated in

**Figure 2.** The primary objective is to develop generic composition datasets for selected waste streams, mapping their respective components, materials, and elements. Within the FutuRaM composition data model, each element of interest, such as Al, Cu, Si is linked to a specific material, for example an alloy, thereby providing not only information on SCRM content but also a comprehensive overview of the materials used. These are linked to a component, which is again assigned to a certain product. It is important to note that it is a mass-based hierarchical linkage, meaning that the sum of the weights of each element within a material equals to the weight of the selected material; the sum of the weights of all the materials within a component equals the weight of the component, and so on, until the sum of the weights of all the products within a waste stream.

This is illustrated by the example in **Figure 2**. Note that the number of elements, materials, and components can vary, and the representation is not limited to the number of boxes shown in the figure. A material may contain a single element or multiple elements, and a component may comprise one or several materials. The number of elements, materials or components may differ depending on the specific waste stream from group 1 being analysed. This expanded level of detail enables a more thorough assessment of recoverability.

**Figure 2.** Generic hierarchical structure of data composition for waste streams in group 1 (i.e. associated with specific products identifiable as products placed on the market).



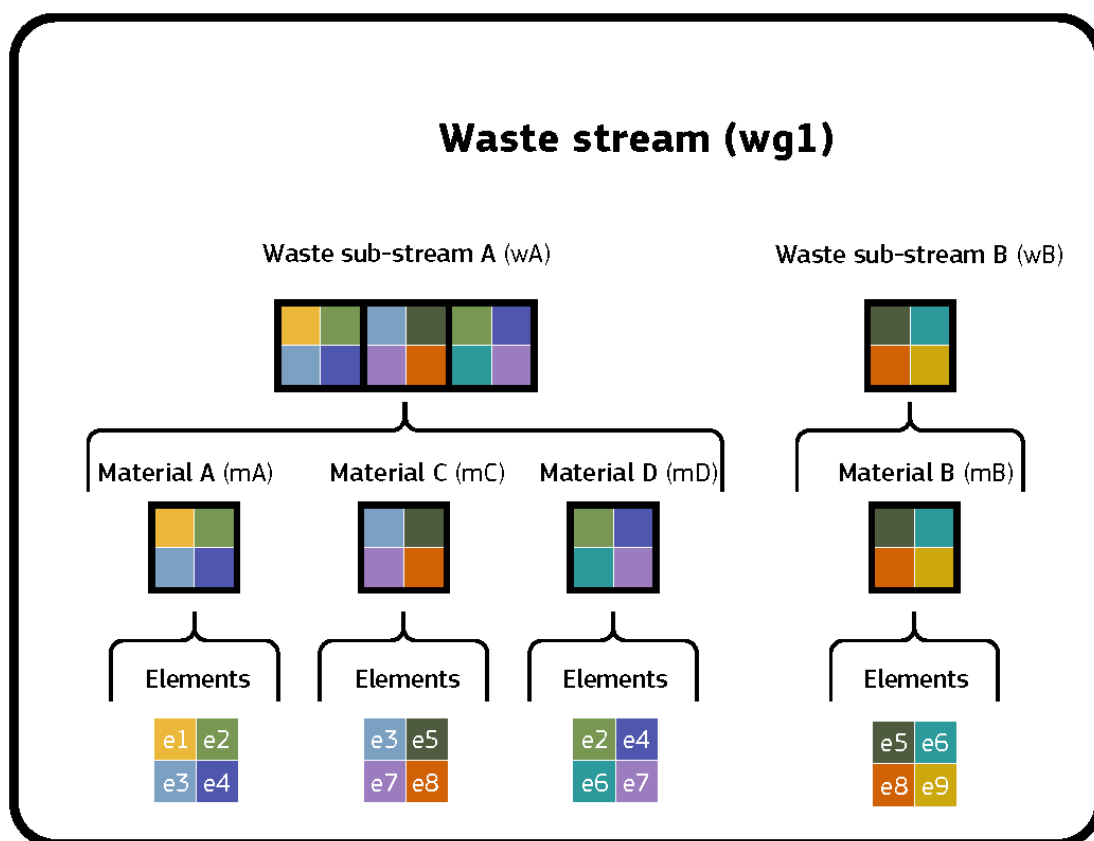
Source: JRC elaboration.

### 2.1.2 Waste streams related to specific flows not identifiable as products placed on the market - group 2

A waste stream related to specific flows not identifiable as products placed on the market can be defined as waste streams where materials are aggregated and cannot be easily separated or identified as individual products or components. This means that the waste stream is generated from the disposal of materials that are mixed or aggregated, such as SLASH and CDW, which stems from the manufacturing of metals, and combustion processes such as coal, biomass, and waste incineration. In waste streams of group 2, the whole periodic table can be represented, and their recoverability potential is mainly based on expert judgement.

The FutuRaM approach establishes a hierarchical linkage among waste streams (ws), materials (m), and elements (e) for waste streams in group 2, as illustrated in **Figure 3** (note that in this case, levels *p* and *c* do not appear as opposed to the hierarchical structure of data in group 1). Note that the number of elements and materials can vary, and the representation is not limited to the number of boxes shown in **Figure 3**. A material may contain a single element or multiple elements. The number of elements or materials may differ depending on the specific waste stream of group 2 being analysed. The primary objective is to develop generic composition datasets for selected waste streams, mapping their respective materials and elements. Within the FutuRaM composition data model, each element of interest is linked to a specific material, thereby providing not only information on SCRM content but also a comprehensive overview of the materials used. The material is assigned to a certain waste stream.

**Figure 3.** Generic hierarchical structure of data composition for waste streams in group 2 (i.e., related to flows not identifiable as product placed on the market).



Source: JRC elaboration.

### **2.1.3 Waste streams with partially available datasets or no data – group 3**

There are additional waste streams of end-of-life products that may be significant due to their content of SCRMs.

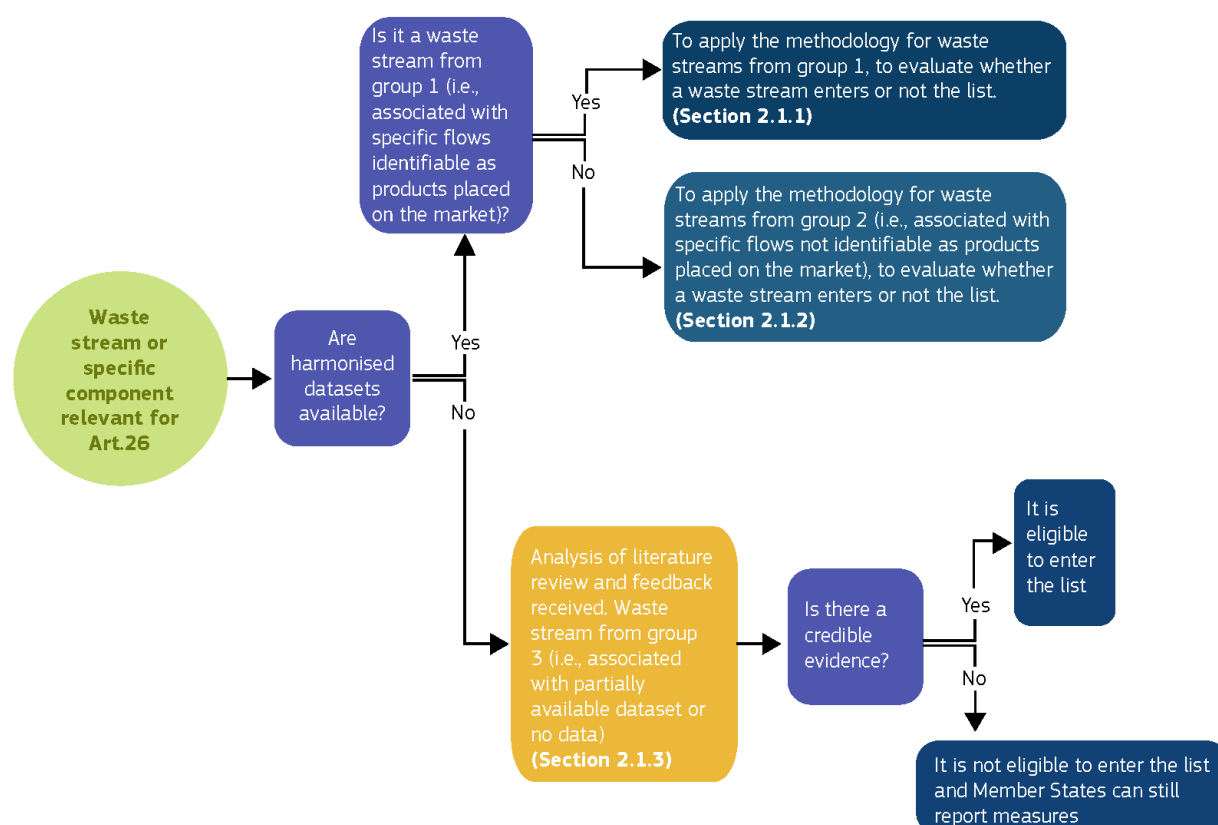
However, there is currently no available data or only partial data; thus, the methodology defined in this report cannot be fully applied. In some cases, by drawing analogies with other waste streams for which data are available, these streams in group 3 without data can be considered eligible for inclusion on the list. Considering the importance of these waste streams highlighted by stakeholders, it is crucial to take them into account to encourage future data collection and to better understand the feasibility of recovering SCRMs. Qualitative aspects based on the steps of the methodology are applied, as described, e.g. in section 3.1.3, as well as further qualitative remarks.

### 3 Methodology

This section outlines the methodology for prioritising products, components and waste streams that have relevant SCRM recovery potential. First, the methodology is introduced in a general overview (Section 3.1), followed by a detailed explanation of the application of this methodology based on the specific waste group targeted. Finally, in Section 3.2, the limitations of the methodology are explained.

The methodology is developed according to the availability of harmonised datasets processed to obtain a list of aspects to prioritise. **Figure 4** presents a decision tree that illustrates the examination of waste streams through three distinct workflows, each with specific characteristics. The workflows are selected based on whether the waste stream belongs to group 1, which includes identifiable flows classified as products placed on the market (PoM), or group 2, which consists of flows that are not identifiable as products PoM, as detailed in Sections 3.1.1 and 3.1.2, respectively. If harmonised datasets are not available, are only partially available, or if there is no data, a third workflow is chosen based on feedback from stakeholders and an analysis of eligibility for inclusion on the list.

**Figure 4.** Decision tree for the definition of the methodological workflow to apply based on the waste stream characteristics. For instance, if harmonised datasets are not available, the workflow to follow is the one associated with the waste stream from group 3, i.e., associated with partially available datasets or no data (Section 3.1.3)



Source: JRC elaboration.

### 3.1 General methodology overview

The methodology herein presented (see **Figure 5**) for the prioritisation of products, components and waste streams that have relevant SCRM recovery potential is considering datasets availability and the characteristics of the waste stream, that can be associated with flows identifiable as products PoM (group 1), or related to flows not identifiable as products PoM (group 2).

The methodology for prioritisation is a two-step methodology based on the five sub-paragraphs of Article 26 (7) of the CRM Regulation:

- **First step**: considers the total amount of recoverable critical raw materials (**sub-paragraph a**).
- **Second step**: considers the legal coverage and legislation gaps (**sub-paragraphs b and c**, respectively), as well as the challenges and existing systems for collection and treatment (**sub-paragraphs d and e**, respectively).

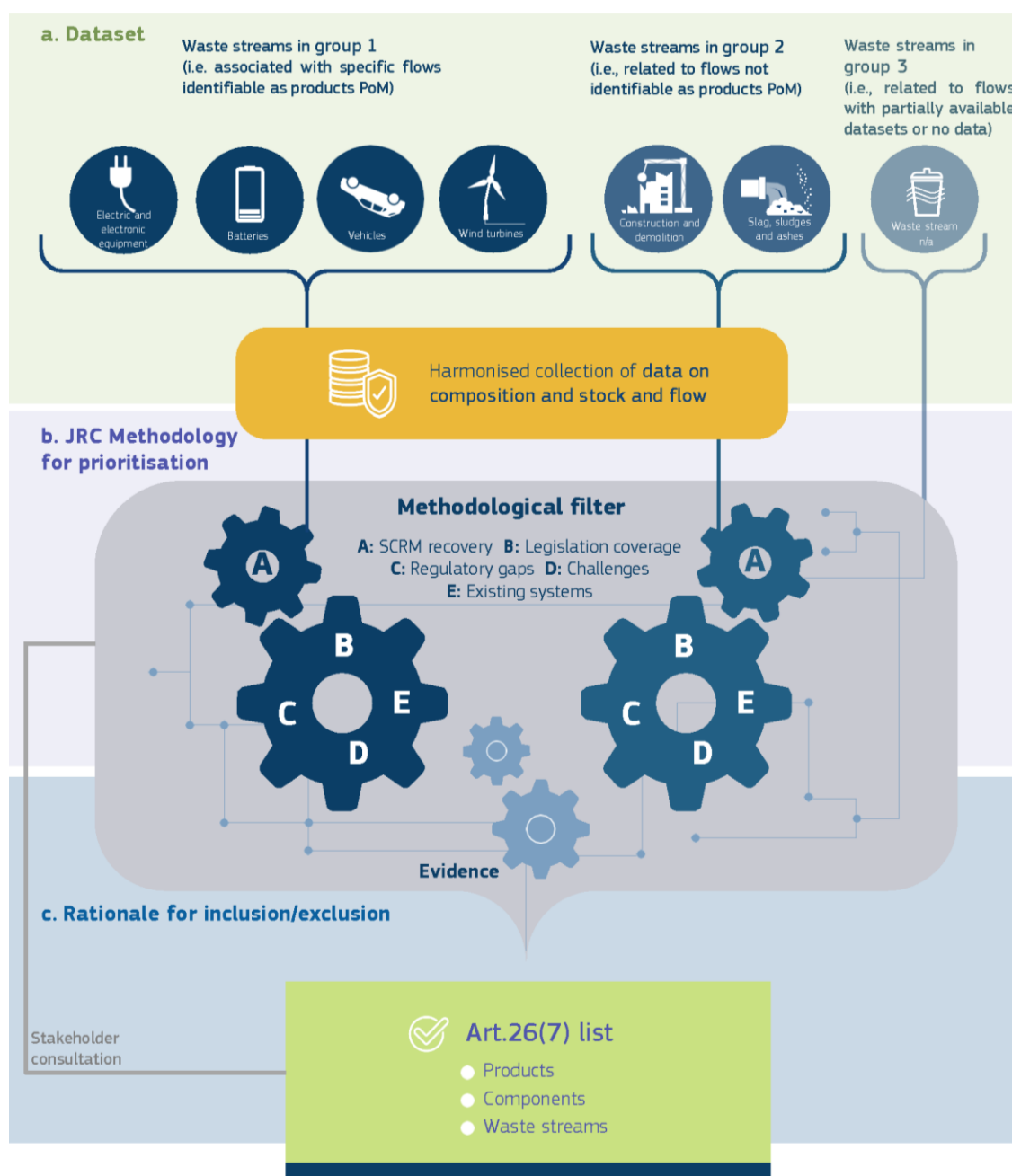
These five aspects, represented by the sub-paragraphs *a* to *e* of Article 26 (7), are also used to elaborate the evidence for the inclusion or exclusion of the products, components and waste streams into the list.

For partially available datasets or no data (group 3), the methodology is followed qualitatively, i.e., making the waste stream eligible for inclusion based on qualitative evidence. Evidence has been extracted from literature data and information but can also be inferred by analogy from waste streams, products, or components for which harmonised data are available.

To further refine the prioritisation results, a stakeholder consultation was conducted by DG-GROW on the initial list of prioritised components, products, and waste streams. The public consultation "[Critical raw materials – products, components and waste streams with a high potential to recover critical raw materials](#)" received 84 responses from stakeholders all over Europe. This consultation aimed to validate the results and gather additional insights from relevant stakeholders. The feedback received was carefully considered and integrated into the final list, particularly for waste streams in group 3, and to enhance the outcomes of already covered waste streams. As a result of the consultation process, new flows not previously detailed by FutuRaM were included, such as fuel cells for motor vehicles. Additionally, existing flows were specified in greater detail, distinguishing between inverters and converters instead of aggregating them under power electronics for motor vehicles. Additional clarifications were also added. This iterative approach ensured that the final list is as comprehensive and accurate as possible, potentially reflecting the collective expertise and knowledge of the stakeholders involved.

The following sections describe the application of the methodology for waste streams associated with each of these three groups.

**Figure 5.** Graphical summary of the general methodology.



Source: JRC elaboration.

### 3.1.1 Methodology applied for waste streams from group 1 – associated with specific products

As previously showed, the methodology follows two steps based on the sub-paragraphs of Article 26 (7).

The **first step** is the “prioritisation of components (and overarching products)” which has been established to respond to the requirements of **sub-paragraph a** of Article 26 (7) that regards to “the total amount of critical raw materials recoverable”. The prioritisation is performed for two

different temporal data frameworks (present<sup>7</sup> – 2022, and future – 2030) based on a composite indicator including three quantitative ranking criteria (RaC) accounting for:

- **Losses of SCRM not collected (RaC1).**
- The **mass fraction of SCRM in waste generated (RaC2).**
- The **strategic dimension (RaC3).**

The three criteria for prioritisation are detailed in **Annex I**. Furthermore, a rationale is given for the prioritised waste products and components, as well as the excluded ones. This rationale is addressed at the category and component levels, with specific observations for each:

- At the category level, the analysis involves examining RaC1 and RaC2 to extract information on the following:
  - **Losses of SCRM not collected** for a category compared to other categories within the waste stream under analysis;
  - The **mass of SCRM in waste generated** of each category within the waste stream under analysis;
  - The **trend of SCRM in waste generated** by category within the waste stream over the two temporal reference periods, i.e., 2030 compared to 2022, whether it increased or decreased, reflecting the technological evolution.
- At the component level, the analysis focuses on cross-components within the same product. Specifically, it utilises:
  - RaC1 data representing **the losses of SCRM not collected of each component** compared to the other components within each product of the waste stream under analysis;
  - RaC2 data estimating the **mass of SCRM in waste generated of each component** compared to the other components within each product of the waste stream under analysis;
  - RaC3 data highlighting the **main SCRMs** based on highest quantities in a component within each product of the waste stream under analysis.
- Regarding the rationale for the excluded products and components, the analysis considers an analysis on the quantity of SCRMs present in the excluded components of a product.

The **second step** is the “analysis of contextual factors, remarks and consolidation of the priority list” which has been established to respond to the requirements of sub-paragraphs b, c, d, and e of Article 26 (7).

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<sup>7</sup> present intended as the most recent available dataset.

The aim of the second step is to consolidate the priority list defined in the first step and provide a further analysis of several contextual factors that will help to formulate recommendations on the components and products in the priority list. This step includes:

- An assessment of the **legal coverage and the legislation gaps (sub-paragraphs b and c of Article 26 (7))**. This assessment is performed to emphasise the components and products that are less covered in the EU legislation and that might need further prioritisation. The legislation coverage assessment considers different lifecycle stages, usually from PoM to EoL, and it addresses the different levels, from products to elements, with a particular emphasis on SCRM. The current legislation may cover products and waste management operations, including collection, treatment, recycling, and re-use, and often exhibits limitations, such as: i) qualitative requirements that lack specificity, e.g., vague targets for improvement; ii) partial coverage, targeting only select products, components, materials, or elements; and iii) narrow focus on specific lifecycle stages, e.g., collection only. Furthermore, if a waste stream is already regulated, it must align with EU law to ensure consistency and effectiveness.
- A semi-quantitative and qualitative assessment of the **challenges and existing systems for collection and waste treatment (sub-paragraphs d and e of Article 26 (7))**.

It is important to highlight that interactions with the experts of FutuRaM project were necessary in some steps of the methodology to refine the results based on feasibility checks to spot and highlight possible products, components and waste streams that were overlooked by the prioritisation done initially, as well as to justify inclusions/exclusions from the list, or to guide on possible hotspots that should be considered, also based on the dataset knowledge.

### **3.1.2 Methodology applied for waste streams from group 2 – related to flows not identifiable as products placed on the market**

Waste streams from group 2 are constituted by two main waste streams, namely SLASH and CDW. Unlike the waste streams from group 1 which are categorised by product or component, for waste streams in group 2 it is not possible to collect products or components as they were PoM, but instead they appear as aggregated waste streams. For example, a building is not collected as a product once it gets demolished.

It should be noted that waste streams in group 2 consist of many waste streams that are unrelated and that the whole periodic table can be represented in some of these two waste streams (e.g., ashes from the incineration of waste for SLASH or demolished materials for CDW), and thus specific expert knowledge is required to assess their recoverability potential. Consequently, the waste streams to be considered in the Article 26 (7) list for SLASH and CDW, are comprised of specific waste stream-SCRM couples.

Thus, a different approach is considered to evaluate the eligibility of waste streams from group 2 to be prioritised in the Article 26 (7) compared to waste streams from group 1. The approach for prioritising waste streams related to flows not identifiable as products placed on the market, shares common aspects for SLASH and CDW, even though specific steps apply to each of them and those are more detailed in the respective sections of the report (4.5 and 4.6, respectively). Similarly to the methodology for group 1, a two-step procedure is applied for the prioritisation of waste streams, and the analysis of contextual factor, remarks and consolidation of the priority list. The approach aims to identify and prioritise waste streams containing SCRM, using quantitative and qualitative analyses to evaluate the recovery potential of these materials.

The **first step** relies on data and quantitative information, which can be summarised in the following workflow:

1. **Waste composition analysis:** to determine the presence of SCRCMs in the waste stream.
2. **Waste quantities and stock and flows analysis:** to assess the quantities of waste produced.
3. **Waste streams comparison:** to evaluate the relevance concerning SCRCMs recovery potential, including considerations on the Technology Readiness Level (TRL).

**The second step** is aligned with the approach for group 1 waste streams and represents an analysis of different contextual factors and remarks for the consolidation of the priority list accounting for the sub-paragraphs b, c, d, and e of the Article 26 (7). This step includes:

- An assessment of the **legal coverage and the legislation gaps (sub-paragraphs b and c of Article 26 (7))**. This assessment is performed to identify and emphasise the waste streams that are less covered in the EU legislation and that might need further prioritisation. The legislation coverage provides a map of the legislative obligations in the EU and is conducted at the waste stream, material, or element level, encompassing all end-of-life (EoL) stages, including collection, treatment, disposal, and circular strategies. This mapping distinguishes between quantitative obligations, such as numerical objectives with specific timelines, and qualitative obligations, like the development of standards. By doing so, the analysis highlights waste streams that, despite being on the priority list, are already well-covered by existing legislation. This approach enables the identification of gaps in the legislative framework, allowing for a targeted focus on waste streams that require additional attention and regulation.
- A semi-quantitative and qualitative assessment of the **challenges and existing systems for collection and waste treatment (sub-paragraphs d and e of Article 26 (7))**. This information is based on the available data for waste generated in 2022 and 2030, which are also analysed in the first step. For each stream, the recoverability of specific SCRCMs is evaluated. Finally, techno-economic aspects are considered to understand whether collection and recovery treatments are feasible or not.

The result of this approach is a priority list consisting of a list of waste streams, with each a sub-list of SCRCMs with a high recovery potential from that waste stream. Rationale of inclusion in the list of Article 26 is presented for each waste stream with information at SCRCMs level, by considering all the aspects investigated in the two steps of the approach mentioned above. All the other waste streams, excluded from the priority list, are reported with a rationale for the exclusion.

### **3.1.3 Methodology applied for waste streams from group 3 - in case of partially available datasets or no data**

In cases where relevant waste streams for Article 26 (7) do not have harmonised datasets available for the specific waste stream, product, or component, a specific analysis of existing information and literature was conducted. The decision tree in **Figure 4** helps guiding the analysis in case of data unavailability. The considerations in this case should follow the same requirements specified in the five sub-paragraphs of Article 26 (7). Evidence can be extracted from literature data and information, but can also be inferred by analogy from waste streams, products, or components for which harmonised data are available (see Section 4.7) and have provided evidence through the application of methodologies described in Sections 3.1.1 and 3.1.2. Further considerations should be

made regarding the fact that data may not be available at the time of assessment but could be produced in the coming years, given the significant amounts of waste that can be generated in the near future. Another aspect to consider is the TRL of the products/technology under scope. For example, if the TRL is low and it is not expected that the technology will achieve significant market uptake in the coming years, there are no conditions to include the waste stream in the list. At this point, evidence must be verified through expert feedback to determine their credibility and whether the waste stream can be deemed eligible for inclusion in the list or not. Note that even if a waste stream is not considered eligible by the methodology, MSs can still report national measures to recover SCRM from the specific waste streams.

### **3.2 Limitations of the methodology**

Stock and flow data, and particularly the collection flows, are recorded at waste stream level, hence, collection rates of embedded components had to be estimated. The collection of components is based on the mass allocation from waste stream level and does not reflect the real collection data for specific components. For example, if 30% of a waste stream is lost during waste collection, this 30% is applied for all components embedded within that waste stream. A potential future reporting requirement for MSs could regard information of collection rates at component level.

There may be a certain level of uncertainty concerning the quantities of SCRM in the composition and the stock and flow model within a material/alloy, or within a component due to the different sources of data. However, the outcomes of the total quantities of the stock and flow model have been validated with global extraction quantities, and EU demand, and the detailed SCRM data have undergone a public consultation by the FutuRaM project in March 2025. Hence, the SCRM quantities within the overall stock and flow model are expected to be the best available harmonized dataset available at the time this report was written.

For wind turbines, FutuRaM has associated the entire potential decommissioning quantities per year, country, sub-technology of the installed wind turbine fleet to waste generated. Please also note that, when decommissioned, wind turbines and their components and parts are not directly classified as waste, since could also be reused. However, at the time of the assessment, no specific data on the characterisation of the post-decommissioning flow was available.

At the time of assessment, no specific data on SCRM recovery treatment was available, and could not be further assessed in the analysis.

Economic potential is not systematically assessed and quantified due to high uncertainty, volatility and data unavailability.

## 4 Prioritised list of waste streams: results and evidence from the analysis

In this chapter, the results and detailed analysis for all the waste streams in the scope of this work are reported. For each waste stream, the following sub-sections are included:

- Scope and background data for the analysis where the datasets as well as the stock and flow model details are explained.
- List of products and components to be prioritised as **the main result of the analysis**.
- Rationale to include (or exclude) the components/materials within the priority list, including the application of the first step of the methodology, see section 3.1.
- Further remarks on the resulting list. It presents the results of the application of the second step of the methodology, i.e. “analysis of contextual factors, remarks and consolidation of the priority list”, sub-divided in three sub-chapters: i) “Legal coverage and legislation gaps (**sub-paragraphs b and c** of the Article 26 (7), respectively)”, ii) “Challenges and existing systems for collection and treatment (**sub-paragraphs d and e** of the Article 26 (7), respectively)”, and iii) further remarks on datasets availability. See section 3.1 for more details on the methodology.
- Key messages for each waste stream.

Please note that six heterogeneous waste streams have been considered for the analysis, namely:

- Batteries;
- Electrical and electronic equipment;
- Wind turbines;
- Motor vehicles;
- Slag, sludges, and ashes;
- Construction and demolition.

The first four are waste streams in group 1, while the last two are waste streams from group 2. These products and waste flow streams have different grades of complexity. As a result, the lists of components and/or materials for each waste stream have been derived considering the application of the methodology developed by the JRC and validated by experts of the different waste streams.

## 4.1 Results and detailed analysis for batteries for the Article 26 of the CRMA

The prioritised list for **batteries** waste stream **applied at the waste stream level**, indicating the **relevant components** to be prioritised for this waste stream, is following presented.

Batteries, with the following components, in particular:

- (a) Cathode active materials\*;
- (b) Anode active materials\*;
- (c) Cathode current collectors\*;
- (d) Anode current collectors\*;
- (e) Battery management systems;
- (f) Internal cables.

\* These components can also be found as main constituents in a mixed fraction after specific end-of-life-treatment, e.g. black mass.

Note that in case of mechanical treatment of waste batteries, prior to hydrometallurgical recovery, the cathode and anode active materials, as well as cathode and anode current collectors, are concentrated in an intermediate fraction named 'black mass' that is obtained from the mechanical shredding of waste batteries (from alkaline-saline to lithium-based ones). The JRC defined the black mass as an intermediate fraction and not as an output fraction (Orefice et al. 2024) and even suggested new waste codes for different lithium-based derived black mass fractions (Egle et al. 2024). The European Commission updated the list of waste in relation to battery-related waste with the Delegated Decision (EU) 2025/934 endorsing, *de facto*, the JRC approach of considering the black mass a waste intermediate fraction and shipping it accordingly. The black mass is the fraction where battery SCRM concentrate most, and it is relevant for both competitiveness and circularity of the EU battery industry. Nonetheless, at least 50% of the black mass obtained in the EU is exported for treatment outside the EU given to lack of domestic refining capacity. The SCRM materials (cobalt, lithium, nickel, manganese) contained in the exported black mass come back to Europe as refined materials in newly manufactured batteries.

It is important to note that the battery waste stream includes several categories based on different applications, and a variety of chemistries are present on the EU market. Additionally, not all listed components need to be prioritised for every category. The following sub-sections provide details on the resulting list, considering the categories of the battery waste stream.

### 4.1.1 Scope and background data

The batteries herein analysed encompass all categories of batteries as defined in the Regulation (EU) 2023/1542 (Batteries Regulation in the following), regardless of their shape, volume, weight, design, material composition, chemistry, use or purpose. The categories included are:

- **Starting, Lighting, and Ignition Battery (SLI Battery)** (Article 3 (12)): a battery that is specifically designed to supply electric power for starting, lighting, or ignition and that can also be used for auxiliary or backup purposes in vehicles, other means of transport or machinery.

- **Electric Vehicle Battery (EV Battery)** (Article 3 (14)): a battery specifically designed to deliver electric power for traction in hybrid or electric vehicles classified under category L, as stipulated in Regulation (EU) No 168/2013 (European Union 2013), with a weight exceeding 25 kg, or designed for traction in hybrid or electric vehicles of categories M, N, or O in accordance with Regulation (EU) 2018/858.
- **Portable Battery** (Article 3 (9)): a sealed battery weighing 5 kg or less, not intended for industrial use, and not classified as an electric vehicle battery, an LMT battery, or an SLI battery. It includes portable batteries of general use (Article 3 (10)).
- **Light Means of Transport Battery (LMT Battery)** (Article 3 (11)): a sealed battery weighing 25 kg or less, specifically designed to provide electric power for the traction of wheeled vehicles operable by an electric motor alone or in conjunction with human power, including type-approved vehicles of category L as defined in Regulation (EU) No 168/2013, and not categorised as an electric vehicle battery.
- **Industrial Battery** (Article 3 (13)): a battery designed for industrial applications, intended for such uses after undergoing preparation for repurposing, or any battery exceeding 5 kg in weight that is not classified as an electric vehicle battery, an LMT battery, or an SLI battery.

Note that batteries can be non-rechargeable batteries (Article 3 (6)) or rechargeable batteries (Article 3 (7)).

Note that batteries incorporated into or added to products or that are specifically designed to be incorporated into or added to products, according to Article 1(3) of the Batteries Regulation are also included in the analysis.

#### **4.1.1.1 Composition**

A comprehensive dataset has been generated after developing the battery key<sup>8</sup>, a classification system that categorises batteries based on their electrochemical systems. This battery key enables the allocation of batteries into distinct categories, allowing for a detailed analysis of battery data. The data is organised in a hierarchical structure, with the highest level of detail being the battery category, which is further subdivided by chemistry. For example, a battery category might be “Industrial batteries”, and a battery chemistry might be “Lithium-based (Li-based) batteries”. Furthermore, the dataset is broken down to the component level, including the main components of the battery cell, such as the anode and cathode. Some of these main components are then further subdivided into sub-components, providing an even more detailed understanding of the battery’s composition.

Components included in the waste batteries stream based on FutuRaM data are the following:

1. Cathode.
2. Anode.

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<sup>8</sup> Battery keys are used to consider all possible batteries made available in the market, considering both the application in which batteries are used and the chemistry, e.g. EV\_ LiNMC111 are EV batteries with LiNMC111 chemistry

3. Collector.
4. Additive.
5. Electrolyte.
6. Battery cell casing.
7. Battery cell separator.
8. Battery cell binder.
9. Battery management system.

Components 1 to 8 are common to EV, SLI, LMT, portable and industrial batteries. Data for component 9 were only available for EV and SLI batteries. However, it is also possible to find it in other battery categories, e.g., LMT. Definitions of battery cell, active material, and battery management system are according to Article 3 (4, 5, 25) of Regulation (EU) 2023/1542, respectively.

Note that data concerning the battery management system are provided in the waste stream Section 4.4.

The battery chemistries that have been included in the analysis, in line with the chemistries in the Batteries Regulation, are grouped in *lithium-based batteries*, and *other batteries* in this context include, among others, lead- and nickel-based batteries. Additionally, *zinc-based batteries*, and *sodium-based batteries* have been introduced for their SCRM content.

For all the above-mentioned chemistries, different sub-chemistries have been analysed:

#### 1. **Lithium-based batteries:**

- (a) Lithium-Nickel-Manganese-Cobalt-Oxides (LiNMC) (LiNMC111, LiNMC532, LiNMC622, LiNMC622Si, LiNMC811, LiNMC811Si, LiNMC955, LiNMC955Si);
- (b) Lithium-Nickel-Cobalt-Aluminium-Oxide (LiNCA) (LiNCA5, LiNCA15);
- (c) Lithium-Cobalt-Dioxide (LiCO);
- (d) Lithium-Manganese-Oxide (LiMO);
- (e) Lithium-Iron-Phosphate (LiFP);
- (f) Lithium-Manganese-Iron-Phosphate (LiMFP);
- (g) Lithium-Carbon-Monofluoride (LiCFx);
- (h) Lithium-Sulfur-Dioxide (LiSO<sub>2</sub>);
- (i) Lithium-Thionyl-Chloride (LiSOCl<sub>2</sub>).

#### 2. **Zinc-based batteries:**

- (a) Zinc-Silver-Oxide (ZnAgO<sub>2</sub>);
- (b) Zinc-Carbon (ZnC);
- (c) Zinc batteries containing mercury (ZnHgO);

- (d) Zinc-Manganese-Dioxide ( $\text{ZnMnO}_2$ );
- (e) Zinc-Air ( $\text{ZnO}_2$ ).

### 3. Sodium-based batteries:

- (a) Sodium and iron-based Prussian blue analogues (NaPBA);
- (b) Sodium nickel chloride ( $\text{NaNiCl}_2$ );
- (c) Sodium magnesium manganese oxide (NaMMO);
- (d) Sodium manganese vanadium phosphate (NaMVP);
- (e) Sodium nickel manganese cobalt (NaNMC);
- (f) Sodium nickel magnesium manganese titanium oxide (NaNMMT);
- (g) Sodium vanadium phosphate (NaVPF).

### 4. Other batteries:

- (a) Lead acid (Pb);
- (b) Nickel-Cadmium (NiCd);
- (c) Nickel-Metal-Hydride (NiMH).

#### 4.1.1.2 Stock and flow model

The stock and flow (see **Table A12** of **Annex VI** for more information) model developed by FutuRaM investigates the batteries PoM, the battery stock and the battery waste generated. For portable batteries, the waste generated is divided into formally collected, exported within WEEE, discarded in mixed municipal waste (MMW) and the undocumented batteries, also called “gap”. For both industrial and LMT batteries, the waste generated is solely divided into either formally collected or undocumented (gap), due to scarce data availability regarding exports and no discard of batteries in MMW is assumed. **Equation 1** illustrates the calculation of the gap flow for portable batteries.

**Equation 1.** Gap flow calculation for portable batteries.

$$\text{Gap} = \text{Waste Generated} - \text{Formally Collected} - \text{Exported for Reuse} - \text{Discarded in MMW}$$

For LMT, industrial and portable batteries, the battery stock and the waste generated are calculated using Weibull distribution according to the different battery types and in which applications they are incorporated. On the other hand, SLI and EV battery stream from the ELV model, developed and presented under Section 4.4.

The data on stocks and flows of batteries require four dimensions, namely temporal, geographic, product-related and electrochemical-related. The temporal scope of the model covers the time frame from 2010 until 2030, but historical assumptions are necessary back to 2000 to calculate the stocks in 2010. The geographical scope covers the European Union (EU) with 27 countries, plus Iceland, Norway, Switzerland and the United Kingdom (UK). Finally, the product-related and electrochemical-related refer to the electrochemical systems, which are reflected in the battery

keys. The stock and flow model for EV and SLI batteries reflects FutuRaM's model for motor vehicles as described in Section 4.4.1.

#### **4.1.2 List of products and components to be prioritised (details per battery category and chemistry)**

The components of batteries that shall be prioritised according to the results of the developed analysis are listed herein. **This list includes details per battery category and chemistry.**

Within the same battery, different components may have different levels of priority due to their SCRM content. For instance, in LiFP batteries, the anode takes higher priority over the cathode due to its graphite content. In contrast, in LiNMC batteries, the cathode has higher priority due to the presence of cobalt, lithium, and manganese, making it a key component for SCRM recovery.

The list of prioritised batteries components, organised by battery chemistry (first level of the bullet), category (second level of the bullet) and component (third level of the bullet), is presented below.

Note that sodium-based batteries will be relevant only for the year of reference 2030 since this is a novel technology expected to be introduced in the EU market nowadays, hence waste sodium-based batteries will become available only in the next decade.

##### ***Relevant components for lithium-based batteries:***

— for electric vehicles (EV), industrial, light means of transport (LMT) and portable rechargeable batteries:

- (a) Cathode active materials;
- (b) Anode active materials;
- (c) Cathode current collectors;
- (d) Anode current collectors;
- (e) Battery management systems (not for portable batteries);
- (f) Internal cables\*

— for portable non-rechargeable batteries:

- (a) Cathode active materials;
- (b) Anode active materials.

##### ***Relevant components for zinc-based batteries:***

— for portable non-rechargeable:

- (a) Cathode active materials;
- (b) Cathode additive.

**Relevant components for sodium-based batteries:**

— for electric vehicles (EV), and industrial batteries, being available from 2030:

- (a) Cathode active material;
- (b) Cathode current collector;
- (c) Anode current collector;
- (d) Battery management system;
- (e) Internal cables.\*

**Relevant components for other batteries chemistries:**

— for industrial rechargeable, portable rechargeable, electric vehicles (EV) batteries:

- (a) Cathode active materials;
- (b) Anode active materials (not for industrial);
- (c) Cathode additive (for industrial rechargeable);
- (d) Battery management system (not for portable);
- (e) Internal cables.\*

\*Cables that are integral part of the battery as made available on the market and necessary to its operation, excluding the cables required to connect the battery to the final equipment

The mapping of the main SCRM's based on the highest quantities within the prioritised components per battery waste chemistry and category is shown in **Table 1**.

**Table 1.** Map of the main SCRM's within the components (column), and waste flow as battery chemistry and category (row), based on the data available.

| <b>Waste flow (battery chemistry and category)</b> | <b>Cathode active materials</b>                                                                                                                | <b>Anode active materials</b>                                                          | <b>Cathode current collectors</b> | <b>Anode current collectors</b> | <b>Cathode additive</b> |
|----------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|-----------------------------------|---------------------------------|-------------------------|
| Li-based - LMT                                     | <b>All:</b> Co, Li, Mn, Ni (+ Al for LiNCA).<br><b>LiPF:</b> Li, P.<br><b>LiMO:</b> Li, Mn.<br><b>LiMFP:</b> Li, Mn, P.                        | <b>All:</b> Graphite.<br><b>662Si,</b><br><b>811Si,</b><br><b>955Si:</b> graphite, Si  | Al                                | Cu                              | -                       |
| Li-based - Industrial                              | <b>All:</b> Co, Li, Mn, Ni (+ Al for LiNCA).<br><b>LiCO:</b> Co, Li.<br><b>LiFP:</b> Li, P.<br><b>LiMO:</b> Li, Mn<br><b>LiMFP:</b> Li, Mn, P. | <b>All:</b> Graphite.<br><b>662Si,</b><br><b>811Si,</b><br><b>955Si:</b> graphite, Si. | Al                                | Cu                              | -                       |

| Waste flow (battery chemistry and category) | Cathode active materials                                                                                                                    | Anode active materials                                                                 | Cathode current collectors                                                                             | Anode current collectors                                                                               | Cathode additive                     |
|---------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|--------------------------------------|
| Li-based - Portable rechargeable            | <b>All:</b> Co, Li, Mn, Ni (+ Ni for LiNCA).<br><b>LiCO:</b> Co, Li.<br><b>LiPF:</b> Li, P.<br><b>LiMO:</b> Li, Mn                          | <b>All:</b> Graphite.<br><b>662Si,</b><br><b>811Si,</b><br><b>955Si:</b> Graphite, Si. | Al                                                                                                     | Cu                                                                                                     | -                                    |
| Li-based - Portable primary                 | <b>LiMnO2:</b> Mn                                                                                                                           | Li.                                                                                    | -                                                                                                      | -                                                                                                      | -                                    |
| Li-based - EV                               | <b>All:</b> Co, Li, Mn, Ni (+ Ni for LiNCA).<br><b>LiPF:</b> Li, P.<br><b>LiMO:</b> Li, Mn.<br><b>LiMFP:</b> Li, Mn, P.                     | <b>All:</b> Graphite.<br><b>662Si,</b><br><b>811Si,</b><br><b>955Si:</b> Graphite, Si. | Al                                                                                                     | Cu                                                                                                     | -                                    |
| Ni-based - Industrial                       | <b>NiCd, NiNaCl2:</b> Ni                                                                                                                    | -                                                                                      | -                                                                                                      | -                                                                                                      | <b>NiCd, Ni-NaCl2:</b> Graphite, Co. |
| Ni-based - Portable                         | <b>NiCd, NiMH:</b> Ni                                                                                                                       | <b>NiMH:</b> Ni, Co, La, Ce, Nd, Mn, Ti, Pr, Al, Sm.                                   | -                                                                                                      | -                                                                                                      | <b>NiCd, NiMH:</b> Graphite, Co.     |
| Ni-based - EV                               | <b>NiMH:</b> Ni                                                                                                                             | <b>NiMH:</b> Ni, Co, La, Ce, Nd, Mn, Ti, Pr, Al, Sm.                                   | -                                                                                                      | -                                                                                                      | -                                    |
| Na-based - Industrial                       | <b>NaPBA:</b> Graphite.<br><b>NaNiCl2:</b> Ni.<br>NaMVP, <b>NaVPF:</b> V, P.<br><b>NaNMC:</b> Ni, Co, Mn.<br><b>NaNMMT:</b> Mn, Ni, Ti, Mg. | -                                                                                      | Al                                                                                                     | -                                                                                                      | -                                    |
| Na-based - EV                               | <b>NaPBA:</b> graphite.<br><b>NaNMMT:</b> Mn, Ni, Ti, Mg.<br><b>NaNMC:</b> Co, Mn, Ni.<br><b>NaVPF, NaMVP:</b> P, V.                        | -                                                                                      | <b>NaMMO,</b><br><b>NaMVP,</b><br><b>NaNMC,</b><br><b>NaNMMT,</b><br><b>NaPBA,</b><br><b>NaVPF:</b> Al | <b>NaMMO,</b><br><b>NaMVP,</b><br><b>NaNMC,</b><br><b>NaNMMT,</b><br><b>NaPBA,</b><br><b>NaVPF:</b> Cu | -                                    |
| Zn-based - Portable                         | Mn                                                                                                                                          | -                                                                                      | Graphite                                                                                               | -                                                                                                      | Mn, Ni                               |

Source: JRC elaboration, based on FutuRaM internal dataset. Note that hyphen (-) denotes that this component is not prioritised for that waste flow.

#### 4.1.3 Rationale of the list of products and components included and not included in the priority list – step 1 of the methodology for waste streams from group 1

The rationale for including or excluding specific waste streams accounts for the first step in the methodology applied for waste streams from group 1, which are defined as flows identifiable as

products placed on the market. The list is further consolidated in Section 4.1.4 and its associated subsections.

The **analysis per battery category, chemistry, and reference year**, as presented in **Table 2**, considered: i) the waste generated; ii) the amount of total SCRMs within waste generated, as well as the mass fraction of total SCRMs in waste generated (this refers to criterion 2, i.e., RaC2); and iii) amount of losses in terms of total SCRMs (this refers to criterion 1, i.e., RaC1).

The prioritised list confirmed that the collection of battery waste significantly impacted battery waste flows, particularly those with a higher content of SCRMs. Specifically, the findings indicated that:

- **Industrial batteries:** The collection of waste from industrial batteries was largely effective, resulting in relatively low losses of SCRMs compared to other battery categories.
- **EV and SLI batteries:** Despite being required to be collected under the Regulation and previous Directive, significant losses of SCRMs were observed in EV and SLI batteries due to undocumented disposal at the end of their life cycle (e.g., unknown whereabouts) (Baron et al. 2023). This issue also affects emerging battery technologies, such as sodium-based batteries, highlighting the need for e.g., improved collection and tracking systems. EV batteries were found to contain a high concentration of SCRMs in the waste generated, which was consistent with the observed losses in both 2022 and 2030. This suggests that EV batteries are a significant source of SCRMs losses and require targeted collection and recycling efforts.
- **LMT batteries:** LMT batteries exhibited a relatively high mass fraction of SCRMs loss in the waste generated. Although losses were notably high in 2022, the implementation of the Battery Regulation measures is expected to decrease these losses by 2030 compared to a business-as-usual scenario. However, sodium-based LMT batteries may still incur significant losses if collection targets are not met, emphasising the importance of effective collection systems for these batteries.
- **Portable rechargeable zinc-based batteries:** In contrast, portable rechargeable zinc-based batteries had relatively lower SCRMs losses in the waste generated, with an estimated increase in collection by 2030. This suggests that collection systems for these batteries are improving.
- Most of **other batteries** category are projected to have decreased SCRMs losses.

The waste generation patterns for different battery chemistries are summarised in **Table 3**, which provides a comparison of the minimum and maximum waste generated for the two reference years.

- **Established battery technologies:** older battery technologies, such as PbA, LiNMC111, and ZnMnO<sub>2</sub>, are significant contributors to waste generation. In contrast, emerging trends indicate that by 2030, LiFP and LiCO technologies is expected to experience substantial growth in waste quantities, with LiFP increasing by 8.3 times and LiCO by 2.1 times compared to 2022 levels, based on the BAU scenario.
- **Declining technologies:** NiCd batteries are projected to decrease gradually in waste generation between 2022 and 2030, according to the BAU scenario. This decline is likely due to the phase-out of NiCd batteries.

- **Predominant chemistries:** For both industrial and LMT batteries, lithium-based chemistries are the dominant technologies throughout the reference period. Specifically, LiFP is the most prevalent chemistry in industrial batteries, while LiNMC622 is the most common in LMT batteries.
- **Emerging technologies:** The adoption of emerging technologies, such as batteries containing silicon, is evident in the relatively low volumes of waste generated in both 2022 and 2030. This is largely driven by the ongoing transition towards lower cobalt-content batteries, such as the shift from LiNMC622 to LiNMC955. Additionally, sodium-based chemistries are expected to gain traction over time, with small quantities of waste anticipated to arise from EV, industrial, and portable rechargeable batteries by 2030. Notably, the minimum and maximum waste generation figures for these emerging technologies are relatively similar.

**Table 2.** Rationale of the list of batteries, by battery category (or application) and chemistry included in the priority list.

| Year | Battery chemistry and category   | Waste generated [t/y] | SCRMs in waste generated [t/y] | SCRMs losses [t/y] | Mass fraction of SCRMs in waste generated [%] |
|------|----------------------------------|-----------------------|--------------------------------|--------------------|-----------------------------------------------|
| 2022 | Li-based EV                      | 83,464                | 45,893                         | 23,752             | 55                                            |
|      | Li-based Industrial rechargeable | 10,202                | 5,209                          | 260                | 51                                            |
|      | Li-based LMT                     | 10,247                | 6,256                          | 5,650              | 61                                            |
|      | Li-based Portable primary        | 4,159                 | 331                            | 118                | 8.0                                           |
|      | Li-based Portable rechargeable   | 40,370                | 23,519                         | 9,657              | 58                                            |
|      | Other EV                         | 4,735                 | 1,794                          | 835                | 38                                            |
|      | Other Industrial                 | 664,235               | 9,740                          | 487                | 1.5                                           |
|      | Other Portable rechargeable      | 18,682                | 4,202                          | 1,519              | 22                                            |
|      | Other SLI                        | 356,212               | 7,637                          | 2,979              | 2.1                                           |
|      | Zn-based Portable rechargeable   | 124,329               | 31,775                         | 11,335             | 26                                            |
| 2030 | Li-based EV                      | 114,089               | 61,519                         | 30,942             | 54                                            |
|      | Li-based Industrial rechargeable | 62,776                | 30,486                         | 1,524              | 49                                            |
|      | Li-based LMT                     | 26,150                | 15,373                         | 10,085             | 59                                            |
|      | Li-based Portable primary        | 6,839                 | 545                            | 165                | 8.0                                           |
|      | Li-based Portable rechargeable   | 77,801                | 45,153                         | 14,888             | 58                                            |
|      | Na-based EV                      | 65                    | 32                             | 18                 | 50                                            |
|      | Na-based Industrial rechargeable | 32                    | 8.1                            | 0.41               | 26                                            |
|      | Na-based LMT                     | 2.3                   | 0.5                            | 0.33               | 21                                            |
|      | Other EV                         | 4,207                 | 1,594                          | 637                | 38                                            |
|      | Other Industrial                 | 569,681               | 8,368                          | 418                | 1.5                                           |
|      | Other Portable rechargeable      | 14,328                | 3,144                          | 954                | 22                                            |
|      | Other SLI                        | 409,981               | 8,790                          | 3,252              | 2.1                                           |
|      | Zn-based Portable rechargeable   | 162,015               | 41,491                         | 12,489             | 26                                            |

Source: JRC elaboration, based on FutuRaM datasets

**Table 3.** Rationale of the list of batteries, details per sub-chemistry considering the minimum and maximum waste generated for the two years of reference.

| Year | Battery chemistry and category   | Sub-chemistry waste battery min | Waste generated min [t/y] | Sub-chemistry waste battery max | Waste generated max [t/y] |
|------|----------------------------------|---------------------------------|---------------------------|---------------------------------|---------------------------|
| 2022 | Li-based EV                      | LiNMC622_Si10                   | 412                       | LiNMC111                        | 42,685                    |
|      | Li-based Industrial rechargeable | LiNMC811_Si10                   | 5.3                       | LiFP                            | 5,301                     |
|      | Li-based LMT                     | LiNMC811_Si10                   | 112                       | LiNMC622                        | 2,920                     |
|      | Li-based Portable primary        | LiCFx                           | 1,040                     | LiCFx                           | 1,040                     |
|      | Li-based Portable rechargeable   | LiNMC811_Si10                   | 34                        | LiCO                            | 23,818                    |
|      | Other EV                         | NiMH                            | 4,735                     | NiMH                            | 4,735                     |
|      | Other Industrial                 | NiCd                            | 6,835                     | PbA                             | 657,400                   |
|      | Other Portable rechargeable      | NiCd                            | 4,662                     | NiMH                            | 8,883                     |
|      | Other SLI                        | PbA                             | 356,212                   | PbA                             | 356,212                   |
|      | Zn-based Portable rechargeable   | ZnHgO                           | 20                        | ZnMnO2                          | 109,741                   |
| 2030 | Li-based EV                      | LiNMC955_Si10                   | 95                        | LiNMC111                        | 25,628                    |
|      | Li-based Industrial rechargeable | LiNMC955_Si10                   | 0.7                       | LiFP                            | 43,959                    |
|      | Li-based LMT                     | LiNMC955_Si10                   | 10                        | LiNMC622                        | 6,725                     |
|      | Li-based Portable primary        | LiCFx                           | 1,710                     | LiCFx                           | 1,710                     |
|      | Li-based Portable rechargeable   | LiNMC955_Si10                   | 3.8                       | LiCO                            | 50,929                    |
|      | Na-based EV                      | NaVPF                           | 10                        | NaNMC                           | 12                        |
|      | Na-based Industrial rechargeable | NaNiCl2                         | 16                        | NaNiCl2                         | 16                        |
|      | Na-based LMT                     | NaPbA                           | 2.3                       | NaPbA                           | 2.3                       |
|      | Other EV                         | NiMH                            | 4,207                     | NiMH                            | 4,207                     |
|      | Other Industrial                 | NiCd                            | 5,959                     | PbA                             | 563,722                   |
|      | Other Portable rechargeable      | NiCd                            | 1,073                     | NiMH                            | 7,630                     |
|      | Other SLI                        | PbA                             | 409,981                   | PbA                             | 409,981                   |
|      | Zn-based Portable rechargeable   | ZnHgO                           | 0.1                       | ZnMnO2                          | 140,947                   |

Source: JRC elaboration, based on FutuRaM internal dataset. Note: SCRMs not collected (i.e., losses) refer to criterion 1, while mass fraction of SCRMs in waste generated refers to criterion 2 of the methodology applied for waste streams from group 1.

**Table 4** provides a detailed breakdown of the targeted battery sub-chemistries at the component level, including the minimum and maximum mass fraction of total SCRMs in waste generated and the corresponding minimum and maximum total SCRMs losses for the two reference years, 2022 and 2030.

It is noteworthy that, although the mass fraction of SCRMs in waste generated may remain almost the same for both 2022 and 2030, the corresponding SCRMs losses can differ. For example, while the anode active material of lithium-based EV batteries maintains a mass fraction of SCRMs in waste generated at around 11% for both 2022 and 2030 in the minimum value, the SCRMs losses in 2030 are nearly six times higher (142 tonnes compared to 25 tonnes). This indicates an increase in quantities of batteries placed on the market, hence an increase in volumes of waste generated, and a constant SCRMs content in waste generated.

Among lithium-based industrial rechargeable batteries, it is observed that the anode active material of LiNMC811 possesses the highest mass fraction of SCRMs in waste generated, whereas the anode active material of LiFP has the lowest. However, the volumes of SCRMs losses are lower for the anode active material of LiNMC811 than for the anode active material of LiFP, primarily due to the lower quantities of LiNMC811 waste generated.

**Table 4.** Rationale of the list of battery components, by battery category (or application) and chemistry included in the priority list.

| Year | Battery chemistry and category     | Waste component                     | Targeted battery sub-chemistry min | Targeted battery sub-chemistry max | Mass fraction of SCRMs in waste generated [%] |       | Corresponded SCRMs losses [t/y] |          |
|------|------------------------------------|-------------------------------------|------------------------------------|------------------------------------|-----------------------------------------------|-------|---------------------------------|----------|
|      |                                    |                                     |                                    |                                    | min                                           | max   | min                             | max      |
| 2022 | Li-based – EV batteries            | Anode active material               | LiNMC622_Si10                      | LiNMC811                           | 11.49                                         | 17.30 | 25.12                           | 341.81   |
|      |                                    | Internal cables                     | LiFP                               | LiNMC811_Si10                      | 2.28                                          | 2.98  | 11.32                           | 6.73     |
|      |                                    | Cathode active material             | LiFP                               | LiMO                               | 7.19                                          | 21.21 | 35.66                           | 2,125.05 |
|      |                                    | Current collector anode             | LiNMC111                           | LiNMC811_Si10                      | 4.54                                          | 7.01  | 977.73                          | 15.82    |
|      |                                    | Current collector cathode           | LiNCA                              | LiNMC811_Si10                      | 1.99                                          | 3.02  | 65.61                           | 6.82     |
|      | Li-based – Industrial rechargeable | Anode active material               | LiFP                               | LiNMC811                           | 19.32                                         | 24.12 | 51.21                           | 1.09     |
|      |                                    | Cathode active material             | LiFP                               | LiNMC111                           | 8.76                                          | 27.74 | 23.21                           | 5.35     |
|      |                                    | Current collector anode             | LiNMC532                           | LiMO                               | 5.79                                          | 9.82  | 0.83                            | 12.52    |
|      |                                    | Current collector cathode           | LiNMC622                           | LiCO                               | 3.71                                          | 6.35  | 0.71                            | 3.79     |
|      | Li-based – LMT                     | Anode active material               | LiFP                               | LiNCA                              | 19.32                                         | 24.93 | 52.00                           | 454.36   |
|      |                                    | Cathode active material             | LiFP                               | LiNMC111                           | 8.76                                          | 27.74 | 23.57                           | 294.89   |
|      |                                    | Current collector anode             | LiNMC532                           | LiMO                               | 5.79                                          | 9.82  | 81.24                           | 61.12    |
|      |                                    | Current collector cathode           | LiNMC622                           | LiMO                               | 3.71                                          | 5.63  | 97.86                           | 35.04    |
|      | Li-based – Portable primary        | Anode active material               | LiCFx                              | LiSOCl2                            | 2.31                                          | 4.69  | 8.58                            | 17.42    |
|      |                                    | Cathode active material             | LiMnO2                             | LiMnO2                             | 17.40                                         | 17.40 | 64.64                           | 64.64    |
|      | Li-based - Portable rechargeable   | Anode active material               | LiFP                               | LiNMC811                           | 19.32                                         | 24.12 | 157.63                          | 51.27    |
|      |                                    | Cathode active material             | LiFP                               | LiNMC111                           | 8.76                                          | 27.74 | 71.44                           | 777.00   |
|      |                                    | Current collector anode             | LiNMC532                           | LiMO                               | 5.79                                          | 9.82  | 67.78                           | 65.97    |
|      |                                    | Current collector cathode           | LiNMC622                           | LiCO                               | 3.71                                          | 6.35  | 41.03                           | 618.33   |
|      | Other - EV batteries               | Anode active material               | NiMH                               | NiMH                               | 16.04                                         | 16.04 | 353.36                          | 353.36   |
|      |                                    | Cathode active material             | NiMH                               | NiMH                               | 21.74                                         | 21.74 | 478.95                          | 478.95   |
|      | Other - Industrial                 | Cathode active material             | NiCd                               | NiCd                               | 15.41                                         | 15.41 | 52.68                           | 52.68    |
|      |                                    | Current collector anode and cathode | NiCd                               | NiCd                               | 1.31                                          | 1.31  | 430.84                          | 430.84   |

|      |                                    |                                     |               |               |       |       |          |          |
|------|------------------------------------|-------------------------------------|---------------|---------------|-------|-------|----------|----------|
|      | Other – Portable                   | Anode active material               | NiMH          | NiMH          | 16.05 | 16.05 | 512.72   | 512.72   |
|      |                                    | Cathode active material             | NiCd          | NiMH          | 15.41 | 21.76 | 266.22   | 695.17   |
|      |                                    | Current collector anode and cathode | NiCd          | NiCd          | 1.31  | 1.31  | 23.79    | 23.79    |
|      | Other – SLI                        | Current collector anode and cathode | Pb            | Pb            | 2.14  | 2.14  | 2,978.56 | 2,978.56 |
|      | Zn-based – Portable                | Cathode active material             | ZnC           | ZnMnO2        | 17.72 | 22.63 | 851.15   | 8,854.10 |
|      |                                    | Current collector cathode           | ZnAgO2        | ZnC           | 0.43  | 6.24  | 0.57     | 299.75   |
|      | Li-based – EV batteries            | Anode active material               | LiNMC622_Si10 | LiNMC955      | 10.97 | 17.14 | 141.94   | 8.51     |
|      |                                    | Internal cables                     | LiMO          | LiNMC955_Si10 | 2.40  | 3.39  | 152.07   | 1.67     |
|      |                                    | Cathode active material             | LiFP          | LiMO          | 6.99  | 21.09 | 278.56   | 1,338.65 |
|      |                                    | Current collector anode             | LiNMC111      | LiNMC955_Si10 | 4.62  | 7.31  | 561.99   | 3.60     |
|      |                                    | Current collector cathode           | LiNMC622      | LiNMC955_Si10 | 2.02  | 3.11  | 216.13   | 1.53     |
| 2030 | Li-based – Industrial rechargeable | Anode active material               | LiMFP         | LiNMC955      | 15.49 | 28.00 | 0.11     | 0.01     |
|      |                                    | Cathode active material             | NaPBA         | LiNMC111      | 7.88  | 27.74 | 0.06     | 9.37     |
|      |                                    | Current collector anode             | NaPBA         | LiMO          | 4.18  | 9.82  | 0.03     | 51.41    |
|      |                                    | Current collector cathode           | LiNMC955      | LiMFP         | 2.30  | 6.50  | 0.00     | 0.05     |
|      | Li-based – LMT                     | Anode active material               | LiMFP         | LiNMC955      | 15.49 | 28.00 | 164.79   | 2.11     |
|      |                                    | Cathode active material             | NaPBA         | LiNMC111      | 7.88  | 27.74 | 0.12     | 232.71   |
|      |                                    | Current collector anode             | NaPBA         | LiMO          | 4.18  | 9.82  | 0.06     | 16.87    |
|      |                                    | Current collector cathode           | LiNMC955      | LiMFP         | 2.30  | 6.50  | 0.17     | 69.15    |
|      | Li-based – Portable primary        | Anode active material               | LiCFx         | LiSOCl2       | 2.31  | 4.69  | 11.93    | 24.21    |
|      |                                    | Cathode active material             | LiMnO2        | LiMnO2        | 17.40 | 17.40 | 89.84    | 89.84    |
|      | Li-based Portable_rechargeable     | Anode active material               | LiFP          | LiNMC955      | 19.32 | 28.00 | 266.08   | 0.43     |
|      |                                    | Cathode active material             | LiFP          | LiNMC111      | 8.76  | 27.74 | 120.60   | 153.71   |
|      |                                    | Current collector anode             | LiNMC955_Si10 | LiMO          | 5.43  | 9.82  | 0.07     | 33.49    |
|      |                                    | Current collector cathode           | LiNMC955      | LiCO          | 2.30  | 6.35  | 0.03     | 1,058.65 |
|      | Na-based EV_batteries              | Anode active material               | NaMVP         | NaMMO         | 19.17 | 26.92 | 1.15     | 1.64     |
|      |                                    | Internal cables                     | NaNMC         | NaVPF         | 2.07  | 2.36  | 0.13     | 0.13     |
|      |                                    | Cathode active material             | NaPBA         | NaNMC         | 7.38  | 17.22 | 0.41     | 1.08     |

|                    |                                     |        |        |       |       |          |          |
|--------------------|-------------------------------------|--------|--------|-------|-------|----------|----------|
|                    | Current collector anode             | NaNMC  | NaVPF  | 1.24  | 1.42  | 0.08     | 0.08     |
|                    | Current collector cathode           | NaNMC  | NaVPF  | 1.78  | 2.03  | 0.11     | 0.11     |
| Other EV_batteries | Anode active material               | NiMH   | NiMH   | 16.04 | 16.04 | 269.72   | 269.72   |
|                    | Cathode active material             | NiMH   | NiMH   | 21.74 | 21.74 | 365.58   | 365.58   |
| Other Industrial   | Cathode active material             | NiCd   | NiCd   | 15.41 | 15.41 | 45.93    | 45.93    |
|                    | Current collector anode and cathode | NiCd   | NiCd   | 1.31  | 1.31  | 369.45   | 369.45   |
| Other Portable     | Anode active material               | NiMH   | NiMH   | 16.05 | 16.05 | 372.60   | 372.60   |
|                    | Cathode active material             | NiCd   | NiMH   | 15.41 | 21.76 | 48.96    | 505.18   |
|                    | Current collector anode and cathode | NiCd   | NiCd   | 1.31  | 1.31  | 21.96    | 21.96    |
| Other SLI          | Current collector anode and cathode | Pb     | Pb     | 2.14  | 2.14  | 3,252.36 | 3,252.36 |
| Zn-based Portable  | Cathode active material             | ZnAgO2 | ZnMnO2 | 17.72 | 22.63 | 1,069.61 | 9,603.68 |
|                    | Current collector cathode           | ZnAgO2 | ZnC    | 0.43  | 6.24  | 0.60     | 376.69   |

Source: JRC elaboration, based on FutuRaM internal dataset. Note that mass fraction of SCRMs in waste generated refers to criterion 2 of the methodology, including the min and max value and targeted sub-chemistry; while SCRMs losses refer to criterion 1 of the methodology (these losses correspond to the targeted sub-chemistries resulted from the min and max mass fraction).

The rationale for excluding specific waste components is detailed in **Table 5**.

**Table 5.** Rationale of the list of batteries by components not included in the priority list.

| Application | Excluded components                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|-------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| LMT         | <p><b>Lithium-based batteries:</b></p> <ul style="list-style-type: none"> <li>• <i>Cathode additive:</i> the mass of critical raw materials as a share of the mass of waste generated of this chemistry type ranges from about 0.8% to about 1.3% compared to the other components. The main SCRM is graphite (C).</li> <li>• <i>Battery cell electrolyte:</i> the mass of critical raw materials as a share of the mass of waste generated of this chemistry type ranges from about 0.4% to about 0.7% compared to the other components. The main SCRMs are Li and P.</li> </ul> <p><b>Sodium-based batteries (NaPBA) (only for 2030):</b> emerging chemistries in the market</p> <ul style="list-style-type: none"> <li>• <i>Collector anode and collector cathode:</i> the mass of critical raw materials as a share of the mass of waste generated of this chemistry type is about 4% compared to the other components. The main SCRM is Al.</li> <li>• <i>Battery cell electrolyte:</i> The mass of critical raw materials as a share of the mass of waste generated of this chemistry type is about 5% compared to the other components. The main SCRM is P</li> <li>• <i>Anode active material:</i> there are no SCRMs.</li> </ul> |

|            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Industrial | <p><b>Lithium-based batteries:</b></p> <ul style="list-style-type: none"> <li>• <i>Cathode additive</i>: the mass of critical raw materials as a share of the mass of waste generated of this chemistry type ranges from about 0.8% to about 1.3% compared to the other components. The main SCRM is graphite (C).</li> <li>• <i>Battery cell electrolyte</i>: the mass of critical raw materials as a share of the mass of waste generated of this chemistry type ranges from about 0.4% to about 0.7% compared to the other components. The main SCRMs are Li and P.</li> </ul> <p><b>Sodium-based batteries (NaPBA, NaNiCl<sub>2</sub>) (only for 2030):</b> emerging chemistries in the market</p> <ul style="list-style-type: none"> <li>• <i>Cathode additive</i> (mainly for NaNiCl<sub>2</sub>): the mass of critical raw materials as a share of the mass of waste generated of this chemistry types about 0.1% compared to the other components. The main SCRM is graphite (C).</li> <li>• <i>Battery cell electrolyte</i>: the mass of critical raw materials as a share of the mass of waste generated of this chemistry type is about 3% for NaNiCl<sub>2</sub> and about 5% for NaPBA compared to the other components. The main SCRM element is P.</li> </ul> <p><b>Nickel-based batteries (NiCd):</b></p> <ul style="list-style-type: none"> <li>• <i>Battery cell electrolyte</i>: the mass of critical raw materials as a share of the mass of waste generated of this chemistry type is about 0.2% compared to the other components. The main SCRM is Li.</li> <li>• <i>Cathode additive</i>: the mass of critical raw materials as a share of the mass of waste generated of this chemistry type is about 0.8% compared to the other components. The main SCRMs are Co and graphite (C).</li> </ul> <p>The other components not included in the priority list have been excluded since they lack the presence of SCRMs.</p> |
|------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

| Application               | Excluded components                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|---------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Portable                  | <p><b>Lithium-based batteries:</b></p> <ul style="list-style-type: none"> <li>• <i>Battery cell electrolyte</i>: the mass of critical raw materials as a share of the mass of waste generated of this chemistry type ranges from about 0.4% to about 0.7% compared to the other components. The main SCRM are Li and P.</li> <li>• <i>Cathode additive</i>: the mass of critical raw materials as a share of the mass of waste generated of this chemistry type ranges from about 0.8% to about 1.3% compared to the other components. The main SCRM is graphite (C).</li> <li>• <i>Current collector cathode</i>: there are no SCRMs.</li> </ul> <p><b>Nickel-based batteries (NiCd):</b></p> <ul style="list-style-type: none"> <li>• <i>Battery cell electrolyte</i>: the mass of critical raw materials as a share of the mass of waste generated of this chemistry type is about 0.2% compared to the other components. The main SCRM is Li.</li> <li>• <i>Cathode additive</i>: the mass of critical raw materials as a share of the mass of waste generated of this chemistry type is about 0.8% compared to the other components. The main SCRMs are Co and graphite (C).</li> </ul> |
| EV batteries              | <p><b>Lithium-based batteries:</b></p> <ul style="list-style-type: none"> <li>• <i>Battery cell electrolyte</i>: the mass of critical raw materials as a share of the mass of waste generated of this chemistry type ranges from about 0.1% to about 1.1% compared to the other components. The main SCRM is Li.</li> </ul> <p><b>Sodium-based batteries:</b></p> <ul style="list-style-type: none"> <li>• <i>Anode active material</i>: there are no SCRMs.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Other excluded components | <ul style="list-style-type: none"> <li>• <i>Battery cell binder</i>: made mainly of plastic and additives (there are no SCRMs).</li> <li>• <i>Battery cell separator</i>: made mainly of plastic (there are no SCRM)</li> <li>• <i>Battery cell casing</i>: made mainly by Al. it is expected that waste management operators do already sort these fractions and have documentation (proof of sale) on those in terms of weight and possibly recycling efficiency from the next actor in the value chain.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |

Source: JRC elaboration based on FutuRaM internal dataset.

#### 4.1.4 Further remarks on the resulting list – step 2 of the methodology for waste streams from group 1

##### 4.1.4.1 Legal coverage and legislation gaps (sub-paragraphs b and c, respectively)

The Regulation (EU)2023/1542 (European Union 2023) that entered into force in 2023, introduced specific requirements considering all stages of the life cycle of batteries (**Table 6**). To address the rapidly evolving battery market, a new battery category for LMT was introduced, compared to the Batteries Directive (Directive 2006/66/EC) (European Union 2006). Regarding waste, the Regulation outlines minimum requirements for the collection of both portable and LMT waste batteries (Articles 59 and 60). It also establishes specific targets for recycling of materials as well as minimum recycled content for new batteries made available in the EU market.

Additionally, both the Batteries Regulation and the CRM Act (European Union 2024b) acknowledge the rapid technological advancements in battery development, such as material substitutions, the emergence of new chemistries, and the introduction of new battery-powered products. These factors can substantially influence the stock and flow of batteries, along with embedded materials, over the next decade.

The results indicate that by 2030, new chemistries with new materials will be available, e.g. LiMFP and Sodium-ion batteries, especially for larger applications, such as EV and industrial batteries. This shift is largely driven by the growing adoption of batteries across various applications and the rapid technological advancements aimed at reducing the use of critical raw materials, including cobalt.

**Table 6.** Overview of legislative coverage related to batteries flows at EU and/or national levels.

| Lifecycle phase     | Product/component/material/element – SCRM related/not related | Legislation coverage                                                                                                                                                                                                                                                                                                                                           | National / EU coverage                            |
|---------------------|---------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------|
| Place on the market | Element - Co, Li, Ni, natural graphite                        | <b>Due diligence</b> - Economic operators shall provide documentation regarding the raw materials (RMs), information on supplier; information on origin and trades of the RMs and quantities of RMs in the place on the market battery. Third-party verification documents or (for conflict-areas raw materials) additional information shall be also provided | EU - Batteries Regulation, Art. 49(2) and Annex X |
|                     | Product - LMT, industrial, EV batteries                       | <b>Digital product passport</b> - History and features of the product. Different levels of confidentiality and granularity are conceived for different actors (e.g., users, economic operators, recyclers, manufacturers)                                                                                                                                      | EU - Batteries Regulation, Art. 77 and Annex XIII |
|                     | Element - Co, Li, Ni, (Pb)                                    | <b>Recycled content</b> - Minimum percentage share of Co, Li, Ni, (Pb) in <b>active materials</b> that have been recovered from battery manufacturing waste or post-consumer waste, for each battery model per year and per manufacturing plant                                                                                                                | EU - Batteries Regulation, Art. 8                 |

| <b>Lifecycle phase</b> | <b>Product/component/material/element – SCRM related/not related</b> | <b>Legislation coverage</b>                                                                                                                                                                                 | <b>National / EU coverage</b>                           |
|------------------------|----------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|
| Use phase              | Product - LMT, portable batteries                                    | <b>Removability and replaceability</b> - All batteries incorporated in market products shall be readily removable and replaceable by the end-user at any time during the lifetime (except some derogations) | EU - Batteries Regulation, Art. 11                      |
|                        | Product - portable batteries                                         | <b>Performance and durability</b> - Minimum values for the electrochemical performance and durability parameters                                                                                            | EU - Batteries Regulation, Art. 9 and Annex III         |
| End of life            | Product - portable, LMT, SLI, industrial, and EV batteries           | <b>Collection</b> - Separate collection with specific collection targets to be achieved by MSs                                                                                                              | EU - Batteries Regulation, Art. 59, 60, 61              |
|                        | Material - Li-based, Ni-based, (Pb-based), other waste batteries     | <b>Recycling efficiency</b> - targets of recycling percentage share                                                                                                                                         | EU - Batteries Regulation, Art. 71 and Annex VII Part B |
|                        | Element - Co, Cu, Li, Ni, (Pb)                                       | <b>Recovery of materials</b> - targets of recycling percentage share                                                                                                                                        | EU - Batteries Regulation, Art. 71 and Annex VII Part C |
|                        | Product - collected waste batteries                                  | <b>Treatment</b> - Collected waste batteries shall not be disposed of or be the subject of an energy recovery operation                                                                                     | EU - Batteries Regulation, Art. 70                      |

Source: JRC elaboration.

#### **4.1.4.2 Challenges and existing systems for collection and treatment (sub-paragraphs d and e, respectively)**

The collection of waste batteries remains a key challenge for all the batteries categories. Note that all industrial, EV and SLI batteries shall be properly collected (Article 61 of the Batteries Regulation), while for portable and LMT batteries specific target are set (Articles 59 and 60 of the Batteries Regulation – see **Table 6**). Currently, portable and LMT batteries are often collected within the same collection system and thus the volumes of waste portable and LMT batteries are reported together. However, dedicated collection schemes for waste LMT batteries are under development, and this can increase the collection of waste batteries available for collection, increase traceability of waste batteries and hence minimise the losses (Bobba et al. 2024).

Especially for the waste collection of batteries belonging to these two categories, results of the developed analysis showed that there is potential for improvement in the short-term.

Note that, despite the high quantity of waste SLI batteries in-use stock in the EU market, Lead-acid batteries are not included in the above list due to the low amount of critical raw materials.

Based on the results of the developed analysis, in 2022 LMT batteries are less collected (only 5 % is currently collected) while industrial batteries have the lowest losses, as 90% is currently collected.

Additionally, considering the potential of collection improvement based on the top three MSs in 2022, portable and EV batteries have the highest potential, of about 50%.

#### **4.1.4.3 Further remarks on datasets availability**

- **Internal cables** are integral part of the battery as made available on the market and necessary to its operation. The cables required to connect the battery to the final equipment are excluded. Internal cables were not included in the quantitative analysis but have been included as an outcome of the stakeholder consultation, also per analogy as component to be prioritised for other waste streams, e.g., WEEE. Additionally, there is no clear evidence from the Batteries Regulation on including cables and aluminium casing. Generally, at treatment plants, cables and casings are usually removed during the batteries dismantling phases and sent for separate treatments to specific copper and/or aluminium recycling plants (Orefice et al. 2024). These are supposed to be collected and recovered. In the adopted delegated act for the implementation of Art. 71 of the Batteries Regulation, Section 1 'Definitions' the cables and casing are included in the input fractions of waste battery recycling. In particular, the definition of cables states 'cables that are integral part of the battery as made available on the market and necessary to its operation, excluding the cables required to connect the battery to the final equipment'. The rationale of this definition is to include any component that belongs to the battery as made available on the market and reasonably internal cabling and casing are necessary to install the battery, but this can be connected to one or other application via the external cabling. Note anyway that although cables and casing recycling would account for the recycling efficiency of the waste batteries, they may practically not be recycled with the waste battery but with other flows. Nonetheless, collection and recycling (treatment) of cables and casing are in scope of the Batteries Regulation and its secondary legislation. Finally, it is expected that waste management operators do already sort these fractions and have documentation (proof of sale) on those in terms of weight and possibly recycling efficiency from the next actor in the value chain.
- **Battery management system.** data concerning battery management system for EV batteries only are provided from the analysis of the motor vehicle waste stream as presented in Section 4.4. Thus, battery management system for industrial and LMT batteries have been included based on expert opinions and consultation with relevant stakeholders.

## **4.1.5 Key messages for battery waste stream**

### **(a) SCRM data and elaboration**

Lithium-based batteries emerged as the most relevant chemistry for SCRM recovery potential due to high quantity of SCRM losses and their high concentration of materials like Co, Ni, Mn, Li, graphite. Most prioritised components, across all chemistries, include cathode active materials (especially in LiNMC), anode active materials (especially in Li-based due to graphite, Si-containing variants), cathode and anode current collectors (especially in other SLI for Al and Cu), battery management systems and internal cables (particularly for EV and industrial applications). New chemistries, like LiMFP, LiNMC955\_Si10, and sodium-based batteries are expected increasing in volume and relevance.

### **(b) What is covered (legislation)**

The Batteries Regulation (EU) 2023/1542 introduced life-cycle requirements concerning e.g. minimum recycled content for Co, Ni, Li, Pb (Art. 8), digital product passports (Art. 77), due diligence obligations for raw materials (Art. 49), collection targets (Art. 59, 60, and 61), and recycling efficiencies and recovery targets for CRM (Art. 71). The legislative framework expects improved collection, better traceability, and higher recovery efficiency, especially for batteries with high SCRM content.

### **(c) Legislation gaps**

The Batteries Regulation does not explicitly cover internal components like cables and casings, though these are treated in practice by recyclers and covered in Delegated Acts. Sodium-based batteries are not specifically mentioned (hence they are included in “Other batteries”), despite emerging waste flows by 2030. At present, no mandatory monitoring or reporting obligations exist for SCRM losses, thereby constraining the assessment of their true recovery potential.

### **(d) Existing systems**

High SCRM losses are particularly associated with Li-based LMT and portable rechargeable batteries, mainly due to lower collection efficiency. Separate collection systems exist for portable, LMT, EV, SLI, and industrial batteries, with mixed effectiveness: portable and LMT batteries are often collected together but are beginning to diverge into dedicated schemes, while SLI, industrial and EV batteries are mostly properly collected through producer responsibility systems and vehicle dismantling networks. Informal or cross-border flows, including exports of end-of-life batteries and grey collection channels, further complicate traceability and diminish the potential for systematic SCRM recovery. At the same time, internal cables and casings are nowadays already sorted by recyclers, showing progress in targeted material recovery practices.

### **(e) Challenges**

Low collection rates for portable and LMT batteries remain a major obstacle, especially for chemistries with high SCRM content like LiNMC and LiFP. Relatively high undocumented losses continue for EV and SLI batteries despite formal obligations and the producer responsibility system in place. Emerging chemistries

lack historical data and recycling routes, making integration into circular systems more complex. Ensuring traceability and enforcement across EU MSs remains uneven. Beyond regulatory barriers, economic drivers play a critical role: the costs of recovery and volatile market prices for secondary Co, Ni, Li, and graphite strongly influence recycling outcomes. Finally, while recycled content obligations provide some incentives, broader and sustained end-market demand for secondary materials will be essential to unlock the full potential of SCRM recovery.

## 4.2 Results for WEEE for the Article 26 of the CRMA

The prioritised list for **electrical and electronic equipment** (EEE) applied **at the waste stream level**, indicating the **relevant components** to be prioritised for this waste stream, is following presented.

Electrical and electronic equipment, with the following components, in particular:

- (a) Permanent magnets;
- (b) Hard disk drives;
- (c) Compressors;
- (d) Display (cathode ray tube, liquid crystal, thin film, plasma);
- (e) Printed circuit boards;
- (f) Cables;
- (g) Photovoltaic cells;
- (h) Photovoltaic frames;
- (i) Remaining fraction after specific dismantling in pre-treatment<sup>9</sup>.

It is important to note that EEE waste stream has several categories associated, and not all the components are to be prioritised for each of these categories. Therefore, the following sub-sections provide details on the resulted list, considering the categories of the electric and electronic equipment waste stream.

### 4.2.1 Scope and background

WEEE refers to waste generating from electrical and electronic equipment including all components, sub – assemblies and consumables which are part of the product at the time of discarding. The WEEE Directive 2012/19/EU (European Union 2012) further defines EEE as “*equipment which is dependent on electric currents or electromagnetic fields to work properly and equipment for the generation, transfer and measurement of such currents and fields and designed for use with a voltage rating not exceeding 1,000 volts for alternating current and 1,500 volts for direct current*”. Batteries are not included within the assessment of the WEEE flows; the quantities of the portable batteries embedded in the WEEE are allocated to the battery waste stream (Section 4.1). The classification of products and components presented in the following sections is consistent with the WEEE Directive 2012/19/EU.

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<sup>9</sup> While not a component, the fraction of waste electrical and electronic equipment that remains after specific dismantling in pre-treatment typically contains high amounts of critical raw materials and may therefore be worth targeting in national circularity programmes.

#### **4.2.1.1 Composition**

The collected composition data includes 54 products groups, the so-called UNU-Key codes (Forti, Baldé, and Kuehr 2018) (see **Table A9** in **Annex IV**), which are further related to the six WEEE categories (plus PV panels) as defined in the WEEE Directive 2012/19/EU. The data collection was performed considering a variety of data sources, including past project outcomes (e.g., ProSUM), project partners' data provision (e.g., French PRO ecosystem), and literature review. The raw data collected was then consolidated to ensure gap filling, outliers detection and consistency with the stock and flow model described in the following sub-section. The composition model mostly applied averaged static material compositions per UNU-KEY over time since there was not sufficient data to model composition changes per UNU-KEY over time. However, the mix of the products within a WEEE category is dynamic and varies per country. The whole list of components and materials are in **Table A10** and **Table A11** in **Annex V**. The consolidated data was aggregated to reflect the six categories of the WEEE Directive and integrated in the stock and flow model:

- Category 1, Temperature exchange equipment;
- Category 2, Screens, monitors, and equipment containing screens (>100 cm<sup>2</sup>);
- Category 3, Lamps;
- Category 4a, Large equipment excluding Photovoltaic panels (>50 cm);
- Category 4b, Photovoltaic panels;
- Category 5, Small equipment (<50 cm);
- Category 6, Small IT and telecommunication equipment (<50cm).

#### **4.2.1.2 Stock and flow model**

The stock and flow model for WEEE (see **Table A12** of **Annex VI** for more information) begins from a quantification of the amount of electrical and electronic equipment (EEE) placed on the market using trade statistics (i.e. import and export) and domestic production data from Eurostat (reference data 2023). It then applies a lifespan model differentiated per UNU-Key to estimate the amount of WEEE generated over time and to derive the EEE in stock. The calculations for EEE PoM up to WEEE generated are produced at UNU-Key level. The data is then aggregated into the six categories of the WEEE Directive 2012/19/EU and integrated with the composition data as described above.

### **4.2.2 List of products and components to be prioritised, (details per WEEE category)**

The components of electrical and electronic equipment that shall be prioritised according to the results of the developed analysis are listed herein. **This list includes details per WEEE category.**

Note that most of the WEEE Directive-compliant management in the EU starts with the separate collection of WEEE by a variety of collectors. The compliant management involves specific hazardous and valuable components removed and selectively treated in the pre-treatment phase, and then the rest is sent for further treatment, often mechanical treatment. The specific components that can be dismantled are listed below, while the residue, which is sent for further (likely mechanical) treatment, is commonly referred to "*remaining fraction after specific dismantling*"

*in pre-treatment*". The remaining fraction resulting from specific pre-treatment cannot be attributed to a single component in WEEE. Furthermore, the recovery of SCRM from this fraction is not always economically or technically feasible. However, this fraction, representing an aggregation of various components, contains numerous critical raw materials and has therefore been included in the priority list.

The prioritised list for electrical and electronic equipment for each category includes the following components, in particular:

- Temperature exchange equipment:
  - (a) Permanent magnets;
  - (b) Compressors;
  - (c) Printed circuit boards;
  - (d) Cables;
  - (e) Remaining fraction after specific dismantling in pre-treatment<sup>10</sup>.
- Screens, monitors, and equipment containing screens (>100 cm<sup>2</sup>):
  - (a) Permanent magnets;
  - (b) Hard disk drives;
  - (c) Display (cathode ray tube, liquid crystal, thin film, plasma) ;
  - (d) Printed circuit boards;
  - (e) Cables;
  - (f) Remaining fraction after specific dismantling in pre-treatment.
- Lamps:
  - (a) Printed circuit boards;
  - (b) Remaining fraction after specific dismantling in pre-treatment.
- Large equipment (>50 cm):
  - (a) Permanent magnets;
  - (b) Hard disk drives;
  - (c) Printed circuit boards;
  - (d) Hard disk drives;

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<sup>10</sup> While not a component, the fraction of waste electrical and electronic equipment that remains after specific dismantling in pre-treatment typically contains high amounts of critical raw materials and may therefore be worth targeting in national circularity programmes

- (e) Cables;
  - (f) Remaining fraction after specific dismantling in pre-treatment.
- Photovoltaic Panels:
  - (a) Permanent magnets;
  - (b) Printed circuit boards;
  - (c) Cables;
  - (d) Photovoltaic cells;
  - (e) Photovoltaic frames;
  - (f) Remaining fraction after specific dismantling in pre-treatment.
- Small equipment (<50 cm):
  - (a) Permanent magnets;
  - (b) Hard disk drives;
  - (c) Printed circuit boards;
  - (d) Cables;
  - (e) Remaining fraction after specific dismantling in pre-treatment.
- Small IT and telecommunication equipment (<50cm):
  - (a) Permanent magnets;
  - (b) Hard disk drives;
  - (c) Printed circuit boards;
  - (d) Cables;
  - (e) Remaining fraction after specific dismantling in pre-treatment.

The rationale of the list of products and components included and not included in the priority list can be found in section 4.2.3.

The mapping of the main SCRM elements based on the highest quantities within the prioritised components within each WEEE category is showed in **Table 7**. Note that Al and Cu are common elements found in various prioritised components across the WEEE categories, such as printed circuit boards or cables. Also note that the composition of permanent magnets is different across each WEEE category, and in some cases, they present elements that are found only in permanent magnets, such as Dy, Nd. This composition might change in the future since there could be a shift in the market towards ferrite magnets to avoid the use of SCRM elements. Finally, Si is specially found in displays and screens, monitors, and equipment containing screens, as well as in photovoltaic cells of PV panels.

**Table 7.** Map of main SCRM within the prioritised components (column) of WEEE categories (row) based on data available.

| WEEE category                                                               | Remaining fraction after specific dismantling in pre-treatment | Compressor | Permanent magnet                  | Printed circuit boards | Cables     | Display            | Hard disk drive | Photovoltaic frame | Photovoltaic cell |
|-----------------------------------------------------------------------------|----------------------------------------------------------------|------------|-----------------------------------|------------------------|------------|--------------------|-----------------|--------------------|-------------------|
| Temperature exchanges equipment                                             | Al, Cu, Mg, Si                                                 | Cu         | Sr, W, Mn, Co, Cu, Al, Ni, Nd, Ti | Cu, Al, Sb             | Cu, Al     | -                  | -               | -                  | -                 |
| Screens, monitors, and equipment containing screens (>100 cm <sup>2</sup> ) | Al, Mg, Cu                                                     | -          | Sr, Al, Nd, Cu, Mn, W             | Cu, Al, Si             | Cu, Al, Sb | Si, Mg, Al, Sb, Ba | Nd, Al          | -                  | -                 |
| Lamps                                                                       | Al, Mg, Cu, Co, Ni, W                                          | -          | -                                 | Al, Cu, Ni             | -          | -                  | -               | -                  | -                 |
| Large equipment (>50cm)                                                     | Al, Mg, Cu, Ni                                                 | -          | Nd, Sr, Dy                        | Cu, Al, Sb             | Cu, Al     | -                  | Nd, Al          | -                  | -                 |
| Photovoltaic panels                                                         | Al, Mg, Cu                                                     | -          | Sr, Mn, W                         | Al, Cu                 | Cu, Al     | -                  | -               | Al                 | Si                |
| Small equipment (<50cm)                                                     | Al, Mg, Cu, W                                                  | -          | Sr, W, Mn, Co, Al                 | Cu, Al, Mg             | Cu, Al     | -                  | Nd, Al          | -                  | -                 |
| Small IT and telecommunication equipment (<50cm)                            | Al, Mg, Cu                                                     | -          | Sr, Co, Nd                        | Cu, Al, Ni, Si         | Cu, Al     | -                  | Al, Cu, Ni, Sb  | -                  | -                 |

Source: JRC elaboration, based on FutuRaM internal dataset. Note that hyphen (-) denotes that this component is not prioritised for that WEEE.

#### 4.2.3 Rationale of the list of products and components included and not included in the priority list – step1 of the methodology for waste streams from group 1

The rationale for including or excluding specific waste streams accounts for the first step in the methodology applied for waste streams from group 1, which are defined as flows identifiable as products placed on the market. The list is further consolidated in Section 4.2.4 and its associated subsections.

The **analysis per WEEE category and reference year**, as presented in **Table 8**, considered: i) the waste generated; ii) the amount of total SCRM within waste generated, as well as the mass fraction of total SCRM in waste generated (this refers to criterion 2, i.e., RaC2); and iii) amount of losses in terms of total SCRM (this refers to criterion 1, i.e., RaC1).

The **total waste generated** in 2022 were approximately 8.7 Mtonnes per year, with a projected increase to around 11 Mtonnes per year in 2030, representing about 27% increase in waste generation over the 8-year period. The **total amount of SCRM in waste generated** in 2022 was approximately 0.9 Mtonnes per year, with a projected increase to around 1 Mtonnes per year in 2030, representing a 20% increase in SCRM in waste generation over the 8-year period. The **total amount of SCRM losses** in 2022 was approximately 0.4 Mtonnes per year, being the biggest SCRM losses were in small equipment (0.2 Mtonnes), with a projected increase to around 0.45 Mtonnes per year in 2030, representing a 13% increase in SCRM losses over the 8-year period.

The **mass fraction of SCRMs in waste generated** varied across waste streams, with the highest mass fraction founded in Lamps, at 32% in 2022 (i.e., approximately 0.027 Mt of SCRMs in 0.083 Mt of waste generated in 2022) and 50% in 2030 (i.e., approximately 0.038 Mt of SCRMs in 0.075 Mt of waste generated in 2030), and the lowest fraction founded in Large equipment, at 6% in 2022 (i.e., approximately 0.18 Mt of SCRMs in 3.1 Mt of waste generated in 2022), and 5% in 2030 (i.e., approximately 0.22 Mt of SCRMs in 4.6 Mt of waste generated in 2030). The **mass fraction of SCRMs losses in waste generated** also varied across waste streams, following the same trend as for the mass fraction of SCRMs in waste generated. This highlighted the products with high SCRMs “concentration” but not sufficiently recycled so far. Additionally, the concentration alone could be misleading, hence please also refer to the quantities in t/y provided in **Table 8**.

Overall, the data highlighted the growing importance of SCRMs in waste generation and losses, emphasizing the need for effective waste reduction and management strategies, including recycling, reuse, and proper disposal of waste, as well as targeted interventions to recover and recycle these critical materials.

**Table 8.** Rationale of the list of electrical and electronic equipment, by WEEE category included in the priority list.

| Year          | WEEE category                                                               | Waste generated [t/y] | SCRMs in waste generated [t/y] | SCRMs losses [t/y] | Mass fraction of SCRMs in waste generated [%] |
|---------------|-----------------------------------------------------------------------------|-----------------------|--------------------------------|--------------------|-----------------------------------------------|
| 2022          | Temperature exchange equipment                                              | 1,495,461             | 168,984                        | 59,751             | 11%                                           |
|               | Screens, monitors, and equipment containing screens (>100 cm <sup>2</sup> ) | 617,278               | 72,100                         | 23,385             | 12%                                           |
|               | Lamps                                                                       | 83,416                | 26,769                         | 13,491             | 32%                                           |
|               | Large equipment (>50 cm)                                                    | 3,153,679             | 180,786                        | 62,914             | 6%                                            |
|               | Photovoltaic Panels                                                         | 138,134               | 20,255                         | 14,893             | 15%                                           |
|               | Small equipment (<50 cm)                                                    | 2,555,894             | 357,511                        | 207,720            | 14%                                           |
|               | Small IT and telecommunication equipment (<50cm)                            | 639,837               | 41,523                         | 19,230             | 6%                                            |
| 2030<br>(BAU) | Temperature exchange equipment                                              | 1,983,799             | 239,062                        | 64,898             | 12%                                           |
|               | Screens, monitors, and equipment containing screens (>100 cm <sup>2</sup> ) | 525,925               | 53,663                         | 17,033             | 10%                                           |
|               | Lamps                                                                       | 75,914                | 38,125                         | 18,322             | 50%                                           |
|               | Large equipment (>50 cm)                                                    | 4,608,187             | 217,581                        | 71,926             | 5%                                            |
|               | Photovoltaic Panels                                                         | 367,236               | 54,616                         | 34,341             | 15%                                           |
|               | Small equipment (<50 cm)                                                    | 2,771,933             | 392,801                        | 228,128            | 14%                                           |
|               | Small IT and telecommunication equipment (<50cm)                            | 673,619               | 46,861                         | 19,967             | 7%                                            |

Source: JRC elaboration, based on FutuRaM internal dataset. Note that SCRMs not collected (i.e., losses) refer to criterion 1, while mass fraction of SCRMs in waste generated refers to criterion 2 of the methodology applied for waste streams from group 1.

**Table 9** illustrates that in terms of mass fraction, the remaining fraction after specific dismantling in pre-treatment is the most significant component across various waste products, accounting for between 5% and 46% of the total mass in 2022 and between 4% and 46% in 2030, depending on the product category. Cables and printed circuit boards are also notable components, with mass fractions ranging between 0.4% and 2% and between 0.02% and 4%, respectively, in both 2022 and 2030. Notably, the mass fraction of displays (cathode ray tube, thin film transistor, plasma) in screens, monitors, and equipment containing screens (>100 cm<sup>2</sup>) is expected to decrease from 4% to 2% between 2022 and 2030. It is encouraged to relate these concentrations in % to the quantities in t/y provided in **Table 9**.

Furthermore, the analysis highlights significant increases in SCRM losses from lamps, from 12,404 t/y to 16,673 t/y, and photovoltaic panels, from 11,226 t/y to 20,638 t/y, between 2022 and 2030. These trends suggest that the generation of waste from these products is likely to become more significant in the future, emphasizing the need for effective waste management strategies to mitigate the environmental impacts of these losses. Additionally, that there is a potential of SCRM lost in remaining fraction after specific dismantling which could potentially be improved.

Overall, the analysis provides insights into the composition and trends of SCRM losses across the prioritised components for the WEEE stream.

Finally, the rationale for excluding specific waste products and components (see **Annex IV** for a whole list of components) is detailed in **Table 10**.

**Table 9.** Rationale of the list of electrical and electronic equipment, by components within WEEE categories included in the priority list.

| WEEE category                                                               | Waste component                                                | SCRM losses 2022 [t/y] | SCRM losses 2030 (BAU) [t/y] | Mass fraction of SCRM in waste generated 2022 [%] | Mass fraction of SCRM in waste generated 2030 (BAU) [%] |
|-----------------------------------------------------------------------------|----------------------------------------------------------------|------------------------|------------------------------|---------------------------------------------------|---------------------------------------------------------|
| Temperature exchange equipment                                              | Remaining fraction after specific dismantling in pre-treatment | 56,524                 | 62,242                       | 11                                                | 12                                                      |
|                                                                             | Compressors                                                    | 2,891                  | 2,249                        | 1                                                 | 0.4                                                     |
|                                                                             | Permanent magnet                                               | 115                    | 92                           | 0.02                                              | 0.02                                                    |
|                                                                             | Printed circuit board                                          | 107                    | 120                          | 0.02                                              | 0.02                                                    |
|                                                                             | Cables                                                         | 110                    | 193                          | 0.02                                              | 0.04                                                    |
| Screens, monitors, and equipment containing screens (>100 cm <sup>2</sup> ) | Remaining fraction after specific dismantling in pre-treatment | 10,419                 | 9,154                        | 5                                                 | 5                                                       |
|                                                                             | Display (cathode ray tube, thin film transistor, plasma)       | 7,279                  | 2,942                        | 4                                                 | 2                                                       |
|                                                                             | Printed circuit board                                          | 4,572                  | 4,003                        | 2                                                 | 2                                                       |
|                                                                             | Cables                                                         | 849                    | 724                          | 0.4                                               | 0.4                                                     |
|                                                                             | Hard disk drives                                               | 97                     | 73                           | 0.05                                              | 0.04                                                    |
|                                                                             | Permanent magnet                                               | 22                     | 13                           | 0.01                                              | 0.01                                                    |
| Lamps                                                                       | Remaining fraction after specific dismantling in pre-treatment | 12,404                 | 16,673                       | 30                                                | 46                                                      |
|                                                                             | Printed circuit board                                          | 914                    | 1,599                        | 2                                                 | 4                                                       |
| Large equipment (>50 cm)                                                    | Remaining fraction after specific dismantling in pre-treatment | 57,306                 | 64,496                       | 5                                                 | 4                                                       |
|                                                                             | Hard disk drives                                               | 19                     | 44                           | 0.002                                             | 0.003                                                   |
|                                                                             | Cables                                                         | 4,214                  | 5,405                        | 0.4                                               | 0.4                                                     |
|                                                                             | Permanent magnet                                               | 257                    | 195                          | 0.02                                              | 0.01                                                    |
|                                                                             | Printed circuit board                                          | 805                    | 1,314                        | 0.1                                               | 0.1                                                     |

| WEEE category                                    | Waste component                                                | SCRMs losses 2022 [t/y] | SCRMs losses 2030 (BAU) [t/y] | Mass fraction of SCRMs in waste generated 2022 [%] | Mass fraction of SCRMs in waste generated 2030 (BAU) [%] |
|--------------------------------------------------|----------------------------------------------------------------|-------------------------|-------------------------------|----------------------------------------------------|----------------------------------------------------------|
| Photovoltaic Panels                              | Remaining fraction after specific dismantling in pre-treatment | 11,226                  | 20,638                        | 11                                                 | 9                                                        |
|                                                  | Photovoltaic cell                                              | 3,062                   | 7,041                         | 3                                                  | 3                                                        |
|                                                  | Photovoltaic frame                                             | 479                     | 5,892                         | 0.5                                                | 3                                                        |
|                                                  | Printed circuit board                                          | 16                      | 28                            | 0.02                                               | 0.01                                                     |
|                                                  | Cables                                                         | 57                      | 105                           | 0.1                                                | 0.05                                                     |
|                                                  | Permanent magnet                                               | 1                       | 2                             | 0.001                                              | 0.001                                                    |
| Small equipment (<50 cm)                         | Remaining fraction after specific dismantling in pre-treatment | 163,776                 | 172,392                       | 11                                                 | 11                                                       |
|                                                  | Hard disk drives                                               | 212                     | 262                           | 0.02                                               | 0.02                                                     |
|                                                  | Cables                                                         | 27,353                  | 31,394                        | 2                                                  | 2                                                        |
|                                                  | Printed circuit board                                          | 15,253                  | 22,891                        | 1                                                  | 1                                                        |
|                                                  | Permanent magnet                                               | 601                     | 562                           | 0.04                                               | 0.03                                                     |
| Small IT and telecommunication equipment (<50cm) | Remaining fraction after specific dismantling in pre-treatment | 7,486                   | 7,263                         | 3                                                  | 3                                                        |
|                                                  | Cables                                                         | 4,467                   | 5,371                         | 2                                                  | 2                                                        |
|                                                  | Printed circuit board                                          | 6,334                   | 6,438                         | 2                                                  | 2                                                        |
|                                                  | Permanent magnet                                               | 411                     | 365                           | 0.1                                                | 0.1                                                      |
|                                                  | Hard disk drives                                               | 205                     | 182                           | 0.1                                                | 0.1                                                      |

Source: JRC elaboration, based on FutuRaM internal dataset. Note that SCRMs losses refer to criterion 2, while mass fraction of SCRMs in waste generated refers to criterion 1 or the methodology for group 1.

**Table 10.** Rationale of the list of WEEE by components not included in the priority list.

| Application                                                                 | Excluded components                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|-----------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Temperature exchange equipment                                              | Display LCD and lighting are excluded due to relatively very low quantities of SCRM's compared with the other components within Temperature exchange equipment, mainly Sr for display LCD, and Cu for lighting. However, the lighting component requires further investigation on the composition.                                                                                                                                                                                                                                                                                                                                                 |
| Screens, monitors, and equipment containing screens (>100 cm <sup>2</sup> ) | Casing plastic based, <i>drivecddint</i> , foil, <i>heatingcoolingfaneee</i> , <i>heatingcoolingheatsinkeeee</i> , remote control, and speaker <i>eee</i> , are excluded due to relatively very low quantities of SCRM's compared with the other components within Screens, monitors, and equipment containing screens (>100 cm <sup>2</sup> ) (mainly Cu and Al).                                                                                                                                                                                                                                                                                 |
| Lamps                                                                       | <i>burneriobitumtube</i> , fluorescent powder, and lighting, are excluded due to relatively very low quantities of SCRM's compared with the other components within lamps (mainly Nb in the first one, P and Y in the second one, and Cu in the third one). However, the lighting component requires further investigation on the composition.                                                                                                                                                                                                                                                                                                     |
| Large equipment (>50 cm)                                                    | <i>powersupply</i> , transformer <i>eee</i> , display LCD, drive unspecified, and <i>sensorunspecified</i> are excluded due to relatively very low quantities of SCRM's within Large equipment (>50 cm) (mainly Al, Cu)                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Photovoltaic panel                                                          | <i>passivejunctionbox</i> and lighting are excluded due to relatively very low quantities of SCRM's compared with the other components within Photovoltaic panel (mainly Cu). However, the lighting component requires further investigation on the composition.                                                                                                                                                                                                                                                                                                                                                                                   |
| Small equipment (<50 cm)                                                    | Electric engine, lighting, <i>casingunspecified</i> , <i>othernonelectriccompunspecified</i> , <i>casingplasticbased</i> , drive <i>cddint</i> , <i>lensas-assembly</i> , <i>heatingcoolingfaneee</i> , <i>transmission</i> , wheel, brush, touch sensor, transmitter, <i>nonelectriccoil</i> , remote control, rotor and lighting are excluded due to relatively very low quantities of SCRM's compared with the other components within Small equipment (<50 cm) (mainly Cu and Al, then Mn in <i>casingunspecified</i> , Sr in display LCD, Nd in <i>driveHDD</i> ). However, some components require further investigation on the composition. |
| Small IT and telecommunication equipment (<50cm)                            | <i>Heatingcoolingfaneee</i> , <i>diplay</i> LCD, <i>drivecddint</i> , power supply, lighting, <i>othernonelectriccompunspecified</i> , <i>casingunspecified</i> , <i>driveunspecified</i> , <i>transformereeee</i> , heatingCoolingHeatSinkEEE, <i>spekereeee</i> are excluded due to relatively very low quantities of SCRM's within Small IT and telecommunication equipment (<50cm (mainly Cu and Al). However, some components require further investigation on the composition.                                                                                                                                                               |
| For all WEEE categories                                                     | The other components not listed within each category above, have been excluded due to no quantity of SCRM's or due to missing information on composition at material and elemental level.                                                                                                                                                                                                                                                                                                                                                                                                                                                          |

Source: JRC elaboration, based on FutuRaM internal dataset.

## 4.2.4 Further remarks on the resulting list – step2 of the methodology for waste streams from group 1

### 4.2.4.1 Legal coverage and legislation gaps (sub-paragraphs b and c, respectively)

A list of legislation coverage for electric and electronic equipment in the EU is provided in **Table 11**.

The legislation encompasses various stages of the product life cycle, from "place on market" to "end-of-life", and specifies the targeted waste and SCRM addressed, along with the corresponding targets and requirements.

For WEEE, the legislation coverage includes EU Regulations, such as the ESPR Regulation (EU) 2024/1781 (European Union 2024c), Waste shipments Regulation (EU) 2024/1157 (European Union 2024a), and the WEEE directive 2012/19/EU (European Union 2012). These targets are set at the WEEE category level, rather than being material-specific, which may limit their effectiveness in addressing the recovery of SCRMs. Furthermore, the collection rate can be reported using two different methods, which may lead to comparability issues and potential inconsistencies in tracking progress towards these targets.

Overall, **Table 11** provides a comprehensive overview of the legislative framework governing WEEE, while also highlighting areas for potential improvement and refinement.

**Table 11.** Overview of legislative coverage related to electric and electronic equipment flows at EU level.

| Life-cycle phase    | Targeted flow – SCRM related/not related                                                                                                                                                                                        | Legislation coverage                                                                                                                                                                                                                                    | EU legislation                                                  |
|---------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|
| Place on the market | Product                                                                                                                                                                                                                         | <b>Digital product passport</b> - Digital technologies provide the possibility to tag, track, trace, localise, and share product related data, down to the level of the individual components and materials                                             | EU - ESPR Regulation (EU) 2024/1781                             |
| End of life         | Component - glass from cathode-ray tubes, lamp, switch, fluorescent tube, capacitor containing PCBs, certain circuit boards, display devices (Full list in two delegated acts 2024/3229 and 2024/3230)                          | <b>Waste shipments</b> - Export of e-waste from the EU to non-OECD countries will be prohibited, while to OECD countries; the import of all e-waste from Third countries into the EU and between EU MSs will be subject to the "prior informed consent" | EU - Shipments of waste and amending Regulations (EU) 2024/1157 |
|                     | Product - WEEE categories, as priority for temperature exchange equipment containing ozone-depleting substances and fluorinated greenhouse gases, fluorescent lamps containing mercury, photovoltaic panels and small equipment | <b>Separate collection</b> - Appropriate measures to achieve high level of separate collection of WEEE                                                                                                                                                  | EU - WEEE Directive 2012/19/EU, Art.5                           |
|                     | Product - WEEE categories                                                                                                                                                                                                       | <b>Disposal</b> - prohibition of disposal of collected WEEE which has not yet undergone the treatment of Art.8                                                                                                                                          | EU - WEEE Directive 2012/19/EU, Art.6                           |

| Life-cycle phase | Targeted flow – SCRM related/not related | Legislation coverage                                                                                                                                                                                                                                  | EU legislation                                     |
|------------------|------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------|
|                  | Product - All WEEE                       | <b>Collection rate</b> - Minimum collection rate of 65 % of the average weight of EEE placed on the market in the three preceding years in the Member State concerned, or alternatively 85 % of WEEE generated on the territory of that Member State. | EU - WEEE Directive 2012/19/EU, Art.7              |
|                  | Product - WEEE categories                | <b>Recovery</b> - Minimum targets for recovery. Category 1: 85%; category 2: 80%; category 3: na; category 4: 85%; category 5: 75%; category 6: 75%                                                                                                   | EU - WEEE Directive 2012/19/EU, Art.11 and Annex V |
|                  | Product - WEEE categories                | <b>Prepared for re-use and recycling</b> - Minimum targets. Category 1: 80%; category 2: 70%; category 3: 80% recycled; category 4: 80%; category 5: 55%; category 6: 55%                                                                             | EU - WEEE Directive 2012/19/EU, Art.11 and Annex V |

Source: Own elaboration.

Furthermore, there are specific legal requirements for minimum removal and selective treatment at the component level, as outlined in Article 8(2) of the WEEE Directive.

Annex VII of the WEEE Directive lists components that must be mandatorily dismantled during WEEE treatment within the EU27. When this list is compared to the draft priority list presented in the previous section, there are overlaps between the two, as well as discrepancies. Some components are included in both Annex VII and the priority list, while others are newly identified in the priority list and not yet present in Annex VII. Conversely, there are components listed in Annex VII that are not on the priority list. The components from Annex VII that also appear on the WEEE priority list include:

- Printed circuit boards larger than 10 cm<sup>2</sup>;
- Cathode ray tubes (e.g., display crt);
- Liquid crystal displays larger than 100 cm<sup>2</sup>;
- External electric cables.

There are components in the priority list that are not yet in Annex VII of the WEEE Directive, as:

- Hard disk drives;
- Permanent magnets;
- Compressor;
- Photovoltaic cell;
- Photovoltaic frame;
- Display (LCD – liquid crystal display, thin film transistor display, plasma).

The exclusion of these components could be due to insufficient attention to SCRM. Therefore, this generates a lack of material-specific targets in the current WEEE directive, which could lead to inconsistencies in monitoring progress towards these targets.

#### **4.2.4.2 Challenges and existing systems for collection and treatment (sub-paragraphs d and e, respectively)**

The undocumented losses have been calculated as *waste undocumented / waste generated* at the year of reference. The calculations are based on the data provided by FutuRaM WEEE waste stream.

The analysis of undocumented losses in WEEE waste streams for 2022, detailed in **Table 12**, reveals significant variations, with photovoltaic panels having the highest percentage of undocumented losses (74%). In contrast, small equipment (<50 cm), and large equipment (>50 cm) have lower undocumented losses (3.9% and 2.7%).

Other waste streams, such as small IT and telecommunication equipment (<50cm), and lamps, have significant undocumented losses (15% and 40%). The analysis highlights the need for targeted efforts to improve waste management practices and minimise undocumented losses to promote the recovery of SCRM. A significant percentage of undocumented losses in PV panels may be attributed to limitations in data availability. Most PV panels do not simply end up as metal or plastic scrap; instead, they may be exported as second hand or as a waste, but there is insufficient data on this aspect. Another uncertainty are the lifespans. The lifespans of PV panels are at this stage technical lifespans obtained from industry, and not (yet) in-situ lifespans. This may cause some overestimation of the calculated waste generation of the PV panels in some countries. Consequently, due to the lack of detailed information regarding these losses and uncertainties of lifespans, they are all classified as undocumented. This situation emphasises the need for improved data collection to comprehend and define PV panel lifespans and their losses.

**Table 12.** Share of undocumented losses within the waste generated for the year 2022 and for each WEEE category.

| <b>Waste stream</b>                                                         | <b>% of the undocumented losses within the waste generated for 2022</b> |
|-----------------------------------------------------------------------------|-------------------------------------------------------------------------|
| Photovoltaic Panels                                                         | 74%                                                                     |
| Small equipment (<50 cm)                                                    | 3.9%                                                                    |
| Small IT and telecommunication equipment (<50cm)                            | 15%                                                                     |
| Large equipment (>50 cm)                                                    | 2.7%                                                                    |
| Temperature exchange equipment                                              | 3.2%                                                                    |
| Lamps (or lighting equipment)                                               | 40%                                                                     |
| Screens, monitors, and equipment containing screens (>100 cm <sup>2</sup> ) | 2.1%                                                                    |

Source: JRC elaboration, based on FutuRaM internal dataset.

#### **4.2.4.3 Further remarks on datasets availability**

- **Solid state drives.** Data is available for this component. However, there are no clear evidence from the dataset that solid state drives can be prioritised for the Art.26 (7) list. Data on solid state drives are aggregated with other components, and a granular analysis is not possible. It is suggested to not include these components in the current priority list. However, considering their use as data storage device and future availability of data can make them possible candidates to be included in the list.

## **4.2.5 Key messages for electrical and electronic equipment waste stream**

### **(a) SCRM data and elaboration**

The analysis highlights the importance of various SCRMs within the WEEE categories, including aluminium (Al), copper (Cu), neodymium (Nd), dysprosium (Dy), and silicon (Si). At the component level, permanent magnets, hard disk drives, compressors, printed circuit boards, and cables are identified as key components containing significant quantities of SCRMs. Special attention should be given to the remaining fraction after specific dismantling in pre-treatment since it still presents high SCRMs recovery potential. The analysis reveals that there are significant losses of SCRMs, particularly in the categories of small equipment (<50 cm), large equipment (> 50 cm), and temperature exchange equipment, with compressors, permanent magnets, cables, and printed circuit boards being key components contributing to these losses. It is important to note for some components (specially the remaining fraction after specific dismantling in the pre-treatment where the SCRMs losses reaches about 319 kt/y) and categories such as lamps (even if the SCRMs quantities lost might not very high in total for this category), the mass fraction (i.e., concentration of SCRMs) is very high and could facilitate the recovery process. For detailed information check Section 4.2.1.

### **(b) Legislative coverage**

The current legislative framework for WEEE in the EU is mainly defined by the WEEE Directive 2012/19/EU, which sets targets for collection, recovery, and recycling of WEEE. It also converges with other legislation, such as the Ecodesign for Sustainable Products Regulation (ESPR), which can drive design-for-recycling, and the Batteries Regulation, where overlaps occur in relation to electronics with embedded batteries.

### **(c) Legislation gaps**

However, there are gaps in the legislation, such as the lack of material-specific targets and the potential for inconsistencies in tracking progress towards these targets. Current mass-based targets under WEEE Directive, incentivise operators to prioritize bulk materials which are easier to process, rather than SCRMs that are more difficult to extract and are present in smaller quantities. Additionally, the collection rate can be reported using two different methods, which may lead to comparability issues.

### **(d) Existing systems**

The average collection rate for WEEE in the EU27 in 2022 is 57%, with significant variations across different WEEE categories. Photovoltaic panels have the lowest collection rate (26%), while screens, monitors, and equipment containing screens (>100 cm<sup>2</sup>) and large equipment (>50 cm) have higher collection rates (68% and 65%, respectively).

### **(e) Challenges**

The analysis highlights significant challenges in the collection and treatment of WEEE, including the lack of effective waste management strategies, inadequate

collection infrastructure, and insufficient recycling capacities. Existing systems are often insufficient, resulting in substantial losses of SCRM, with undocumented losses particularly high – for example, photovoltaic panels having the highest percentage of undocumented losses (74%), mainly due to unavailability of detailed data on documented losses (e.g., waste export). Informal flows and illegal exports, such as WEEE shipped as “used equipment,” represent major pathways for SCRM leakage. In addition, market and economic barriers, including the costs of recovery and limited demand for secondary materials, further constrain the efficiency and effectiveness of WEEE recycling and recovery systems.

## 4.3 Results for wind turbines for the Article 26 of the CRMA

The prioritised list for **wind turbines and related infrastructure** applied at the waste stream level, indicating the **relevant components** to be prioritised for this waste stream, is following presented.

Wind turbines and related infrastructure, with the following components, in particular:

- (a) Permanent magnets;
- (b) Generators;
- (c) Transformers;
- (d) Converters and inverters;
- (e) Cables.

It is important to note that wind turbines and related infrastructure waste stream has several categories associated, and not all the components are to be prioritised for each of these categories (or wind turbine types). Therefore, the following sub-sections provide details on the resulted list, considering the categories of wind turbines and related infrastructure waste stream.

### 4.3.1 Scope and background data

#### 4.3.1.1 Composition

The sub-technologies of wind turbines analysed can be divided into two main categories: **gearbox (GB)** and **direct-drive (DD)**<sup>11</sup>. All sub-technologies can be installed both onshore and offshore, but only some are installed offshore:

1. Squirrel cage induction generator (GB-SCIG).
2. Double-fed induction generator (GB-DFIG).
3. Electrically excited synchronous generator (DD-EESG).
4. Electrically excited synchronous generator (GB-EESG).
5. Wound rotor induction generator (GB-WRIG).
6. Permanent magnet synchronous generator, direct (DD-PMSG).
7. Permanent magnet synchronous generator, geared (GB-PMSG).

Due to data gaps and limits, FutuRaM dataset excluded high-temperature superconducting wind turbine sub-technology, wind farm substations and other components outside of the wind turbine, and vertical axis wind turbines. Permanent magnets were assumed to be only within PMSG

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<sup>11</sup> A hybrid category was also analysed and is considered under PMSG technology (DD).

technologies. As for the foundations (offshore and onshore), representative foundations were selected and averaged, considering low groundwater level and monopile foundations for respectively onshore and offshore wind turbines. Other wind turbine foundations (e.g. high groundwater level, jacket, floating, etc.) were not integrated in this assessment. The wind turbine component key is based on some original equipment manufacturers (OEM) Life Cycle Assessment (LCA) (e.g., Allekotte and Garrett 2024), considering only the most common ones that can be also found in other LCAs (Ardente et al. 2008; Martínez et al. 2010; Guezuraga, Zauner, and Pölz 2012; Tremeac and Meunier 2009; Weinzettel et al. 2009). As wind turbines have over 10,000 components, which vary between model types and manufacturers, the components used in FutuRaM are generic components representing functional units of wind turbines. The collected data includes all references including previous JRC reports such as (Samuel Carrara et al. 2020), the SURFER project (Monfort et al. 2019) and from (Liu, Meng, and Barlow 2022). The composition values are close to the ones found in (Samuel Carrara et al. 2020) and (MC Govern, Tapoglou, and Georgakaki 2024).

Wind turbines present the following components. In bold, the components that have been included in the current analysis, as separate data were available, while the text not in bold resulted from data aggregation:

1. **Export cables (or external cables)**, connection between the turbines and to the main substation.
2. Foundations.
3. **Permanent magnet**<sup>12</sup>, if present in the turbine type.
4. Other key components of wind turbine, excluding the mentioned above, which includes components such as tower, nacelle, rotor blades, etc.

The latter component category was aggregated in the assessment. Additionally, certain authors identify the presence of magnets in small quantities in the tower or in the yaw system motor, but it is not a technological/default choice for all the manufacturers. Therefore, the “turbine component, permanent magnet” refers only to the permanent magnet in the generator. Electronic devices in wind turbines are not considered due to the lack of data. Besides, the total weight of electronic devices installed in the turbine is neglectable compared the total weight of wind turbines but remains significantly higher when compared to other WEEE categories<sup>13</sup>. Finally, steel alloys used in the wind turbines technologies are not considered in the assessment because steel is neither critical nor strategic in the CRM Regulation 2024/1252. Vanadium, which can be present in some specialised steel alloys, could be assessed in the future following a similar approach for all alloys elements in all the waste streams. Note that substation components (converter, inverter) were not included in the FutuRaM quantitative analysis, but have been included as an outcome of the stakeholder consultation due to their relevancy as SCRM rich components.

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<sup>12</sup> Different magnet types and categories are used in wind turbine systems (e.g. NdFeB, SmCo, etc.). However, due to lack of data, all permanent magnets in wind turbines were considered as NdFeB.

<sup>13</sup> An illustrative example would be the amount of copper and copper alloys in a 2 MW wind turbine, with a total weight of 49 tonnes and representing 0.6% of the total weight of the wind turbine. Source: (Garrett and Razdan 2018)

#### **4.3.1.2 Stock and flow model**

The stock, the placed on the market capacity and waste generated capacity flows of WT for all countries in the EU are calculated through a material flow analysis (Brunner and Rechberger 2016). The wind power capacity through the life cycle is calculated with both a material flow analysis inflow-driven model, where the material stock is determined from historic inflows from the first year of installation for each country until 2024, and a material flow analysis stock-driven model after 2024 where the material stock is modelled with the change in stock from future scenarios.

The European wind parks (wind farms) in production and already dismantled are collected from the Wind Power database<sup>14</sup>. This same private database delivers a wind power turbines model database which was used to know the type of the parks according to the turbine model.

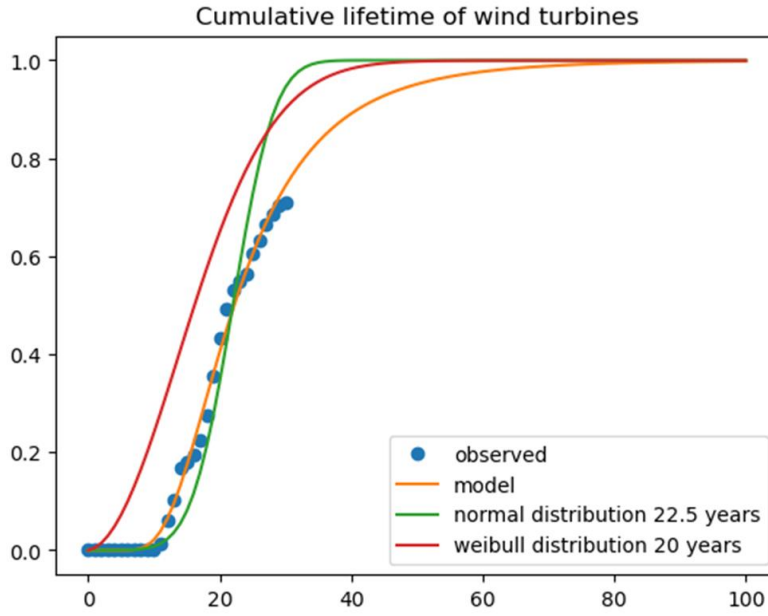
The type-split (which represents the market share of the different turbine type placed on the market) in the EU is obtained from a 2020 JRC report (Alves Dias et al. 2020) for both onshore and offshore parks, with observed data from 1991 to 2018 and projected data until 2050 with the middle demand scenario chosen. Additionally, the WindEurope association provides future projection for each country's future capacity stock of onshore and offshore wind power by year until 2030 (Costanzo, Brindley, and Tardieu 2024). The EU objectives for 2050 are thus used to complete future capacity.

In the present study, the lifetime was calculated from observed data, from The Wind Power database, of already dismantled turbines. A ratio of the cumulative dismantled wind turbines on the total amount of wind turbines installed each year was calculated from the year of installation until 2024. Then, the average of five consecutive years (1988-1992) of cumulative proportion is calculated. The lifetime used is the interpolation with a mathematical Weibull function of the 1988-1992 cumulative proportion of turbines dismantled (see **Figure 6**).

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<sup>14</sup> <https://www.thewindpower.net/>

**Figure 6.** Lifetime of wind turbines.



Source: FutuRaM elaboration.

Please note that, FutuRaM has associated the entire potential decommissioning quantities per year, country, sub-technology of the installed wind turbine fleet to waste generated. Please also note that, when decommissioned, wind turbines and their components and parts are not directly classified as waste but could also be reused.

### Inflow-driven model

The inflow capacities are taken from the Wind Power Database; however, some changes are needed to improve the database and to combine all the data used.

The WindPower database has some data gaps, where already dismantled parks do not have information about the year when it happened. By definition, it happened before 2024. In the case the dismantling year is 2024, a uniform probability for 2018-2023 is applied and for parks still in production and the dismantling will happen after 2024. A uniform probability is applied for years between 2025 and 2035 if the dismantling year is 2025.

As each park has a year of dismantling the outflows can be calculated the same through **Equation 2**.

**Equation 2.** Outflows calculation.

$$Waste_{year,type,country} = \sum_i EoL_{year,type,country,i}$$

With  $EoL$  being the capacity of each park  $i$  reaching their end-of-life for the year, country and type calculated.

### Stock-driven model

The wind turbines waste capacity is the sum of the parks, installed before 2024 and still in production in 2024, reaching their end-of-life in year “n”, and the amount of wind capacity, installed after 2024, leaving the stock according to the survival function (see **Equation 3** and **Equation 4**).

**Equation 3.** Wind turbine waste capacity by type.

$$Waste_{year, country, type} = \sum_i WTcap\_EoL_{year, country, type, i} + \sum_{n=2024}^{year} PoM_{n, country, type} * surv(year - n)$$

With  $WTcap\_EoL$  being the capacity of wind turbine  $i$  reaching their end-of-life in the year, the country and the type.

**Equation 4.** Total wind turbine waste capacity by country.

$$Waste_{year, country} = \sum_{type} Waste_{year, country, type}$$

With  $Waste_{year, country}$  being the total waste of the country, in the year in MW.

Waste products in 2022 for this analysis concern following product categories: SCIG onshore and offshore, DFIG onshore, DD-EESG onshore, GB-EESG onshore, WRIG onshore, DD-PMSG onshore and offshore.

In 2030, in addition to the waste product categories already considered for 2022, the waste flows also included DD-EEDG offshore and DFIG offshore.

#### 4.3.2 List of products and components to be prioritised, (details per wind turbine category)

The components of wind turbines that shall be prioritised according to the results of the developed analysis are listed herein. **This list includes details per wind turbine category (or sub-technology).**

Wind turbines and related infrastructure, with the following components, in particular:

- (a) Permanent magnets **(for DD-PMSG and GB-PMSG, both onshore and offshore);**
- (b) Generators **(for All);**
- (c) Transformers **(for All);**
- (d) Converters and inverters **(for All);**
- (e) Cables **(for All).**

It has been necessary to extend the scope beyond the wind turbine to include wind farm substations and connexions to the grid, to capture all SCRM-rich streams. By expanding the scope with “...and related infrastructure”, cables should cover: i) export cables, going from the offshore substation and

to land (to an onshore substation), ii) inter-array cables connecting the windmills with the substation, and iii) cabling within the wind turbines. Besides, other components such as wind farm generator are included separated from the cables, while the data result aggregated as internal cables and generators. Finally, converters and inverters, and transformers, refer to the components with relevant content of SCRM in substations.

The mapping of the main SCRM based on the highest quantities within the prioritised components within each decommissioned wind turbine type is showed in **Table 13**.

**Table 13.** Map of main SCRM within the prioritised components (column) of decommissioned wind turbines (row), based on the data available.

| Waste stream                            | Export cables   | Internal cables and generator within the wind turbine | Permanent magnets within the wind turbine |
|-----------------------------------------|-----------------|-------------------------------------------------------|-------------------------------------------|
| Wind turbine and related infrastructure | Al (Mg, Si), Cu | Al, Cu                                                | Nd(Pr), Dy(Tb), B                         |

*Source: JRC elaboration, based on FutuRaM internal dataset. Due to lack of data, only NdFeB materials and elements were considered for the permanent magnet stream.*

### 4.3.3 Rationale of the list of products and components included and not included in the priority list – step1 of the methodology for waste streams from group 1

The rationale for including or excluding specific waste streams accounts for the first step in the methodology applied for waste streams from group 1, which are defined as flows identifiable as products placed on the market. The list is further consolidated in Section 4.3.4 and its associated subsections.

The **analysis per wind turbine category (or sub-technology) and reference year**, as presented in **Table 14**, considered: i) the waste generated; ii) the amount of total SCRM within waste generated, as well as the mass fraction of total SCRM in waste generated (this refers to criterion 2, i.e., RaC2); and iii) amount of losses in terms of total SCRM (this refers to criterion 1, i.e., RaC1).

As presented in **Table 14** and **Table 15**, the mass fraction of SCRM in the waste generated is relatively small (from 0.50% to 1.59%), representing from 0.08 t/y to 1.2 kt/y of the waste generated. This is explained by the relatively small fraction of SCRM compared to the two major material flows at wind turbine level that are steel and composites (88% and 6.4%, respectively) and to the two major material flows at wind park level that are concrete and steel (70% and 25.6%, respectively)<sup>15</sup>. SCRM losses varies in 2022, depending on the technology, between 0.07 t/y and 293 t/y, to sum a total of 1.9 kt/y.

<sup>15</sup> Comparison made for a 2MW wind turbine and 50MW wind park, based on (Vestas, 2018)

However, these flows will tend to increase over time. The SCRM quantity in waste generated would varies between 3t/y to 26kt/y in 2030 depending on the sub-technology, and the SCRM losses between 2t/y and 18 kt/y, to sum a total of 47 kt/y. It is therefore recommended to monitor these flows and increase their circularity to reduce the potential SCRMs losses from each steam.

Finally, the rationale for excluding specific products and components is detailed in **Table 16**.

**Table 14.** Rationale of the list for wind turbines, by wind turbine category (or sub-technology) included in the priority list.

| Year | Wind turbine category | Waste generated [t/y] | SCRMs in waste generated [t/y] | SCRMs losses [t/y] | Mass fraction of SCRMs in waste generated [%] |
|------|-----------------------|-----------------------|--------------------------------|--------------------|-----------------------------------------------|
| 2022 | DD-EESG_onshore       | 26,993                | 429                            | 843                | 1.59                                          |
|      | DD-PMSG_offshore      | 31                    | 0.19                           | 35.03              | 0.62                                          |
|      | DD-PMSG_onshore       | 8,449                 | 114                            | 0.07               | 1.35                                          |
|      | GB-DFIG_onshore       | 114,040               | 1,229                          | 287                | 1.08                                          |
|      | GB-EESG_onshore       | 5,773                 | 63                             | 98                 | 1.10                                          |
|      | GB-PMSG_offshore      | 16                    | 0.08                           | 292.69             | 0.51                                          |
|      | GB-PMSG_onshore       | 4,627                 | 51                             | 78                 | 1.10                                          |
|      | GB-SCIG_offshore      | 23,249                | 115                            | 0.16               | 0.50                                          |
|      | GB-SCIG_onshore       | 38,784                | 418                            | 43                 | 1.08                                          |
|      | GB-WRIG_onshore       | 26,772                | 289                            | 198                | 1.08                                          |
| 2030 | DD-EESG_offshore      | 385                   | 3                              | 14,467             | 0.73                                          |
|      | DD-EESG_onshore       | 1,334,221             | 21,190                         | 2                  | 1.59                                          |
|      | DD-PMSG_offshore      | 227,999               | 1,418                          | 1,873              | 0.62                                          |
|      | DD-PMSG_onshore       | 203,253               | 2,739                          | 1,203              | 1.35                                          |
|      | GB-DFIG_offshore      | 133,251               | 662                            | 17,643             | 0.50                                          |
|      | GB-DFIG_onshore       | 2,386,604             | 25,723                         | 562                | 1.08                                          |
|      | GB-EESG_onshore       | 29,711                | 326                            | 3,006              | 1.10                                          |
|      | GB-PMSG_offshore      | 199,313               | 1,014                          | 861                | 0.51                                          |
|      | GB-PMSG_onshore       | 397,065               | 4,384                          | 4,581              | 1.10                                          |
|      | GB-SCIG_offshore      | 303,550               | 1,508                          | 1,280              | 0.50                                          |
|      | GB-SCIG_onshore       | 619,624               | 6,678                          | 224                | 1.08                                          |
|      | GB-WRIG_onshore       | 229,924               | 2,478                          | 1,700              | 1.08                                          |

Source: JRC elaboration, based on FutuRaM internal dataset. Note that Mass fraction of SCRMs in waste generated refers to criterion 2 of the methodology applied for waste streams from group 1.

**Table 15:** Rationale of the list of wind turbines, by category (or sub-technology) and components included in the priority list.

| <b>Waste product</b> | <b>Waste component</b>         | <b>SCRMs in waste generated 2022 [t/y]</b> | <b>SCRMs in waste generated 2030 (BAU) [t/y]</b> | <b>Mass fraction of SCRMs in waste generated 2022 [%]</b> | <b>Mass fraction of SCRMs in waste generated 2030 (BAU) [%]</b> | <b>SCRMs losses 2022 [t/y]</b> | <b>SCRMs losses 2030 (BAU) [t/y]</b> |
|----------------------|--------------------------------|--------------------------------------------|--------------------------------------------------|-----------------------------------------------------------|-----------------------------------------------------------------|--------------------------------|--------------------------------------|
| DFIG_onshore         | Export cables                  | 798.9                                      | 16,719.9                                         | 0.7                                                       | 0.7                                                             | 547.96                         | 11,467.7                             |
|                      | Internal cables and generators | 430.2                                      | 9,003.3                                          | 0.38                                                      | 0.38                                                            | 295.1                          | 6,175.1                              |
| GB-PMSG_onshore      | Export cables                  | 32.4                                       | 2,780.5                                          | 0.7                                                       | 0.7                                                             | 22.2                           | 1,906.4                              |
|                      | Internal cables and generators | 18.4                                       | 1,575.3                                          | 0.4                                                       | 0.4                                                             | 12.6                           | 1,080                                |
|                      | Permanent magnets              | 0.33                                       | 28.4                                             | 0.01                                                      | 0.01                                                            | 0.23                           | 19.5                                 |
| GB-PMSG_offshore     | Export cables                  | 0.05                                       | 643.3                                            | 0.32                                                      | 0.32                                                            | 0.04                           | 546.3                                |
|                      | Internal cables and generators | 0.03                                       | 364.5                                            | 0.18                                                      | 0.18                                                            | 0.02                           | 309.5                                |
|                      | Permanent magnets              | 0.0005                                     | 6.6                                              | 0.003                                                     | 0.003                                                           | 0.0004                         | 5.6                                  |
| SCIG_onshore         | Export cables                  | 271.7                                      | 4,340.9                                          | 0.70                                                      | 0.70                                                            | 186.4                          | 2,977.3                              |
|                      | Internal cables and generators | 146.3                                      | 2,337.5                                          | 0.38                                                      | 0.38                                                            | 100.4                          | 1,603.2                              |
| SCIG_offshore        | Export cables                  | 75.1                                       | 9,79.97                                          | 0.32                                                      | 0.32                                                            | 63.74                          | 832.2                                |
|                      | Internal cables and generators | 40.4                                       | 527.7                                            | 0.17                                                      | 0.17                                                            | 34.32                          | 448.1                                |
| DD-EESG_onshore      | Export cables                  | 188.1                                      | 9,297.1                                          | 0.70                                                      | 0.70                                                            | 128.4                          | 6,347.4                              |
|                      | Internal cables and generators | 240.6                                      | 11,893                                           | 0.89                                                      | 0.89                                                            | 164.3                          | 8,119.7                              |
| DD-PMSG_onshore      | Export cables                  | 59                                         | 1,419.1                                          | 0.70                                                      | 0.70                                                            | 40.3                           | 970.4                                |
|                      | Internal cables and generators | 51.2                                       | 1,232.4                                          | 0.61                                                      | 0.61                                                            | 35                             | 842.8                                |

| Waste product    | Waste component                | SCRMs in waste generated 2022 [t/y] | SCRMs in waste generated 2030 (BAU) [t/y] | Mass fraction of SCRMs in waste generated 2022 [%] | Mass fraction of SCRMs in waste generated 2030 (BAU) [%] | SCRMs losses 2022 [t/y] | SCRMs losses 2030 (BAU) [t/y] |
|------------------|--------------------------------|-------------------------------------|-------------------------------------------|----------------------------------------------------|----------------------------------------------------------|-------------------------|-------------------------------|
|                  | Permanent magnets              | 3.6                                 | 87.4                                      | 0.04                                               | 0.04                                                     | 2.5                     | 59.8                          |
| DD-PMSG_offshore | Export cables                  | 0.1                                 | 734.9                                     | 0.32                                               | 0.32                                                     | 0.08                    | 623.2                         |
|                  | Internal cables and generators | 0.09                                | 638.2                                     | 0.28                                               | 0.28                                                     | 0.07                    | 541.3                         |
|                  | Permanent magnets              | 0.01                                | 45.3                                      | 0.02                                               | 0.02                                                     | 0.01                    | 38.4                          |
| GB-EESG_onshore  | Export cables                  | 40.4                                | 208.1                                     | 0.70                                               | 0.70                                                     | 27.7                    | 142.7                         |
|                  | Internal cables and generators | 22.9                                | 117.9                                     | 0.40                                               | 0.40                                                     | 15.7                    | 80.8                          |
| WRIG_onshore     | Export cables                  | 187.6                               | 1,610.8                                   | 0.70                                               | 0.70                                                     | 128.6                   | 1,104.8                       |
|                  | Internal cables and generators | 101                                 | 867.4                                     | 0.38                                               | 0.38                                                     | 69.3                    | 594.9                         |
| DD-EESG_offshore | Export cables                  | -                                   | 1.24                                      | -                                                  | 0.32                                                     | -                       | 1.05                          |
|                  | Internal cables and generators | -                                   | 1.58                                      | -                                                  | 0.41                                                     | -                       | 1.3                           |
| DFIG_offshore    | Export cables                  | -                                   | 430.2                                     | -                                                  | 0.32                                                     | -                       | 365.3                         |
|                  | Internal cables and generators | -                                   | 231.6                                     | -                                                  | 0.17                                                     | -                       | 196.7                         |

Source: JRC elaboration, based on FutuRaM internal dataset. Note that Mass fraction of SCRMs in waste generated refers to criterion 1 of the methodology, while SCRMs losses refer to criterion 2 of the methodology. Hyphen (-) denotes that this component is not prioritised (and/or not decommissioned yet) for this year.

**Table 16.** Rationale of the list of wind turbines by components NOT included in the priority list.

| Wind turbine category                                                            | Excluded components                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|----------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| All wind turbines:<br>DD-EESG, DD-PMSG, DFIG,<br>GB-EESG, GB-PMSG, SCIG,<br>WRIG | <ul style="list-style-type: none"> <li>• It was considered that <u>foundations</u> do not have critical and strategic materials in the composition, which is made of concrete and steel. Ferrous metals do not have details of SCRM.</li> <li>• It was considered that <u>blades</u> do not have SCRM.</li> <li>• It was considered that <u>towers</u> do not have SCRM in significant quantities. However, steel may contain SCRM in the form of alloying elements in the case of stainless steel. For instance, specialized steels can contain V. At the moment, no details are available.</li> </ul> |

Source: JRC elaboration, based on FutuRaM internal dataset.

#### 4.3.4 Further remarks on the resulting list – step 2 of the methodology for waste streams from group 1

##### 4.3.4.1 Legal coverage and legislation gaps (sub-paragraphs b and c, respectively)

In principle, MSs are already framing rules related to commissioning permitting of wind turbine projects, including aspects related to environmental impact assessment. A list of legislation coverage for wind turbines in the European Union and when available, for specific MSs is provided in **Table 17**.

**Table 17.** Overview of legislative coverage related to wind turbine flows at EU and/or national levels.

| Lifecycle phase     | Targeted flow – SCRM related/not related                            | Legislation coverage                                                                                              | National/EU coverage                                                                                                                      |
|---------------------|---------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| Place on the market | Component/material – Permanent magnet (CRMs related)                | Recycled content declaration and/or use                                                                           | EU – Critical raw material Regulation (EU) 2024/1252, Art.28 and Art.29                                                                   |
|                     |                                                                     |                                                                                                                   | EU – Net-Zero Industry Regulation (EU) 2024/1735, Art.26                                                                                  |
|                     |                                                                     |                                                                                                                   | EU – Net-Zero Industry Regulation (EU) 2024/1735, Art.26                                                                                  |
|                     | Product - but also at component level – not necessarily CRM related | Recyclability, reusability, reparability, remanufacturing and refurbishment                                       | EU – Net-Zero Industry Regulation (EU) 2024/1735, Art.26<br>FR – Arrêté 22 Juin 2020                                                      |
| End of life         | Component                                                           | Decommissioning and dismantling operations, in most cases covering financial guarantees to ensure EoL dismantling | Dk – Decommissioning and resource management, according to Bekendtgørelse af lov om miljøbeskyttelse (Environment Protection Act).        |
|                     |                                                                     |                                                                                                                   | FR – ICPE, decommissioning and partial recovery of land, according to Arrêté 26 août 2011                                                 |
|                     |                                                                     |                                                                                                                   | DE – 2017 Renewable Energy Act and the Building Code, Ban of composite landfill                                                           |
|                     |                                                                     |                                                                                                                   | ES – regulating the production of electricity from renewable sources in facilities located at sea (Disposition 19172 – 25 September 2024) |
|                     |                                                                     |                                                                                                                   | NL – Landfill of composite waste, unless solutions are considered too costly                                                              |

Source: JRC elaboration, based on (WindEurope 2020).

Still, not all lifecycle aspects related to wind turbines are covered, and SCRM might not always be targeted by legislation. Parts and components containing high SCRMs concentration such as cables (underground or subsea) are not covered in principle by EU or MS legislation, and they can also be placed in international waters. Furthermore, once the decommissioning is finalised, the fate of SCRMs in each waste stream is unknown. Thus, up to date, with the exemption of what is intended to be covered under Article 26 of the CRMA, the above-mentioned list is not covered in MS / EU

legislation, leading potentially to no or low circularity of SCRM from the wind turbine stream, more specifically:

- Downcycling and/or loss of SCRM embedded in these products and components.
- Lack of scalable business model addressing the recovery of SCRM from this flow, and/or promoting higher circularity strategies such as reuse.

The remit of the CRMA Art.26 secondary legislation is justifying an intervention at EU level to identify, collect and recover higher quantities and qualities of SCRM. Afterwards, as highlighted in **Table 17** national or EU legislation might not sufficiently cover other components or materials from the wind turbine stream such as the wind turbine foundations, blade composite or the balsa wood.

Afterwards, further SCRM can in principle be incorporated in steel alloys used in wind turbine. This is the case of silicon steel in generators potentially using silicon metals, or tower steel using niobium. Due to lack of relevant data on these materials and elements use and recycling from wind turbines, as well as the non-functional recycling of steel streams (except for stainless steel), it was not possible to further investigate SCRM recovery potential from this (steel) flow.

#### ***4.3.4.2 Challenges and existing systems for collection and treatment (sub-paragraphs d and e, respectively)***

Wind turbine decommissioning and end of life is not yet regulated at EU level. The wind turbine supply-chain does not allow the deployment of virtuous R-strategies that support higher circularity goals (Morseletto 2020; Nacef Tazi and Bouzidi 2023), including improving resource efficiency and life cycle approaches when putting on the market wind turbines. The situation might also change from onshore to offshore applications, where the latter environment would in principle complicate such aspects.

Most of the base metals (mainly steel, copper and aluminium) that can be reintroduced into the economy are collected and managed. However, other materials, mainly SCRM, are not effectively collected, treated or recycled (Nacef Tazi and Bouzidi 2023; Jurrius and van Hoof 2024).

The following section provides a brief overview of existing EoL activities related to wind turbine:

- **Decommissioning:** decommissioning of onshore wind farms is currently happening in the EU, and some MS also provide standardisation documents to support such operations (e.g. DIN SPEC 4866:2020-10 (DIN 2020)). Offshore decommissioning is relatively recent and present several challenges related to the nature of installation as well as the types of foundations used. For instance, offshore installation using floaters might be challenging to decommission with usual offshore vessels equipment, it would also apply to mooring or connexion cables. Overall, there is a lack of consensus and planning approaches for installation and decommissioning of offshore wind turbines (Chitteth Ramachandran et al. 2022; Topham et al. 2019).

- **Collection:** at **wind farm level**, while the wind turbine has a designed lifetime of about 20-25 years (sometimes even longer), other wind farm components such as cables could last for 40-50 years (Birkeland 2011), and foundations could last even more (e.g. 100 year as stated for gravity based foundations (Hou et al. 2017)). Besides their lifetime variance, their collection and decommissioning are somehow unsure as these wind farm components are not foreseen to be decommissioned and recovered. At **wind turbine level**, it was assumed a collection rate of 90% of shadow components and permanent magnets onshore and offshore, 10% collection rate of onshore foundations and external cables, while offshore foundations and external cables were not in principle collected. The remote nature of wind turbine waste generation hotspots remains a challenge to optimised collection, including transport. This is for instance the case for blades, cables and foundations collection and end of life management, but more specifically a challenge to collect relevant SCRM within the collected wind turbine stream. It is also unsure whether electric and electronic equipment from wind turbines is separately collected from the main waste flow regrouping base metals. Same observation would apply to permanent magnets in generators, or cables (internal or grid ones) that are diluted in the collected base streams of steel and aluminium. Collection measures would follow in principle available standardisation documents (e.g. DIN SPEC 4866), but the remote location of wind turbine, availability of flows and transport parameters would be considered as a constraint when deciding how these CRMs based flows would be collected and treated. These challenges related to collection of CRMs based components and materials are also due to the absence of dedicated collection schemes.
- **Treatment and End of life management:** focusing mainly on SCRM based components and materials, the separate removal and sorting of these flows is challenging, as their concentration in the wind turbine flow, compared to steel or aluminium, is low. Such is the case of copper or permanent magnet that are not properly sorted from base metals. This challenge is also marked by the collection barriers that are not enhancing separate sorting of these CRM based flows. Afterwards, wind turbine components and flows follow in principle the same R-strategies available for CRM-waste flows in the EU, and sharing also same challenges related to end-of-life management. Based on the literature, existing recycling schemes main challenges are related to scalable fractions allowing cost-effective recycling, recycling efficiencies with actual recycling technologies and processes leading to losses of materials, finding the most suitable circularity strategy (e.g. reuse, lifetime extension, recycle, etc.) for the component or the material towards higher resource efficiency (Sangwongwanich et al. 2024; Rahman et al. 2021). Finally, existing end of life systems and challenges are also closely affected to market pricing. Thus, the treatment, recovery and circularity potential of CRM based components from wind turbine is not maximised, leading to circularity failures.

#### **4.3.4.3 Further remarks on datasets availability**

- **Wind park substations** (mainly transformers, converters and inverters). Data of substation were not available for these components. Besides, there is no clear evidence on the circularity barriers related to wind park substations and components allowing the connexion of the wind park to the electricity grid or system. Additionally, these components were considered as outside of the FutuRaM scope and hence not assessed. However, they have been added based on expert opinions and the consultation of relevant stakeholders, since from SCRM perspective, these components contain high amounts of e.g. Al or Cu, and should in principle be potentially monitored. For instance, wind park substations considered in (Allekotte and Garrett 2024) contain 206 t of Al and Al alloys as well as 550 t of Cu per total wind park.

- **Steel alloys.** SCRM present in steel alloys (e.g. Vanadium, Niobium) are also relevant and the functional recycling of this flow from wind turbine waste stream is unknown. Future assessment might lead to the integration of this flow as relevant to be collected, pending data availability, failures and gaps mentioned under Article 26 (7) of the CRMA.

### **4.3.5 Key messages for wind turbine waste stream**

#### **(a) SCRM data and elaboration**

The analysis highlights the importance of some SCRM within all wind turbine technologies. Within this waste stream, the most relevant components by weight of SCRM losses (with Al and Cu as key materials) are: Internal cables & generator, as well as Export cables, (Internal and Export cables, both with similarly high flows of SCRM losses); and Permanent magnets in DD-/GB-PMSG turbines – representing lower total quantity of SCRM losses but high-value materials (e.g. Nd, Dy, B). It is important to note that the mass fraction of SCRM related to the total weight of the stream is relatively small, representing 0.08 t/y to 1.2 kt/y of waste generated nowadays. However, these SCRM flows are expected to grow significantly to represent 3t/y to 25 kt/y by 2030. It is therefore important to monitor and potentially recover this flow to increase the Union secondary market capacity.

#### **(b) Legislative coverage**

The current legislative framework in the EU do not include specific EU Regulation related to wind turbines, although the RePowerEU and the Net Zero Industry Act is creating bases to boost competitiveness and resilience of EU targeted industries, including wind energy industry. The CRMA is introducing circularity requirement targeting also wind turbine components (permanent magnets). At national level however, some MSs (e.g. France, Germany, etc.) have set the background for the decommissioning, collection, recovery and recycling of wind turbine components and materials. All in all, it is expected that end of life operations such as decommissioning, collection and recovery of main materials, including some SCRM would be enhanced.

#### **(c) Legislation gaps:**

There are still some potential gaps such as the lack of specific targets related to collection and material-specific targets, as well as gaps on potential undocumented flows. The current legislation landscape does not clearly cover wind farm components and linkages with the electricity network (e.g., cables, transformers).

#### **(d) Existing systems:**

According to data, the collection rate of this waste stream (as a system) is very high within the EU. The existing system is not supported with sufficient producer responsibility system to support collection and recovery operations. Besides, end of life operations related to wind turbines are not tracked under EU legislation and are only tracked in a few MSs. For the moment, it is the responsibility of the wind farm owner/manager to handle wind turbine end-of-life flows.

#### **(e) Challenges:**

Although the collection rate for the wind turbine system is rather high, the collection for SCRM rich components might be low. Potential high SCRM losses are associated to the existing system design that is targeted towards base metals (e.g. steel) rather than specified SCRM. Besides, the decommissioning of SCRM rich wind turbine technologies is not mature enough to provide effective feedback. The lower concentration of SCRM in the wind turbine stream compared to steel and/or

concrete make the collection and recovery operations targeting SCRM's challenging. Data gaps and information shortcomings, together with the confidentiality of industry data on the presence or absence of SCRM's-rich components in the wind turbine stream, may further complicate the end-of-life management as well as reporting and traceability of these operations.

## 4.4 Results for motor vehicles for the Article 26 of the CRMA

The prioritised list for end-of-life vehicles (focused on **motor vehicles**) applied at the waste stream level, indicating the **relevant components** to be prioritised for this waste stream, is following presented.

Motor vehicles, as defined in the Regulation (EU) 2018/858 (European Union 2018), with the following components, in particular:

- (a) Permanent magnet traction motor;
- (b) Induction traction motors;
- (c) Non-traction electric motors;
- (d) Electrical and electronic components subject to re-use, recycling or any other form of recovery under relevant Union acts in their valid version;
- (e) Converters and inverters;
- (f) Main wiring harnesses;
- (g) Fuel cells;
- (h) Catalytic converters;
- (i) Wrought aluminium components and/or parts;
- (j) Cast aluminium components and/or parts;
- (k) Magnesium components and/or parts.

It is important to note that motor vehicles waste stream has several categories associated, and not all the components are to be prioritised for each of these categories (or vehicle types). Therefore, the following sub-sections provide details on the resulted list, considering the categories of motor vehicles waste stream.

### 4.4.1 Scope and background data

End-of-Life Vehicles (ELV), focused on motor vehicles, refer to any vehicle that qualifies as waste under the legal provisions of the current ELV directive (Directive 2000/53/EC on end-of life vehicles). The legislation applies to vehicles below 3.5 tonnes, i.e. passenger vehicles and small trucks (M1 and N1 categories according to the EU vehicle classification<sup>16</sup>) but not to trucks, vintage vehicles, special-use vehicles and motorcycles. A proposal for a Regulation on circularity

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<sup>16</sup> <https://alternative-fuels-observatory.ec.europa.eu/general-information/vehicle-types>

requirements for vehicle design and on management of end-of-life vehicles”<sup>17</sup>, motor vehicles below and above 3.5 tonnes used for the carriage of passengers or goods or trailers are also included in the scope of the proposal. The scope of this study corresponds to the scope of the current ELV directive (M1 and N1 vehicles). We note that increasing the scope according to the new proposal would present additional challenges in terms of limited availability of official statistics on the end-of-life of such heavier vehicles.

#### **4.4.1.1 Composition data**

Motor vehicles are categorised by three physical properties and one time-dependent property: drivetrain type or vehicle category, cylinder capacity, weight category and cohort (meaning the year when placed on the market). Based on Eurostat statistics for vehicles<sup>18</sup>, these properties are combined into more than 100 so-called vehicle keys (also named drivetrains or vehicle categories). The vehicle categories included are:

1. Battery electric vehicle (BEV).
2. Plugin hybrid electric vehicle (PHEV).
3. Hybrid electric vehicle (HEV).
4. Diesel (diesel).
5. Petrol (petrol).
6. Liquefied petroleum gas (LPG).
7. Natural gas (NG).
8. Other.

These vehicle categories are referred to as motor energy in Eurostat. The category “Other” refers to e.g. hydrogen and biofuels.

Each vehicle category is represented by compositions data in terms of mass per vehicle. Data relies on previous work presented in a JRC report (Løvik et al. 2021) also complemented with compositions data on EV batteries. The compositions data relies on data collection for specific cases, for trends in time and across categories, as well as hypotheses used for interpolating and extrapolating the data where no specific data is available. One example is that it is often relevant to differentiate the composition data over vehicle categories. Another example is that it is often relevant to scale the mass of materials or components per vehicle by the vehicle weight category. A third example is that due to technology development, compositions data can differ over time for a

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<sup>17</sup> Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on circularity requirements for vehicle design and on management of end-of-life vehicles, amending Regulations (EU) 2018/858 and 2019/1020 and repealing Directives 2000/53/EC and 2005/64/EC

<sup>18</sup> Vehicles keys are used to distinguish between different vehicle types. An example of a vehicle key is V01010202 which represents cars with petrol drivetrains of cylinder volume 1400-1999 cm<sup>3</sup> in the weight range of 1000-1249 kg.

specific vehicle category. When there is no known reason to believe that a systematic difference between different types of vehicle categories or over time exists, data is assumed to be identical.

The data follow a hierarchical structure: each vehicle is composed by components, followed by materials and elements. Since vehicle data is often reported based on specific components or materials for which either the “material layer” or “component layer” might be lacking, unspecified materials and components are included so that the hierarchical structure remains intact. One example is wrought aluminium which can be found in several different structural and body components although it is often reported as one aggregated value. For each component and material, two level of details are quantified: the mass of the component or the material per vehicle category, and the mass fraction of each element in each material and component. Based on this, the mass of each element contained in material or component per vehicle and the total mass of each element per vehicle can be calculated. The data thus includes six components (and unspecified materials) and six materials (and unspecified components) and, in each of these, elements are included (**Table 18**). There are no overlaps between materials and components.

**Table 18.** Materials, components and elements included in the ELV compositions data.

| MATERIALS/COMPONENTS: <b>mass/kg</b> | ELEMENTS: <b>mass fraction/ppm</b> |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|--------------------------------------|------------------------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
|                                      | Ag                                 | Al | Au | Cu | Dy | Fe | La | Mg | Mn | Mo | Nb | Nd | Pd | Pt | Rh | Si |
| Cast aluminium                       |                                    | x  |    | x  |    | x  |    | x  | x  |    |    |    |    |    |    | x  |
| Wrought aluminium                    |                                    | x  |    | x  |    | x  |    | x  | x  |    |    |    |    |    |    | x  |
| Mild steel                           |                                    |    |    | x  |    | x  |    |    | x  |    |    |    |    |    |    | x  |
| High strength steel                  |                                    |    |    | x  |    | x  |    |    | x  | x  | x  |    |    |    |    | x  |
| Cast iron                            |                                    |    |    | x  |    | x  |    |    | x  |    |    |    |    |    |    | x  |
| Magnesium alloys                     |                                    | x  |    |    |    |    |    | x  | x  |    |    |    |    |    |    |    |
| Catalytic converter                  |                                    |    |    |    |    |    | x  |    |    |    |    |    | x  | x  | x  |    |
| Electrics and electronics            | x                                  |    | x  | x  | x  |    | x  |    |    |    |    | x  | x  |    |    |    |
| Power electronics (xEV)              | x                                  |    | x  | x  |    |    |    |    |    |    |    |    | x  |    |    |    |
| Battery management system (xEV)      | x                                  |    | x  | x  |    |    |    |    |    |    |    |    | x  |    |    |    |
| Drive motor, induction (xEV)         |                                    |    |    | x  |    |    |    |    |    |    |    |    |    |    |    |    |
| Drive motor. PM (xEV)                |                                    |    |    | x  | x  |    |    |    |    |    |    | x  |    |    |    |    |

Source: FutuRaM elaboration based on (Løvik et al. 2021).

**Table 19** shows the dependencies of the compositions data affected by the properties that define the vehicle categories (fuel type, engine size and vehicle mass) and over time (cohorts = year when placed on the market) to account for technology development.

**Table 19.** Dependencies of variables on vehicle characteristics (x=at least one vehicle category is different from the rest)

|                                 | Dependencies               |           |             |              |                        |           |             |              |
|---------------------------------|----------------------------|-----------|-------------|--------------|------------------------|-----------|-------------|--------------|
|                                 | material or component mass |           |             |              | element mass fractions |           |             |              |
|                                 | cohort                     | fuel type | engine size | vehicle mass | cohort                 | fuel type | engine size | vehicle mass |
| Cast aluminium                  | x                          | x         | x           | x*           |                        |           |             |              |
| Wrought aluminium               | x                          | x         | x           | x*           |                        |           |             |              |
| Mild steel                      | x                          | x         |             | x            |                        |           |             |              |
| High strength steel             | x                          |           |             | x            |                        |           |             |              |
| Cast iron                       | x                          | x         |             | x            |                        |           |             |              |
| Magnesium alloys                |                            | x         |             |              |                        |           |             |              |
| Catalytic converter             | x                          | x         | x           |              |                        | x         |             |              |
| Electrics and electronics       | x                          | x         |             | x            | x                      | x         |             |              |
| Power electronics (xEV)         |                            | x         |             |              |                        |           |             |              |
| Battery management system (xEV) |                            | x         |             | x            |                        |           |             |              |
| Drive motor, induction (xEV)    |                            | x         |             | x            |                        |           |             |              |
| Drive motor, PM (xEV)           |                            | x         |             | x            |                        |           |             |              |

Source: FutuRaM elaboration based on (Løvik et al. 2021). \* Means only for xEVs.

Overall, for the motor vehicle waste stream, the vehicle categories are considered as products with the following materials and component types:

1. Materials of parts and components:
  - (a) wrought aluminium;
  - (b) cast aluminium;
  - (c) magnesium;
  - (d) cast iron;
  - (e) mild steel;
  - (f) high strength steel.
2. Components:
  - (a) battery management system, which includes printed circuit boards, cables and connectors inside the battery pack;
  - (b) electric and electronic system (EE system), which includes all EE components in vehicles except electric traction motor, batteries and power electronics for electric vehicles;
  - (c) traction motor, permanent magnet based;
  - (d) traction motor, induction based;

- (e) power electronics, which include the inverter, DC-DC converter, on-board charger (in PHEVs and BEVs only) and related controller;
- (f) catalytic converter.

Note that the six materials are embedded in numerous parts of a vehicle; similarly, electric and electronic system includes numerous components. The six materials are the sum of common materials that are spread over many components in vehicles, e.g. in different structural parts. Examples are high-strength steel and cast and wrought aluminium.

#### 4.4.1.2 Stock and flow model

The analysis of the vehicle fleet in the EU27+ 4 EFTA countries (i.e., Iceland, Liechtenstein, Norway and Switzerland) is conducted by FutuRaM based on a stock-flow model programmed in Python (illustrated schematically in **Figure 7**; see also **Table A12** of **Annex VI** for more information), which was developed and refined in several previous research projects. Its primary goal is to ensure that the stock and the flow remain consistent across various parts of the vehicle fleet. The stock flow model accounts for the number of vehicles and is combined with mapping of vehicle metal composition over time to acquire the amount and types of SCRM available in each vehicle flow.

To perform the stock and flow quantifications for each flow shown in **Figure 7** below, historical stock data and data on newly registered vehicles (placed on market, POM), imports (from inside and outside the EU27+4) and exports (to inside and outside the EU27+4) for each MS is used. Using several vehicle categories for which data has been organised by age groups (cohorts) ranging from 0 to over 30 years, the stock-flow model provides an estimation of the number of deregistered vehicles. This is done by calculating the projected number of vehicles for the next period (t+1) and comparing it with the actual recorded stock for each vehicle category and year of data. The projected stock at time (t+1) is calculated as in **Equation 5**.

**Equation 5.** Projected stock of vehicles calculation.

$$ProjectedStock_{t+1,c} = Stock_{t,c} + Nettrade_{t+1,c} + PoM_{t+1,c} - Deregistered_{t,c}$$

Each term represents a component of the stock and flow model for vehicle fleets at time 't' in country 'c'.

- *Stock (t, c)* is the period's stock, showing the number of vehicles available at the start.
- *Net trade (t+1, c)* reflects the balance of imported and exported vehicles within the period 't+1' for the country 'c', calculated as Import flows(t) - Export flows(t).
- *PoM (t+1, c)* represents the addition of new vehicles to the fleet, also known as "placed on the market" at the time 't+1' for country 'c'.
- *Deregistration (t, c)* is the number of no longer used vehicles, often referred to as "EoL flows" at time 't' for country 'c'.

The difference between projected and recorded stock indicates the quantity of deregistered vehicles. The model develops this calculation by incorporating detailed vehicle category information and estimates of age distribution. For future predictions, PoM and trade data are calculated based on the growth of purchasing power parity (PPP) and population of respective MSs. Additionally, the model employs an inferred death / loss function to estimate total vehicle deregistration.

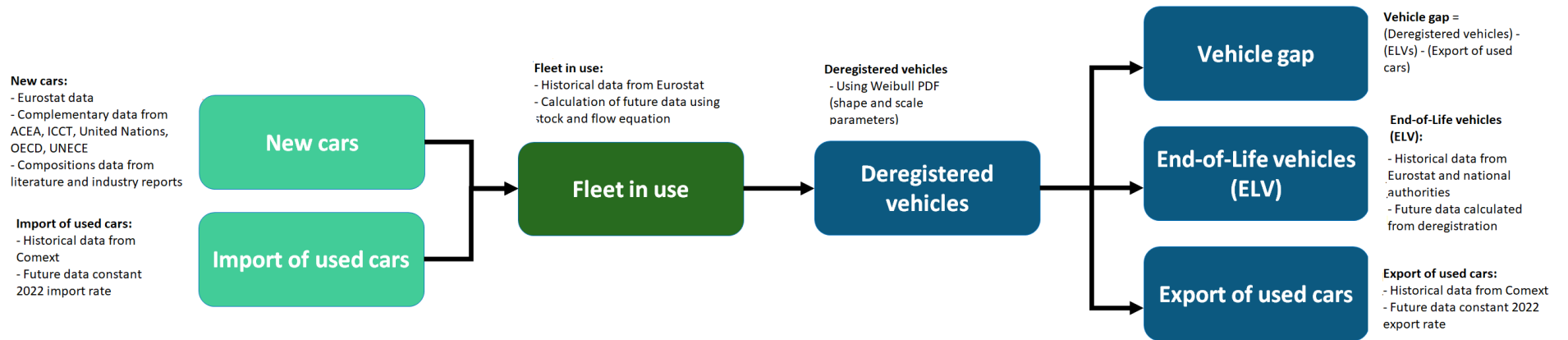
It is important to note that these deregistered vehicles are not necessarily collected or available for recycling but are instead classified into 4 different flows:

1. ELV registered for recycling.
2. Exports within EU27+4.
3. Exports outside EU27+4.
4. Undocumented flows (such as non-registered ELV scrapping, illegal dumping, or passive stock).

The size of the first three flows is determined based on historical end-of-life vehicle statistics (reported numbers of certificates of destruction) and export data. The undocumented loss for a given year for each MS is calculated as the difference between the number of deregistered vehicles and the sum of the number of vehicles exported and registered for recycling that year.

This approach may differ from other waste streams, where only end-of-life registered products are accounted for, rather than their deregistered counterparts. For the vehicle waste stream however, this calculation step is necessary step as there are yearly more vehicles that have been deregistered than the sum of vehicles that have been exported and registered for recycling.

**Figure 7.** Depiction of the ELV stock and flow model used to generate the results for the ELV waste stream.



Source: FutuRaM elaboration.

#### 4.4.2 List of products and components to be prioritised, (details per motor vehicle category)

The components of motor vehicles that shall be prioritised according to the results of the developed analysis are listed herein. **This list includes details per motor vehicle category.**

Motor vehicles, as defined in the Regulation (EU) 2018/858 (European Union 2018), with the following components, in particular:

- (a) Permanent magnet traction motors **(for BEV, PHEV, HEV);**
- (b) Induction traction motors **(for BEV);**
- (c) Non-traction electric motors **(All motor vehicle categories);**
- (d) Electrical and electronic components subject to re-use, recycling or any other form of recovery under relevant Union acts in their valid version **(All motor vehicle categories);**
- (e) Converters and inverters **(for BEV, PHEV, HEV);**
- (f) Main wiring harnesses **(All motor vehicle categories);**
- (g) Fuel cells **(for other motor vehicle categories);**
- (h) Catalytic converters **(All motor vehicle categories, except for BEV);**
- (i) Wrought aluminium components and/or parts **(All motor vehicle categories);**
- (j) Cast aluminium components and/or parts **(All motor vehicle categories);**
- (k) Magnesium components and/or parts **(All motor vehicle categories).**

For electrical and electronic systems and for power electronics, an additional shortlist was prepared, based on SCRM concentration and the possibility to recover these SCRM (which was assessed previously in Tazi et al. 2023, and EVA II project<sup>19</sup>). Next, power electronics refer to inverters and converters. These specificities have been included considering the feedback loop with stakeholders.

The mapping of the main critical and strategic raw materials ELV waste stream is shown in **Table 20**.

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<sup>19</sup> Marmy, C.; Capelli, M.; Böni, H.; Bartolome, N.; Marseiler, U., Projekt EVA II: Synthesebericht, Empa, St. Gallen, 2023.

**Table 20.** Map of main SCRM within the prioritised components (column) of motor vehicle categories (row).

| Motor vehicle category | Wrought aluminium parts / components | Cast aluminium parts / components | Electrical and electronic system | Magnesium parts / components | Traction motor, permanent magnet | Power electronics | Traction motor, induction based | Catalytic converters      |
|------------------------|--------------------------------------|-----------------------------------|----------------------------------|------------------------------|----------------------------------|-------------------|---------------------------------|---------------------------|
| EV (BEV, PHEV, HEV)    | Al                                   | Al                                | Al, Cu                           | Mg                           | Cu, Nd, Dy                       | Cu                | Cu                              | HEV, PHEV: Pt, Pd, La, Rh |
| Diesel                 | Al                                   | Al                                | Cu, Nd, La                       | Mg                           | -                                | -                 | -                               | Pt, Pd, La                |
| Petrol, LPG, NG, Other | Al                                   | Al                                | Cu, Nd, La                       | Mg                           | -                                | -                 | -                               | Pt, Pd, La, Rh            |

Source: JRC elaboration, based on FutuRaM internal dataset. Power electronics also contain in principle Ga and PGM (i.e., Ag, Au) but not highlighted in this table due to limited data availability. Note that hyphen (-) denotes that this component is not prioritised for that motor vehicle.

#### 4.4.3 Rationale of the list of materials and components included and not included in the priority list – step1 of the methodology for waste streams from group 1

The rationale for including or excluding specific waste streams accounts for the first step in the methodology applied for waste streams from group 1, which are defined as flows identifiable as products placed on the market. The list will be further consolidated in Section 4.4.4 and its associated subsections.

The **analysis per motor vehicle category and reference year**, as presented in **Table 21**, considered: i) the waste generated; ii) the amount of total SCRM within waste generated, as well as the mass fraction of total SCRM in waste generated (this refers to criterion 2, i.e., RaC2); and iii) amount of losses in terms of total SCRM (this refers to criterion 1, i.e., RaC1).

The results indicate that **petrol and diesel vehicles** continue to produce the largest volumes of waste in Europe, with diesel vehicles projected to surpass petrol vehicles in waste generation based on the BAU scenario.

**HEV, BEV, and PHEV vehicles** show significant increases in both SCRM in waste and SCRM losses from 2022 to 2030. Notably, BEVs exhibit the highest mass fraction of SCRM in waste generated, rising from 16% in 2022 to 18% in 2030, and the highest mass fraction of SCRM losses, increasing from 9% in 2022 to 10% in 2030.

**LPG and NG vehicles** show comparatively lower volumes of waste and SCRM losses. The mass fraction of SCRM in waste generated for LPG and NG vehicles increases from 2022 to 2030, but the SCRM loss fractions remain relatively low.

The key findings from this analysis are:

- BEVs and other electric vehicle types will require focused attention in future SCRM recovery efforts due to their high SCRM content and losses.
- The growing volumes of waste from hybrid and electric vehicles necessitate a shift in focus towards these technologies in waste management and recycling strategies.

- Improved waste management and recycling strategies are essential to mitigate the increasing SCRM losses across all vehicle types, particularly for electric vehicles.
- The projected increase in waste generation from diesel vehicles by 2030 underlines the need for continued monitoring and optimization of waste management practices for traditional vehicle types.

**Table 21.** Rationale of the list for motor vehicles, by motor vehicle category included in the priority list.

| Year | Motor vehicle category | Waste generated [t/y] | SCRM in waste generated [t/y] | SCRM losses [t/y] | Mass fraction of SCRM in waste generated [%] |
|------|------------------------|-----------------------|-------------------------------|-------------------|----------------------------------------------|
| 2022 | Petrol                 | 3,529,912             | 312,847                       | 111,474           | 9%                                           |
|      | Diesel                 | 3,040,670             | 281,919                       | 114,031           | 9%                                           |
|      | Other                  | 505,511               | 43,824                        | 16,382            | 9%                                           |
|      | HEV                    | 426,761               | 47,276                        | 22,905            | 11%                                          |
|      | BEV                    | 242,848               | 37,828                        | 20,948            | 16%                                          |
|      | PHEV                   | 235,591               | 31,055                        | 16,735            | 13%                                          |
|      | LPG                    | 185,705               | 16,081                        | 2,610             | 9%                                           |
|      | NG                     | 28,391                | 2,337                         | 647               | 8%                                           |
| 2030 | Diesel                 | 3,919,453             | 517,610                       | 193,548           | 13%                                          |
|      | Petrol                 | 3,306,206             | 401,805                       | 143,270           | 12%                                          |
|      | Other                  | 658,123               | 78,802                        | 28,140            | 12%                                          |
|      | HEV                    | 616,217               | 86,197                        | 37,718            | 14%                                          |
|      | BEV                    | 344,107               | 63,520                        | 34,343            | 18%                                          |
|      | PHEV                   | 299,606               | 45,829                        | 24,467            | 15%                                          |
|      | LPG                    | 223,262               | 27,919                        | 4,326             | 13%                                          |
|      | NG                     | 38,582                | 4,567                         | 1,199             | 12%                                          |

Source: JRC elaboration, based on FutuRaM internal dataset. Note that SCRM losses not collected (i.e., losses) refer to criterion 1, while mass fraction of SCRM in waste generated refers to criterion 2 of the methodology applied for waste streams from group 1.

**Table 22** provides an analysis of waste components associated with various vehicle technologies for the years 2022 and 2030. The table outlines the minimum and maximum waste products, the mass fraction of SCRM in waste generated, and the corresponding SCRM losses. Here are the key messages.

- **Battery management systems** in HEVs and BEVs for both 2022 and 2030, exhibit a significant range in SCRM losses, with an increase from a maximum of 844 tonnes in 2022 to 1,169 tonnes in 2030. The mass fraction of SCRM remains consistent.
- **Catalytic converters** show very low mass fractions and SCRM losses, with a slight increase in 2030. This indicates limited impact on SCRM losses.
- The SCRM losses for **electrical and electronic systems** increase notably from 71-1,637 tonnes in 2022 to 97-2,316 tonnes in 2030, reflecting the growing complexity and volume of electronic components, especially in BEVs.
- **Power electronics** in HEVs and PHEVs maintain a consistent mass fraction but see an increase in SCRM losses from approximately 221-223 tonnes in 2022 to 294-285 tonnes in 2030.

- Both **cast and wrought aluminium parts/components** show a significant increase in SCRM losses from 2022 to 2030. Cast aluminium parts increase dramatically, with maximum SCRM losses rising from 7,652 tonnes in 2022 to 111,697 tonnes in 2030. Wrought aluminium also sees an increase from 10,551 tonnes to 17,040 tonnes, highlighting the importance of aluminium recycling. Magnesium parts show relatively stable mass fractions but see a slight increase in SCRM losses from 2022 to 2030.
- **Induction-based traction motors** have consistent SCRM losses (349 tonnes in 2022 to 484 tonnes in 2030), while permanent magnet-based motors see an increase from 536 tonnes to 687 tonnes, indicating the growing importance of these components in EVs.

The data indicates that as electric vehicle technology advances, the complexity and volume of waste components, particularly electronic and aluminium parts, will increase, leading to higher SCRM losses. Effective recycling and waste management strategies will be crucial to handle the rising SCRM losses, especially for components like aluminium parts and traction motors. The transition to more complex vehicle technologies requires a focus on improving the recovery of SCRM to reduce environmental impact and resource scarcity.

**Table 22.** Rationale of the list of ELV, by category (waste product) and components included in the priority list.

| Year | Waste component                        | Waste product min | Waste product max | Mass fraction of SCRM in waste generated [%] |       | Corresponded SCRM losses [t/y] |         |
|------|----------------------------------------|-------------------|-------------------|----------------------------------------------|-------|--------------------------------|---------|
|      |                                        |                   |                   | Min                                          | max   | min                            | max     |
| 2022 | Battery management system              | HEV               | BEV               | 0.04                                         | 0.63  | 88                             | 844     |
|      | Catalytic converter                    | BEV               | BEV               | <0.01                                        | <0.01 | 3.5                            | 1.1     |
|      | Electrical and electronic system       | NG                | BEV               | 0.90                                         | 1.22  | 71                             | 1,637   |
|      | Power electronics                      | HEV               | PHEV              | 0.11                                         | 0.18  | 221                            | 223     |
|      | Cast aluminium parts / components      | NG                | PHEV              | 4.89                                         | 6.03  | 384                            | 7,652   |
|      | Magnesium parts / components           | BEV               | LPG               | 0.08                                         | 0.44  | 102                            | 132     |
|      | Wrought aluminium parts /components    | NG                | BEV               | 2.04                                         | 7.85  | 160                            | 10,551  |
|      | Traction motor, induction based        | BEV               | BEV               | 0.26                                         | 0.26  | 349                            | 349     |
|      | Traction motor, permanent magnet based | HEV               | PHEV              | 0.26                                         | 0.32  | 536                            | 402     |
| 2030 | Battery management system              | HEV               | BEV               | 0.04                                         | 0.63  | 115                            | 1,169   |
|      | Catalytic converter                    | Diesel            | LPG               | <0.01                                        | <0.01 | 8.4                            | 0.33    |
|      | Electrical and electronic system       | NG                | BEV               | 0.96                                         | 1.24  | 97                             | 2,316   |
|      | Power electronics                      | HEV               | PHEV              | 0.11                                         | 0.18  | 294                            | 285     |
|      | Cast aluminium parts / components      | BEV               | Diesel            | 6.61                                         | 7.62  | 12,304                         | 111,697 |
|      | Magnesium parts / components           | BEV               | LPG               | 0.08                                         | 0.44  | 144                            | 153     |
|      | Wrought aluminium parts /components    | NG                | BEV               | 3.63                                         | 9.16  | 368                            | 17,040  |
|      | Traction motor, induction based        | BEV               | BEV               | 0.26                                         | 0.26  | 484                            | 484     |
|      | Traction motor, permanent magnet based | HEV               | PHEV              | 0.25                                         | 0.32  | 687                            | 506     |

Source: JRC elaboration, based on FutuRaM internal dataset. Catalytic converted included based on SH feedback. Note that Mass fraction of SCRM in waste generated refers to criterion 1 of the methodology, including the min and max value and targeted vehicle category; while SCRM losses refer to criterion 2 of the methodology (these losses correspond to the targeted vehicle category resulted from the min and max mass fraction).

Finally, the rationale for excluding specific components is detailed in **Table 23**.

**Table 23.** Rationale of the list of motor vehicle categories by components not included in the priority list.

| Motor vehicle category | Excluded components                                                                                                                                                                                                     |
|------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| All                    | <ul style="list-style-type: none"> <li>• <i>High strength steel</i>, and <i>mild steel</i> and cast iron have been excluded since iron and steel have not been classified as critical or strategic material.</li> </ul> |

Source: JRC elaboration.

#### 4.4.4 Further remarks on the resulting list – step 2 of the methodology for waste streams from group 1

##### 4.4.4.1 Legal coverage and legislation gaps (sub-paragraphs b and c, respectively)

A list of legislation coverage for ELV in the EU is provided in **Table 24**.

**Table 24.** Overview of legislative coverage related to ELV flow at EU level.

| Lifecycle phase     | Targeted flow – SCRM related/not related                                                                                                                                  | Legislation coverage                                                                                                                                                                                                                   | EU coverage                                                                                            |
|---------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|
| Place on the market | Product - M1 and N1 vehicles                                                                                                                                              | <b>Circularity vehicle passport</b> - a digital tool used to improve the provision of information on the safe removal and replacement of vehicle parts and components                                                                  | EU - Vehicle Regulation proposal (EU) 2023/0284/COD, Art.13                                            |
|                     | Component - permanent magnet in e-drive motors (traction motor)                                                                                                           | <b>Data carrier and labelling</b> - information on supplier, information on weight, location, etc., for place on the market product with permanent magnets (NdFeB, SmCo, AlNiCo)                                                       | EU - Vehicle Regulation proposal (EU) 2023/0284/COD, Art. 11 and its Annex V, and Art.12, and Annex VI |
|                     | Product - M1 and N1 vehicles                                                                                                                                              | <b>Reusability, recyclability, and recoverability</b> - minimum requirements on the reusability, recyclability and recoverability of vehicle types, specifying the rates to be achieved by each type                                   | EU - Vehicle Regulation proposal (EU) 2023/0284/COD, Art. 4                                            |
|                     | Material/element - permanent magnet, Al and alloys, Mg and alloys, (steel)                                                                                                | <b>Recycled content</b> - Declaration (by manufacturers) of recycled content and minimum recycled content, and potential targets related to CRM and SRM                                                                                | EU - Vehicle Regulation proposal (EU) 2023/0284/COD, Art. 10, and Art. 6                               |
| Use phase           | Component - Parts and components listed in Part C of Annex VII of the vehicle Regulation proposal, and electric vehicle (EV) batteries and e-drive motor (traction motor) | <b>Design for removability</b> - Design to not hinder removal of specific parts (list in Annex VII, part C), but to enable removal and replacement of certain parts and components in vehicles in a readily and non-destructive manner | EU - Vehicle Regulation proposal (EU) 2023/0284/COD, Art. 7 and Annex VII Part C                       |

| Lifecycle phase | Targeted flow – SCRM related/not related                                                                     | Legislation coverage                                                                                                                                                                                                                                                                                                                                                                                                                    | EU coverage                                                                                  |
|-----------------|--------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|
| End of life     | Components highlighted under EU 2023/0284, Annex VII Part C                                                  | <b>Mandatory removal of components</b> - removal (by authorised treatment facilities) of the parts and components listed in the mentioned                                                                                                                                                                                                                                                                                               | EU - Vehicle Regulation proposal (EU) 2023/0284/COD, Art. 30 and Annex VII Part C            |
|                 | Product - M1 and N1 vehicles                                                                                 | <b>Reuse, remanufacturing and refurbishment of parts and components</b> - MS to take necessary incentives to promote reuse, remanufacturing and refurbishment of parts and components, whether removed during use or end of life of a vehicle                                                                                                                                                                                           | EU - Vehicle Regulation proposal (EU) 2023/0284/COD, Art. 33                                 |
|                 | Product - M1 and N1 vehicles                                                                                 | <b>Reuse, recycling and recovery targets</b> - Minimum targets as percentage share (i.e., minimum reuse and recovery of 95% by average weight per vehicle, excluding batteries and year; minimum reuse and recycling of 85% by average weight per vehicle, excluding batteries and year)                                                                                                                                                | EU - Vehicle Regulation proposal (EU) 2023/0284/COD, Art. 34                                 |
|                 | Product - M1 and N1 vehicles                                                                                 | <b>Collection</b> - Collection systems and associated requirements of ELVs by producers, functioning of these systems by MSs                                                                                                                                                                                                                                                                                                            | EU - Vehicle Regulation proposal (EU) 2023/0284/COD, section 3, Art. 23 and Annex VII Part A |
|                 | Product - M1 and N1 vehicles                                                                                 | Shipment of the ELV                                                                                                                                                                                                                                                                                                                                                                                                                     | EU - Vehicle Regulation proposal (EU) 2023/0284/COD, Art. 36                                 |
|                 | Product - M1 and N1 vehicles                                                                                 | Controls and requirements on the export of used vehicles                                                                                                                                                                                                                                                                                                                                                                                | EU - Vehicle Regulation proposal (EU) 2023/0284/COD, Art. 38                                 |
|                 |                                                                                                              | Reporting to the Commission                                                                                                                                                                                                                                                                                                                                                                                                             | EU - Vehicle Regulation proposal (EU) 2023/0284/COD, Art. 49                                 |
|                 | Component - SLI, EV batteries, permanent magnet, Cu, electronic components, non-ferrous fractions (e.g. pcb) | <b>Treatment requirements of the removed parts, components, materials</b> - SLI and EV batteries as Art. 70 Batteries Regulation; permanent magnet materials containing Dy, Nd, Pr (i.e., NdFeB), Cu from traction motors, in case of lack of recycling, stock-piled and labelled in accordance with Regulation EU 2024/1252, Art.28(1); electronic components and nonferrous fractions (e.g., pcb) as Art.8(3) of Directive 2012/19/EU | EU - Vehicle Regulation proposal (EU) 2023/0284/COD, Annex VII Part F                        |

Source: JRC elaboration.

The Regulation on **circularity requirements for vehicle design and on management of end-of-life vehicles**, being the current new Regulation proposal (2023/0284), introduced a new set of requirements to increase the circularity of components and materials incorporated in vehicles, notably on SCRM. The proposal establishes obligations on collection (e.g. section 2 on collection of end-of-life vehicles, article 23) of ELVs, as well as obligations of ELVs delivery to authorised treatment facilities (article 24). Such obligations will contribute to reducing the share of undocumented flows, including illegal exports and *unknown whereabouts*, and thus to reducing the losses of SCRMs (criteria (i) above).

Afterwards, the Regulation proposal also provides measures to increase waste management operators' knowledge on components, materials and elements incorporated in vehicles, and this to further facilitate and enhance circular economy measures. This is inter alia article 7<sup>20</sup> or article 11<sup>21</sup> or article 12<sup>22</sup> on information to provide by OEMs to waste management operators, notably on SCRMs in components as electric vehicle batteries, or traction motors.

Then, to further facilitate recovery of materials, including SCRMs, a mandatory removal list of parts was included in Annex VII Part C (linked to article 30). In addition, this includes in principle the components highlighted in the shortlist above, except magnesium materials, as well as a more specified/defined list of components from electrical and electronic components, power electronics, and wrought/cast aluminium materials. Their specific removal is in general assessed against accessibility to the part and proportionality of the removal option. The magnesium materials were not included in the mandatory removal list, as this material can be incorporated very differently in different vehicle types, which makes difficult to specify and define a component in the legislative proposal.

#### **4.4.4.2 Challenges and existing systems for collection and treatment (sub-paragraphs d and e, respectively)**

The percentage of undocumented losses (see **Table 25**) have been calculated as *waste\_undocumented / waste generated* at the year of reference. The calculations are based on the data provided by FutuRaM ELV arbitrary waste stream. We noted that the share of undocumented losses is relatively consistent. For more information about the methodology behind the calculation of the undocumented losses, please see section 3.4.1.2.

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<sup>20</sup> Design to enable removal and replacement of certain parts and components in vehicles

<sup>21</sup> Information on removal and replacement of parts, components and materials present in vehicles

<sup>22</sup> Labelling of parts, components and materials present in vehicles

**Table 25.** Percentage of undocumented losses in waste generated at the year 2022 for each vehicle category.

| Waste stream   | % of the undocumented losses within the waste generated for 2022 |
|----------------|------------------------------------------------------------------|
| Petrol         | 33%                                                              |
| Diesel         | 37%                                                              |
| Other vehicles | 44%                                                              |
| HEV            | 35%                                                              |
| BEV            | 47%                                                              |
| PHEV           | 49%                                                              |
| NG             | 40%                                                              |
| LPG            | 27%                                                              |

Source: JRC elaboration, based on FutuRaM internal dataset.

#### 4.4.4.3 Further remarks on datasets availability and potential future recommendations

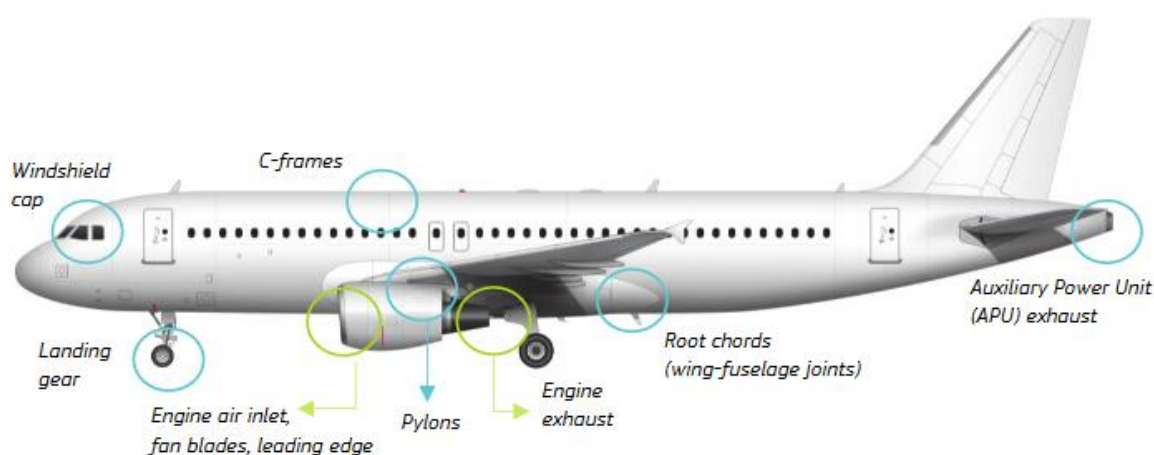
- **Electric (non-traction) motors and magnetic applications, containing REE magnets.** Data were not available for this component. Thus, it has been added based on expert opinions and the consultation of relevant stakeholders. It represents a tiny mass of small motors, and it has high dispersion in the car. However, proportionality shall be considered. Power assisted steering can contain permanent magnets but based on a recent ADEME study on PM recovery potential from ELV, it was noted that the likelihood of finding PMs in power assisted steering is only 44%.
- **Main wire harnesses, including, if present, internal and external charging cables** (if criteria under Annex VII part G of Regulation 2023/0284 are not met). Data were not available for this component. Thus, it has been added based on analogy with the forthcoming end of life vehicle Regulation (2023/0284/COD), expert opinions and the consultation of relevant stakeholders. Besides, their potential inclusion might be relevant also as an analogy with other waste streams where cables were highlighted (e.g. wind turbine).
- **Inverters, and converters.** Data were not available for this component. Thus, it has been added based on expert opinions and the consultation of relevant stakeholders. These components might be relevant in case of datasets available. Inverters and converters regroup significant SCRMs, mainly Al and Cu. For instance, a hybrid motor vehicle inverter contains circa 8 kg of Al and 1.2 kg of Cu (Umwelt Bundesamt 2017).
- **Fuel cell.** Data were not available for this component. Currently, the scenarios indicate that the quantity placed on the market will be very limited by 2030. It is suggested to include these components in the current priority list and further assess their relevancy in the future, based on the stakeholder consultation. Fuel cells are used in transport applications (vehicle, buses, trucks, etc.) and regroup several SCRMs (S Carrara et al. 2023).
- **Photovoltaic (PV) panels.** Data were not available for this component. These components might be relevant in case of datasets available and pending their high penetration in future vehicle fleets. PV panels were mentioned in the Annex VII part C of the new vehicle Regulation proposal for their future relevance. Thus, it is suggested to not include these components in the current priority list and further assess their relevance in the future.

- **Oxygen, radar and lidar sensors if present.** Data were not available for these components. Sensors in general were excluded from the assessment due to 1) low SCRM content compared with other components in a vehicle, 2) not technically and economically feasible to collect them from vehicles (long dismantling time) Small dimension, small quantities of precious metals, and in different parts of the vehicles. According to (Umwelt Bundesamt 2017) the oxygen sensors have for instance a mass of 73 g and the amount of SCRMs is relatively low, estimated to be respectively 0.6 g/kg and 0.3 g/kg of component for platinum and palladium, both parts of the platinum group metal. It is suggested to not include these components in the current priority list and further assess their relevance in the future.

#### 4.4.4.4 Additional contribution of the potential extension of vehicle scope

As mentioned in this section, FutuRaM dataset cover mainly M1 and N1 vehicles. However, from a SCRM perspective, the mobility sector includes also light mean of transport, bus, truck, airplane, rail and ship would in principle represent a relevant untapped potential for recoverable SCRMs. For instance, the ELVR SWD<sup>23</sup> is providing preliminary evidence on SCRM content in lorries, buses and motorcycles such as copper or permanent magnet. Titanium as an SRM is also widely used in civil aviation products, especially jetliners and can represent up to 5% of the airframe content (see **Figure 8** for titanium alloys distribution). The use of SCRMs in ships and shipbuilding is also common, such as titanium, aluminium, copper and tungsten for the structure and mechanical components, as well as copper and platinum group metals for electric and electronic devices (Stefanakis and Ioannis 2024).

**Figure 8.** Example of titanium alloys distribution in airplanes



Source: JRC elaboration, extracted from (Stefanakis and Ioannis 2024).

The electrification of mobility and the use of more connectivity applications (e.g. advanced driver assistance systems) are likely to increase in the future the share of SCRM content in all the mobility

<sup>23</sup> <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD%3A2023%3A256%3AFIN&qid=1689321960044>

sector. However, due to limited data availability, it was not possible to further assess products, components and materials to be potentially highlighted in this assessment. Considering the relevance of the mobility sector, it could be relevant, in the future, to extend the priority list to bus, truck, airplane, ship, and rail, and this by analogy to the SCRM content in M1 and N1 vehicles.

#### **4.4.5 Key messages for motor vehicle waste stream**

##### **(a) SCRM data and elaboration**

Petrol and Diesel vehicles present a high SCRM recovery potential since they continue to produce the highest volumes of wastes and present high SCRM losses. And this trend will be maintained until 2030, with diesel overpassing petrol in the waste generation and the SCRM losses. Electrified powertrains (HEV, PHEV and BEV) also show continuous increase in SCRM to be generated from 2022 to 2030, while BEV vehicles are expected to contain moderate SCRM losses and the highest mass fraction of SCRM in all electrified powertrains. As for LPG and NG vehicles, they show comparatively lower SCRM losses compared to other vehicle categories, with also low concentrations of SCRM. Concerning components, wrought aluminium parts /components, and cast aluminium parts/components present the highest SCRM losses (mainly Al) presenting both a relative high concentration of SCRM within this waste stream, and also electric and electronic system (with Cu, Nd, La and Dy) present relevant SCRM losses.

##### **(b) What is covered (legislation)**

The forthcoming Regulation (EU) related to vehicle circularity (2023/0284) introduces life-cycle based requirements targeting inter-alia declaration and use of recycled content, vehicle circularity strategy, design to enable removal and replacement of parts and components, as well labelling of CRM rich parts and components such as the e-drive (traction) motors with permanent magnets. It also introduces end of life requirements related to collection, depollution, mandatory removal prior to shredding as well recovery and recycling targets. The forthcoming legislative framework is expected to significantly improve the circularity of vehicles as well as waste management operations (collection, recovery, recycling and traceability). The Union legislative framework covers all materials, including SCRM rich parts and components for the targeted vehicle scope.

##### **(c) Legislation gaps**

It is still unclear what would be the remaining legislative gaps once the forthcoming vehicle circularity regulation enters into force. However, traceability of SCRM and their tracking at end of life already appears as key challenges within the forthcoming regulation, and even more if no harmonised reporting is in place. Undocumented losses and a wide and robust producer extended responsibility would be operational challenges that need to be further assessed. Furthermore, the forthcoming regulation scope is limited to specific vehicle categories, and circularity requirements

##### **(d) Existing systems**

Relatively high undocumented losses are consistent in all ELV categories (between 27% and 49%). High SCRM losses are generally associated with downcycling SCRM rich parts and components that are not targeted in the current waste management system. For instance, separate collection and recovery of wrought and cast Al alloys are not widespread within the automotive recycling industry, nor the recovery of cables and electrical equipment and components prior to shredding.

### **(e) Challenges**

The major challenge is related to undocumented flow and unknown whereabouts, especially vehicle categories with high SCRMs content such as diesel, petrol and electrified powertrains (HEV, PHEV and BEV). Exports of ELVs outside the EU contribute significantly to these unknown flows. Besides, electrified powertrains are relatively new in the EU market and waste management operators lack historical data and potential knowledge to effectively collect and recover SCRMs from targeted parts and components. Finally, ensuring traceability and enforcement of circularity and export of ELVs across EU MSs remain uneven. It is also still not clear how authorised treatment facilities and recyclers would collect and recover permanent magnets from ELVs, as reporting for monitoring related to these materials, parts and components is not established in the current system.

## 4.5 Results for SLAGs, sludges and ASHes (SLASH) for the Article 26 of the CRMA

The list of slag, sludge and ashes waste streams to be prioritised is reported hereinafter:

- (a) Sewage sludge from urban wastewater treatment;
- (b) Bottom and fly ashes resulting from the mono-incineration of sludges from the treatment of urban wastewater;
- (c) Bottom ashes from municipal solid waste incineration;
- (d) Bottom ashes from commercial or industrial waste incineration.

### 4.5.1 Scope and background data

SLASH refers to SLAGs, sludges and ASHes. It is essential to regard SLASH as a heterogeneous group of materials that possess limited economic value. These materials cannot be allocated to specific products or components. Within this context, FutuRaM selected particular waste streams and reported them under the corresponding List of Waste (LoW) code, as per the European Waste Catalogue (EWC), rather than examining all wastes assigned to specific LoW codes. The analysis encompassed both hazardous waste (identified by an asterisk) and non-hazardous waste. **Table 26** presents all the waste streams included in this analysis, along with their respective EWC codes.

**Table 26.** Waste streams and their European Waste Catalogue (EWC) codes under SLASH that were included in the analysis for the Art. 26 priority list.

| Waste code   | Description                                                                                                                                                                                                 |
|--------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>10 01</b> | <b>Wastes from power stations and other combustion plants (except 19)</b>                                                                                                                                   |
| 10 01 01_B   | Bioenergy (pure biomass incineration)                                                                                                                                                                       |
| 10 01 01_C   | Coal                                                                                                                                                                                                        |
| 10 01 02     | Coal fly ash                                                                                                                                                                                                |
| 10 01 03     | Fly ash from peat and untreated wood                                                                                                                                                                        |
| 10 01 15     | Bottom ash, slag and boiler dust from co-incineration other than those mentioned in 10 01 14                                                                                                                |
| 10 01 15_A   | Agricultural waste (e.g., energy crops and agricultural wastes including wheat straw, rice husk, groundnut shell)                                                                                           |
| 10 01 15_B   | Biowaste (e.g., animal manure, sewage sludges and food waste). Please consider that the definition of biowaste in this context is broader than the definition provided by the EU Waste Framework Directive. |
| 10 01 17     | Fly ash from co-incineration other than those mentioned in 10 01 16                                                                                                                                         |
| 10 01 17_A   | Agricultural waste (e.g., energy crops and agricultural wastes including wheat straw, rice husk, groundnut shell)                                                                                           |
| 10 01 17_B   | Biowaste (e.g., animal manure, sewage sludges and food waste). Please consider that the definition of biowaste in this context is broader than the definition provided by the EU Waste Framework Directive. |
| <b>10 02</b> | <b>Wastes from the iron and steel industry</b>                                                                                                                                                              |
| 10 02 02     | Unprocessed slag                                                                                                                                                                                            |
| <b>10 03</b> | <b>Wastes from aluminium thermal metallurgy</b>                                                                                                                                                             |
| 10 03 04*    | Primary production slags                                                                                                                                                                                    |
| 10 03 08*    | Salt slags from secondary production                                                                                                                                                                        |
| <b>10 04</b> | <b>Wastes from lead thermal metallurgy</b>                                                                                                                                                                  |
| 10 04 01*    | Slags from primary and secondary production                                                                                                                                                                 |

| Waste code   | Description                                                                 |
|--------------|-----------------------------------------------------------------------------|
| <b>10 05</b> | <b>Wastes from zinc thermal metallurgy</b>                                  |
| 10 05 01     | Slags from primary and secondary production                                 |
| <b>10 06</b> | <b>Wastes from copper thermal metallurgy</b>                                |
| 10 06 01     | Slags from primary and secondary production                                 |
| <b>11 02</b> | <b>Wastes from non-ferrous hydrometallurgical processes</b>                 |
| 11 02 02*    | Sludges from zinc hydrometallurgy (including jarosite, goethite)            |
| <b>19 01</b> | <b>Wastes from incineration or pyrolysis of waste</b>                       |
| 19 01 11*    | Bottom ash and slag containing hazardous substances                         |
| 19 01 12     | Bottom ash and slag other than those mentioned in 19 01 11 – sewage sludges |
| 19 01 13*    | Fly ash containing hazardous substances                                     |
| 19 01 14     | Fly ash other than those mentioned in 19 01 13 – sewage sludges             |

Source: JRC elaboration. Note that the overarching waste is in bold.

#### 4.5.1.1 Composition

Within the FutuRaM project, co-incineration ashes comprise all ashes derived from the combustion of wood biomass, agricultural biomass, animal waste, and industrial sludge (including paper sludge). However, it is noteworthy that not all co-incineration types are encompassed within this scope. Sewage sludges fall within the SLASH remit due to their potential for phosphorus recovery. Indeed, in addition to the phosphorus retained in the biogeochemical cycle through the reuse or recycling of sewage sludges, mono-incineration serves as an effective thermal treatment method for recovering phosphorus. Data were sourced from Eurostat and subsequently elaborated upon by the FutuRaM project. Specifically, the composition of fly ashes was derived from the studies conducted by (Moreno et al. 2005; Franus, Wiatros-Motyka, and Wdowin 2015). The composition of bottom ashes, on the other hand, was obtained from the RIS-ALiCE Registry of secondary mineral raw materials<sup>24</sup>.

#### 4.5.1.2 Stock and flow model

The data calculations are based on the FutuRaM project (see **Table A12** of **Annex VI** for more information). However, the availability of data on volumes and composition for SLASH is limited, which complicates the derivation of representative numbers for individual MSs. As a result, the data and derived results are subject to a high degree of uncertainty, with a root mean square error (RMSE) exceeding 50%.

### 4.5.2 List of slag, sludge and ashes waste streams to be prioritised

The list of slag, sludge and ashes waste streams to be prioritised is reported hereinafter:

- Sewage sludge from urban wastewater treatment.
- Bottom and fly ashes resulting from the mono-incineration of sludges from the treatment of urban wastewater.

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<sup>24</sup> <https://www.alice-registry.eu/>

- Bottom ashes from municipal solid waste incineration.
- Bottom ashes from commercial or industrial waste incineration.

The list for the SLASH is obtained based on the following steps, namely:

1. Determination of the waste stream composition for EU27+4 (aggregated) based on a comprehensive review of scientific literature and industry association data.
2. Determination of the yearly production of the waste stream for each EU27+4 MSs based on Eurostat data or production volumes (economic data).
3. Recovery potential of SCRM from the waste stream is estimated by comparing the waste stream grade<sup>25</sup> of the target SCRM with the primary ore grade of each SCRM. If the waste stream grade is similar to or higher than that of the primary ore, extraction of the element may be economically viable. However, it is essential to consider the overall composition of the waste stream, as other elements may complicate the extraction process or introduce contaminants.
4. Expert judgement determines the final prioritised list based on:
  - (a) waste stream grade;
  - (b) the most probable form of the critical raw materials (and elements) in the waste stream (*e.g.*, metallic, oxide or alloy);
  - (c) waste production by year (current and future);
  - (d) current recovery routes available in the industrial state-of-the-art; and
  - (e) alternative uses of each waste stream (*e.g.*, cement replacer).

It is worth noting that some SLASH waste streams (*e.g.*, ashes from waste incineration) can contain a wide range of elements, representing a significant portion of the periodic table. Consequently, expert knowledge is required to assess their recoverability potential. The waste streams considered for inclusion in the Article 26 list for SLASH are presented in **Table 27**, which is comprised of specific waste stream-SCRM couples<sup>26</sup>. All the other waste streams, along with the mapped SCRM present, that are excluded from the priority list, are summarised in **Table 28**.

The data used to evaluate the eligibility of each waste stream for inclusion in the list are reported as aggregated figures in **Table 29**, along with the rationale for determining the waste stream's eligibility.

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<sup>25</sup> Grade is used in the mining industry to describe the concentration of the target element inside ores.

<sup>26</sup> SLASH consists of many waste streams that are unrelated. Hence, the priority list contains a list of waste streams, with each a sub-list of critical materials with a high recovery potential from said waste stream.

**Table 27.** Waste stream-SCRM couples to be included on the Art. 26 priority list.

| Waste sub-stream                                                                                                                    | SCRM                             |
|-------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|
| Sewage sludge from urban wastewater treatment                                                                                       | P (through biogeochemical cycle) |
| Bottom and fly ashes resulting from the mono-incineration of sludges from the treatment of urban wastewater (19 01 12 and 19 01 14) | P                                |
| Bottom ashes from municipal solid waste incineration (19 01 11*)                                                                    | Cu, Al (Ni, PGMs, Mg)            |
| Bottom ashes from commercial or industrial waste incineration (by analogy with 19 01 11*)                                           | Cu, Al (Ni, PGMs, Mg)            |

Source: JRC elaboration, based on FutuRaM internal dataset.

**Table 28.** Waste streams to be excluded from the Art. 26 priority list.

| Waste sub-stream                                                                                                                               | SCRM                     |
|------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|
| Wastes from power stations and other combustion plants – 10 01 XX. The individual entries XX covered by the analysis are reported in Table 26. | -                        |
| Wastes from lead thermal metallurgy – 10 01 04*                                                                                                | Cu, Sb, Bi               |
| Wastes from the iron and steel industry – 10 02 02                                                                                             | Cr, V, Ti                |
| Wastes from aluminium thermal metallurgy – 10 03 XX                                                                                            | -                        |
| Wastes from zinc thermal metallurgy – 10 05 01                                                                                                 | -                        |
| Wastes from copper thermal metallurgy – 10 06 01                                                                                               | Ni, PGMs, Pb (Cu and Co) |
| Sludges from zinc hydrometallurgy – 11 02 02*                                                                                                  | Cu, In, Ge, Ga           |
| Wastes from incineration or pyrolysis of waste – 19 01 13*                                                                                     | -                        |

Source: JRC elaboration, based on FutuRaM internal dataset. Note that hyphen (-) denotes that there is no relevant SCRM in the associated waste sub-stream.

#### 4.5.3 Rationale of the list of waste streams included and not included in the priority list – step1 of the methodology for waste streams from group 2

The rationale for including specific waste streams in the resulting list for the SLASH stream (**Table 29**) considers the different aspects as detailed in the workflow in Section 4.5.2. The rationale for excluding specific waste products and components is detailed in **Table 30**.

**Table 29.** Rationale of the list of SLASH included in the priority list.

| Waste sub-stream                              | SCRM included | Rationale for inclusion                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|-----------------------------------------------|---------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Sewage sludge from urban wastewater treatment | P             | <p>According to FutuRaM research, the generation of sewage sludge in 2022 was approximately 7,414,925 Mg/year in dry matter, which is nearly identical to the value reported in 2011, but represents a decrease of 6.8% compared to 2018. Several possible reasons for this reduction in sewage sludge generation include:</p> <ul style="list-style-type: none"> <li>- The expansion and increased efficiency of anaerobic sludge stabilisation.</li> <li>- The use of grit or grease traps in wastewater treatment plants.</li> <li>- A trend towards abandoning small sewage treatment plants and connecting the affected residents to larger, centrally located sewage treatment plants, which have better treatment technology).</li> <li>- Industrial plants that previously discharged indirectly into the sewage collection system have also optimised their production processes, for instance, by decreasing the load through in-house pre-treatment/purification or adopting alternative recycling methods for specific organic-rich waste or by-products from production.</li> </ul> <p>The routes of sewage sludges utilisation and disposal in EU MSs indicate that approximately 31.2% of the material is used in agricultural land, 21.7% in compost and other applications, 31.4% in thermal treatment, 4.0% in landfills, and 11.7% in other disposal (according to EUROSTAT, national reports). When sewage sludge data was not available in EUROSTAT, information from the national reports of 12 countries was used.</p> <p>The direct application of sewage sludge, possibly following a sanitation treatment, is a common practice that can reduce the use of primary phosphate rock. The total phosphorus content in land-spread sewage sludge amounts to approximately 5% of the phosphorus mineral fertiliser inputs to EU agricultural land.</p> <p>Some EU MSs have increased or predominantly utilised agricultural land and compost and other applications, such as Bulgaria, Czech Republic, Denmark, Estonia, Ireland, Spain, France, Italy, Lithuania, Hungary, Portugal, Slovakia, Finland, and Sweden. In contrast, other countries have developed the industry of sewage sludge thermal treatment, such as Germany, The Netherlands, Austria, and Belgium, based on FutuRaM research.</p> <p>There is no clear European tendency towards incineration alone. The phosphorus recycling target to be adopted within the Urban Wastewater Treatment Directive 2024/3019 should encompass the direct application of sewage sludge, possibly following a certain sanitation treatment. However, the presence of pollutants in sewage sludge, such as heavy metals, micro/nano plastics, medicaments, micropollutants, and other chemicals, including per- and polyfluoroalkyl substances (PFAS), poses a challenge. Implementing actions to better monitor and reduce pollution at source from non-domestic discharges will contribute to improving the quality of the sludge produced and ensuring its safe use in agriculture.</p> <p>Beyond the phosphorus retained in the biogeochemical cycle through reuse or recycling of sewage sludges, mono-incineration is a valuable thermal treatment for recovering phosphorus. The phosphorus content in the ash is crucial for determining the product-specific production costs and, thus, the economic efficiency of the recovery processes.</p> |

| Waste sub-stream                                                                                                                                  | SCRM included | Rationale for inclusion                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|---------------------------------------------------------------------------------------------------------------------------------------------------|---------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                   |               | This waste sub-stream has been included through to the stakeholder feedback loop.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Bottom and fly ashes resulting from the mono-incineration of sludges from the treatment of urban wastewater (respectively, 19 01 12 and 19 01 14) | P             | <p><b>Bottom ashes resulting from the mono-incineration of sludges from the treatment of urban wastewater (19 01 12):</b></p> <p>The estimated quantity of dry matter was 541,039 tonnes in 2022, as derived from EUROSTAT data. The phosphorus content of these ashes, with a weighted average of 28.8 g/kg sewage sludge in dry matter across the 27 EU countries in 2022, renders them a viable substitute for phosphorus (P) fertilizers derived from phosphate rock. However, phosphorus recovery as a fertilizer is only feasible if the sludges are processed in dedicated mono-incinerators.</p> <p>The potential for phosphorus recovery from sewage sludges is significant, as demonstrated by a case study, which indicated that Germany could produce 8.4% of the EU's phosphorus demand for fertilizers if all sewage sludges in Germany were to be processed via mono-incineration. Nevertheless, the costs associated with establishing mono-incineration facilities for all sewage sludges and subsequent processing remain to be determined.</p> <p><b>Fly ashes resulting from the mono-incineration of sludges from the treatment of urban wastewater (19 01 14):</b></p> <p>The estimated quantity in dry matter was 388,709 tonnes in 2022. Phosphorus can be recovered from sewage sludge mono-incineration fly ashes using fluidised bed technology. In fluidised bed incinerators, approximately 95% of the ash is captured as fly ash in the dust collector after the post-combustion zone, whereas fluidised bed systems produce minimal to no bottom ash (around 5% or less).</p> <p>Although phosphorus is the primary focus in fluidised bed technology for sewage sludge mono-incineration, the potential for recovering other valuable materials, such as certain heavy metals, also exists. However, the feasibility and economic viability of extracting these metals depend on their concentrations and the specific technologies employed.</p> <p><b>Co-incineration of sewage sludges with other wastes</b> often results in contaminated ash, which would pollute the soil if used as a soil improver. Consequently, these co-incineration ashes are frequently unsuitable for subsequent phosphorus recovery. Currently, phosphorus recovery from co-incineration ashes is not (economically or technically) viable, thus <u>not included</u> in the priority list.</p> |

| Waste sub-stream                                                                                                                                 | SCRM included         | Rationale for inclusion                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|--------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Bottom ashes from municipal solid waste incineration (19 01 11*) and</p> <p>Bottom ashes from commercial or industrial waste incineration</p> | Cu, Al (Ni, PGMs, Mg) | <p><b>Bottom ashes from municipal solid waste incineration (19 01 11*)</b></p> <p>As stated in the Bottom Ash Factsheet published by the Confederation of European Waste-to-Energy Plants (CEWEP) “In 2018, around 96 million tonnes of waste (municipal, commercial and industrial) were treated in Waste-to-Energy plants in Europe. The combustion process produced approximately 19 million tonnes of bottom ash, which is the in-combustible residual part of the incinerated waste. Important quantities of metals and minerals are present in these residues and offer many opportunities for recycling”<sup>27</sup>.</p> <p>Annually, approximately 18.7 million tonnes of municipal waste incineration bottom ashes (MWIBA) are generated, containing roughly 2-5 wt% recoverable non-ferrous metals, with Al accounting for approximately two-thirds of this content<sup>28</sup>. The recovery of Al and Cu is already extensively implemented in some MSs, such as Belgium and the Netherlands, demonstrating the availability of the necessary technology.</p> <p>Estimates for the EU27+4 region indicate that, in 2021, 223.2 kt of Al and 39.21 kt of Cu were recovered from 9 Mt of MWIBA. However, if the landfill and waste directive targets were met, 3.15 Mt of additional ashes would have been produced, and if all ashes were to be fully processed (50-2 mm fraction), up to an additional 430 kt of Al and 150 kt of Cu could have been recovered from 21.8 million tonnes of MWIBA in 2021 (note that these numbers present high uncertainty and are based in optimistic scenarios). This highlights the substantial potential for recovery of these metals, which are currently largely lost in landfills.</p> <p>Al and Cu collectively account for approximately 60% of the SCRM content that can be recovered today. Other metals, such as Mg, Ni, and platinum group metals (PGMs), which comprise 16.6 wt% of the total SCRM content, are also recovered to some extent, either as alloying elements or through secondary streams (e.g., PGMs from copper slimes). However, the exact quantities of these metals that can be recovered were not estimable within the scope of the FutuRaM project.</p> <p>To address this, a proportional target based on the actual measured Al and Cu content in the mixed waste of each individual MS could be considered. From this content, 30% of Al and 40% of Cu should be recovered, with these percentages potentially increasing over time (up to 65% of Cu and 50% of Al, which seems feasible with current state-of-the-art technology).</p> |

<sup>27</sup> Available at: <https://www.cewep.eu/wp-content/uploads/2017/09/FINAL-Bottom-Ash-factsheet.pdf>

<sup>28</sup> Bunge, R. 2019. Recovery of Metals from Waste Incinerator Bottom Ash. Available online: [https://www.umtec.ch/fileadmin/user\\_upload/umtec.hsr.ch/Dokumente/Metals\\_from\\_MWIBA\\_6\\_2019.pdf](https://www.umtec.ch/fileadmin/user_upload/umtec.hsr.ch/Dokumente/Metals_from_MWIBA_6_2019.pdf) (accessed on 30 March 2020).

| Waste sub-stream | SCRM included | Rationale for inclusion                                                                                                                                                                                   |
|------------------|---------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                  |               | By analogy with 19 01 11*, <b>bottom ashes from commercial or industrial waste incineration</b> are also considered within the scope of the Art.26 priority list, based on the stakeholder feedback loop. |

Source: JRC elaboration, based on FutuRaM internal dataset.

Finally, the rationale for excluding specific waste sub-streams is detailed in **Table 30**.

**Table 30.** Rationale of the list of SLASH not included in the priority list.

| Waste sub-stream                                                                                                                                              | SCRMs included | Rationale for exclusion                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 10 01 XX. The individual entries "XX" covered by the analysis are reported in <b>Table 26</b> .<br><br>Wastes from power stations and other combustion plants | -              | Approximately 10-12 million tonnes of ashes are generated annually, representing a relatively small volume. However, the recovery of phosphorus (P) as a fertiliser is not feasible due to the hazardous nature of these ashes. Furthermore, the particle size of these ashes is too small to enable further processing. The presence of silicates in these ashes also poses a challenge, as they can produce silica gel in acidic environments, rendering leaching impossible. Nevertheless, these ashes have been found to be excellent substitutes for cement, thereby potentially reducing the carbon footprint of concrete production.                                                                                                                                                                                                                                   |
| 10 02 02<br>Wastes from the iron and steel industry                                                                                                           | Cr, V, Ti      | In 2022, the EU27 produced approximately 9.6 million tonnes of unprocessed slag from Basic Oxygen Furnace (BOF) steel production. A distinction needs to be made between slags generated from primary production and those from secondary production.<br><br><b>Slag generated from primary steel production:</b><br><br>In the primary steel production process, the first step involves reducing iron ore to pig iron in a blast furnace, resulting in the generation of blast furnace slag as a by-product. This slag, when rapidly cooled (granulated) and ground, becomes Ground Granulated Blast Furnace Slag (GGBFS), which is widely used as a supplementary cementitious material (SCM). The next step involves refining the pig iron to steel in an oxy-steel furnace, such as a Basic Oxygen Furnace (BOF) or a Linz-Donawitz (LD) furnace, generating steel slag, |

| Waste sub-stream                                                    | SCRMs included | Rationale for exclusion                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|---------------------------------------------------------------------|----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                     |                | <p>commonly referred to as BOF or LD slag. Generally, these types of slags do not contain high amounts of SCRMs. Research is ongoing to explore the potential use of these materials as cement replacers.</p> <p>Due to the relatively low SCRm content in these slags, this stream is <u>not included</u> in the priority list.</p> <p><b>Slag generated from secondary steel production:</b></p> <p>In contrast, the EU27 generated approximately 9.8 million tonnes of unprocessed slag from Electric Arc Furnace (EAF) steel production in 2022. The recycling of steel from scrap is typically carried out in EAFs, resulting in the production of EAF slag. To produce stainless steels, alloying elements such as Cr, Ni, and Mo are added during the secondary steelmaking processes, which are performed in EAFs, Argon Oxygen Decarburisation (AOD) furnaces, or ladles. A portion of these alloying metals ends up in the slag, resulting in EAF slags with higher concentrations of SCRMs, including Cr, V, and Ti, which could potentially be recovered.</p> <p>However, this stream is <u>not included</u> in the list at present, as there are no viable techniques available for SCRm recovery (low TRL)</p> |
| 10 01 04* Wastes from lead thermal metallurgy                       | Cu, Sb, Bi     | <p>These SCRMs are already recovered from this waste stream today as it is both economically and technically feasible. However, to determine the full potential for further recovery, a more detailed examination of the stocks and flows within the EU is required, particularly to quantify the current losses.</p> <p>As the remaining potential for recovery is considered unlimited, this stream <u>does not warrant inclusion</u> in the priority list.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 10 03 04* and 10 03 08*<br>Wastes from aluminium thermal metallurgy | -              | <p>According to available data, approximately 39 kilo tonnes of primary production dross were generated in the EU27 in 2021. Aluminium metallurgy produces two types of dross: white dross, which is a primary aluminium slag, and black dross, which is a slag resulting from aluminium recycling. Both types of dross are rich in aluminium.</p> <p>White dross typically contains 40-80 wt% aluminium and is almost entirely processed alongside aluminium scrap in recycling facilities for further aluminium recovery, resulting in negligible losses. In contrast, black dross is classified as hazardous waste and contains 5-25 wt% aluminium. The Landfill Directive (1999/31/EC) prohibits the landfilling of untreated hazardous waste, while the Waste Framework Directive (2009/98/EC) encourages the treatment of both black and white dross due to their high aluminium content.</p> <p>Therefore, no significant volumes of black dross remain available for further SCRMs recovery within the EU27+4, as the existing regulatory framework ensures that these materials are prioritised for treatment and recycling. Consequently, waste stream is <u>not included</u> in the priority list.</p>            |

| Waste sub-stream                                | SCRMs included           | Rationale for exclusion                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|-------------------------------------------------|--------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 10 05 01<br>Wastes from zinc thermal metallurgy | -                        | Currently, no data is available for this stream. However, it is worth noting that only zinc sludges are considered relevant in this context, due to the limited pyrometallurgical production of zinc in the EU. Globally, approximately 90% of zinc production occurs via the hydrometallurgical pathway. Within the EU, there is no notable pyrometallurgical zinc capacity, which further limits the potential for zinc dross generation. Most secondary zinc is obtained from fly ashes generated during the recycling of galvanized steel and brass, which accounts for around 75% of all zinc usage. The zinc oxide (ZnO) present in these fly ashes is typically recovered via hydrometallurgy, often in conjunction with primary zinc production. The low melting point of zinc results in minimal dross formation during die casting and semi-fabrication processes, which account for approximately 18% of all zinc usage. As a result, the potential for significant zinc dross generation and subsequent recovery of SCRMs from this stream is limited. Therefore, this stream is <u>not included</u> in the priority list. |
| 10 06 01 Wastes from copper thermal metallurgy  | Ni, PGMs, Pb (Cu and Co) | Approximately 5 million tonnes of slags from primary and secondary copper thermal metallurgy were generated in the EU27 in 2021. Ni, Pb, and PGMs are already being recovered from this waste stream, as it is both economically and technically feasible, with a high TRL. However, to determine the full potential for further recovery, a more detailed examination of the stocks and flows within the EU is required, particularly to quantify the current losses. This will help to identify opportunities for increasing the recovery of these critical raw materials. Due to the unlimited remaining potential for recovering Ni, Pb, and PGMs from this stream, it does <u>not warrant inclusion</u> in the priority list. Nevertheless, it is worth noting that some end-slags from this process can be relatively rich in Cu and Co. Although the recovery of these metals is technically possible, it is currently not economically viable due to the high energy demand associated with the process.                                                                                                                       |
| 11 02 02* Sludges from zinc hydrometallurgy     | Cu, In, Ge, Ga           | Approximately 1.5 million tonnes of sludges from zinc hydrometallurgy, including jarosite and goethite, were generated in the EU27 in 2021. The SCRMs present in this waste stream are either already being recovered, as it is both economically and technically feasible, or are still at a TRL that does not indicate significant recycling capacity within the next 10-15 years. To determine the full potential for further recovery, a more detailed examination of the stocks and flows within the EU is required, particularly to quantify the current losses. However, due to the relatively low TRL of the current available technologies, this stream does <u>not warrant inclusion</u> in the priority list.                                                                                                                                                                                                                                                                                                                                                                                                               |
| 19 01 13*                                       | -                        | The volume of this waste stream is negligible, with only approximately 2 tonnes generated in the EU27+4 in 2021. This stream poses the same technical challenges as the 10 01 XX waste stream.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

| Waste sub-stream                               | SCRMs included | Rationale for exclusion                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|------------------------------------------------|----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Wastes from incineration or pyrolysis of waste |                | The complex mixture of numerous metals present in this waste stream significantly increases the cost of hypothetically extracting SCRMs. Furthermore, this waste stream has relatively high concentrations of hazardous substances, including Hg, Zn, Cd, and Pb, which renders it a hazardous waste. The presence of these hazardous substances also prevents the direct recovery of P as a fertilizer, due to the potential risks associated with its use. Therefore, this stream is <u>not included</u> in the priority list. |

Source: JRC elaboration, based on FutuRaM internal dataset. Note that hyphen (-) denotes that there is no relevant SCRm in the associated waste sub-stream.

#### 4.5.4 Further remarks on the resulting list – step 2 of the methodology for waste streams from group 2

##### 4.5.4.1 Legal coverage and legislation gaps (sub-paragraphs b and c, respectively)

A list of legislation coverage for SLASH in the EU or national legislations is provided in **Table 31**.

**Table 31.** Overview of legislative coverage related to SLASH flows at EU and/or national levels.

| Life cycle phase | Targeted flow – SCRM related/not related        | Legislation coverage                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | National / EU                                                    |
|------------------|-------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|
| End of life      | Ashes                                           | For certain recovered wastes, such as struvite, biochar and ash-based products, within the meaning of Directive 2008/98/EC of the European Parliament and of the Council (8), a market demand for their use as fertilising products has been identified. Furthermore, certain requirements are necessary for the waste used as input in the recovery operation and for the treatment processes and techniques, as well as for fertilising products resulting from the recovery operation, to ensure that the use of those fertilising products does not lead to overall adverse environmental or human health impacts                                                                                                                                                                                                                                                                                                                                 | Fertilising Products Regulation (2019/1009)                      |
|                  | Generic waste (including municipal solid waste) | <b>Re-use and Recycling</b><br>In order to comply with the objectives of this Directive, and move towards a European recycling society with a high level of resource efficiency, Member States shall take the necessary measures designed to achieve the following targets:<br>(a) by 2020, the preparing for re-use and the recycling of waste materials such as at least paper, metal, plastic and glass from households and possibly from other origins as far as these waste streams are similar to waste from households, shall be increased to a minimum of overall 50 % by weight;<br>(b) by 2020, the preparing for re-use, recycling and other material recovery, including backfilling operations using waste to substitute other materials, of non-hazardous construction and demolition waste excluding naturally occurring material defined in category 17 05 04 in the list of waste shall be increased to a minimum of 70 % by weight. | Waste framework directive 2008/98/EC - Art.11(2)                 |
|                  | Generic waste (including municipal solid waste) | <b>Disposal</b><br>Member States shall ensure that, where recovery in accordance with Article 10(1) is not undertaken, waste undergoes safe disposal operations which meet the provisions of Article 13 on the protection of human health and the environment                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Waste framework directive 2008/98/EC - Art.12                    |
|                  | Incineration plants                             | <b>Applications for permits</b> – measures for the prevention, preparation for re-use, recycling and recovery of waste generated by the installation;                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | EU - Industrial Emissions Directive (2010/75/EU), Art.11 (h)     |
|                  | Ashes                                           | <b>Residues</b><br>1. Residues shall be minimised in their amount and harmfulness. Residues shall be recycled, where appropriate, directly in the plant or outside.<br>3. Prior to determining the routes for the disposal                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | EU - Industrial Emissions Directive (2010/75/EU), Art. 53 (1, 3) |

| Life cycle phase | Targeted flow – SCRM related/not related       | Legislation coverage                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | National / EU                                                       |
|------------------|------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------|
|                  |                                                | or recycling of the residues, appropriate tests shall be carried out to establish                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                     |
|                  | Residues from incineration and co-incineration | <b>Applications for permits</b><br>c) the residues will be minimised in their amount and harmfulness and recycled where appropriate;<br>(d) the disposal of the residues which cannot be prevented, reduced or recycled will be carried out in conformity with national and Union law.                                                                                                                                                                                                                                                                                                                                                                                                                                             | EU - Industrial Emissions Directive (2010/75/EU), Article 44 (c, d) |
|                  | Slag and bottom ashes                          | <b>Operating conditions</b><br>Waste incineration plants shall be operated in such a way as to achieve a level of incineration such that the total organic carbon content of slag and bottom ashes is less than 3 % or their loss on ignition is less than 5 % of the dry weight of the material. If necessary, waste pre-treatment techniques shall be used.                                                                                                                                                                                                                                                                                                                                                                      | EU - Industrial Emissions Directive (2010/75/EU), Art. 50 (1)       |
|                  | Slag and bottom ashes                          | Waste incineration plants shall be operated in such a way as to achieve a level of incineration such that the total organic carbon content of slag and bottom ashes is less than 3 % or their loss on ignition is less than 5 % of the dry weight of the material. If necessary, waste pre-treatment techniques shall be used.                                                                                                                                                                                                                                                                                                                                                                                                     | Industrial Emissions Directive (2010/75/EU) - Art 50 (1)            |
|                  | Treatment of slags and ashes                   | Activities under scope of the Industrial emissions directive.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Industrial Emissions Directive (2010/75/EU) - Annex I (5.3)         |
|                  | Recovery of Phosphorus from sludge             | To ensure the proper and safe recovery of nutrients, including the critical substance phosphorus, from sludge, a minimum combined reuse and recycling rate should be set at Union level. Member States should be able to choose whether to reuse or recycle, or both, urban wastewater or sludge, or both, to recover phosphorus. The combined minimum reuse and recycling rate should consider the phosphorus content of sludge, which can vary from one area to another. It should also consider the level of saturation of each national market, for example the availability of other sources of phosphorus from organic sources, for instance from livestock farming, and the possibilities of its absorption in agriculture. | Urban Wastewater Treatment Directive (EU) 2024/3019                 |
|                  | Recovery of phosphorus from wastewater         | By way of derogation from paragraphs 3 and 5, Member States may decide that an individual urban wastewater treatment plant situated in an area included in the list referred to in paragraph 2 is not to be subject to the requirements set out in paragraphs 3 and 5 where it can be shown that the minimum percentage of reduction of the overall load entering all urban wastewater treatment plants in that area is: (a) at least 75 % for total phosphorus and at least 75 % for total nitrogen from 1 January 2025; (b) 82,5 % for total phosphorus and 80 % for total nitrogen by 31 December 2039; (c) 87,5 % for total phosphorus and 82,5 % for total nitrogen by 31 December 2045.                                      | Urban Wastewater Treatment Directive (EU) 2024/3019 - Art.7         |
|                  | Recovery of phosphorus from sludges            | 1. Member States shall encourage the recovery of valuable resources and take the measures necessary to ensure that sludge management conforms to the waste hierarchy provided for in                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Urban Wastewater Treatment Directive (EU) 2024/3019 - Art.20        |

| Life cycle phase | Targeted flow – SCRM related/not related | Legislation coverage                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | National / EU |
|------------------|------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|
|                  |                                          | <p>Article 4 of Directive 2008/98/EC. Such sludge management shall: (a) maximise prevention; (b) prepare for reuse, recycling and other recovery of resources, in particular phosphorus and nitrogen, considering national or local valorisation options; and (c) minimise the adverse effects on the environment and human health.</p> <p>2. The Commission is empowered to adopt delegated acts in accordance with the procedure referred to in Article 27 to supplement this Directive by specifying a combined minimum reuse and recycling rate for phosphorus from sludge and from urban wastewater not reused under the derogation of Article 15(1), taking into account available technologies, resources and the economic viability of phosphorus recovery as well as the phosphorus content of the sludge and the level of saturation of the national market with organic phosphorus from other sources while ensuring that there is safe sludge management and no adverse impact on the environment or human health. The Commission shall adopt those delegated acts by 2 January 2028.</p> |               |

Source: JRC elaboration.

The current legislation lacks specific requirements for the management of slag and ashes, with most requirements being qualitative and applying to generic waste flows, and there are no targets or provisions for incineration or mineral recovery from these materials, although some regulations do address the recovery of phosphorus from wastewater and sludge.

#### **4.5.4.2 Challenges and existing systems for collection and treatment (sub-paragraphs d and e, respectively)**

##### **The integrated metal industry**

The integrated metal industry plays a crucial role in the successful implementation of advanced metal recycling. The removal of impurities by one process often becomes the feed for subsequent processes, highlighting the need for a holistic approach to the Article 26 priority list. Specifically, copper, zinc, lead, steel, and cobalt/nickel are considered "base metals" that may produce fractions rich in other SCRMs, such as PGMs and antimony. Consequently, these trace elements may be recovered downstream from the by-products of "base metal" processes. To facilitate recovery, these processes may need to be operated in a way that allows these trace metals to end up in a by-product from which they can be recovered, such as lithium from batteries, which may not be recoverable if it ends up in the cobalt/nickel slag phase. Separate collection and sorting could potentially reduce losses to unrecoverable by-products.

This situation has two important implications. Firstly, recoverability may need to be assessed within the context of the entire value chain. Secondly, tracing the flow of materials through the value chain, where different streams are combined and processed, and understanding how much of a particular material is retained or lost at each stage, may be a complex task that falls outside the scope of FutuRaM. In the EU, metal production from primary and secondary resources is often performed in the same factories, which may make it challenging to estimate individual losses from secondary materials. As industrial processes were not within the a priori determined scope of FutuRaM, volumes may not be assessed for certain materials, despite potential recovery

opportunities. For instance, in the case of 19 01 11\*, some nickel may be recovered from stainless steel scrap, PGMs may be produced from the copper fraction, and magnesium might be re-used in aluminium alloys, but these volumes may be difficult to estimate.

### **The waste ecosystem**

The waste ecosystem is also critical in this context. While some process residues, such as white dross (primary aluminium slag), may contain significant economic value (15-80 wt% aluminium), these streams are often already further processed, leaving only low-grade materials. Consequently, slags and ashes (SLASH) may be considered as a funnel for materials with limited to no remaining inherent economic value, which may make landfilling a common and often economic fate. However, depending on landfilling costs and legislation, some MSs may find alternative end-uses for these waste streams, which typically require additional processing that can only exist within a larger "waste ecosystem". The authors suggest that it may be important to consider alternative options, such as the recovery of CRMs from municipal waste incineration bottom ashes (MWIBA), which may contain 7-10 wt% CRMs. While MWIBA can be separated into steel, copper, and aluminium scrap, as well as useful aggregates (>80 wt%), further processing using hydrometallurgical techniques could potentially yield higher CRM recovery rates, albeit at the cost of producing a large volume of waste with no potential use beyond landfilling. Both options may need to be carefully considered.

The industry and waste treatment sector have focused on bulk materials solutions for many of these materials, such as steel slag, which may avoid landfilling, reduce CO<sub>2</sub> footprint, and decrease natural mineral materials extraction. However, focusing solely on CRM recovery may potentially underestimate the management of non-recovered fractions. CRM recovery projects may therefore need to consider the management of these fractions. Legislation, such as the Waste Framework Directive (2008/98/EC) and the Landfill Directive (2018/850/EC), may drive a higher degree of recycling and CRM recovery by increasing landfilling costs. The exchange of BAT between MSs could also potentially enhance recycling and material recovery from waste.

#### **4.5.4.3 Further remarks on datasets availability**

- **Bottom ashes from commercial or industrial waste incineration.** This stream was included in the list based on expert opinions and the consultation of relevant stakeholders. The rationale for inclusion is also given for consistency with the incineration of municipal solid waste. However, it is important to note that the availability of data on the potential recovery of SCRM from specific industrial waste streams is limited. While some data have been analysed for certain waste streams, such as "waste from power stations and other combustion plants" and "waste from incineration or pyrolysis of waste", no data are available for other industrial waste streams. Nevertheless, according to expert opinion and stakeholder feedback, it is possible that specific industrial waste streams could be prioritised for SCRM recovery if more comprehensive data were available. Further research and analysis may be necessary to fully understand the potential for SCRM recovery from these waste streams and to identify the most promising areas for prioritisation.

## **4.5.5 Key messages for SLASH**

### **(a) SCRM data and elaboration**

The most relevant SCRM data for their recovery potential are P, Cu, and Al from sewage sludge and bottom ashes from municipal solid waste incineration. However, it is noted that the recovery of certain SCRM data, such as Cu, Sb, Bi, Ni, and PGMs within slags, is already well addressed in metallurgical processes.

### **(b) What is covered (legislation)**

There are no specific legislations prescribing detailed requirements for the management of slags and ashes. The existing requirements are mostly qualitative, and when they are quantitative, the targets or requirements apply to generic waste flows. It appears that there are no specific legislation requirements for incineration targets or mineral recovery targets from the resulting ashes, although there are specific requirements for recovering phosphorus from urban wastewaters.

### **(c) Legislation gaps**

Despite the existence of legislations and targets for phosphorus recovery, there are still significant gaps in the legislation, particularly with regards to specific requirements and targets for the management of bottom ashes and slag, and the recovery of other SCRM data. This could potentially lead to missed opportunities for the recovery of materials such as Al and Cu.

### **(d) Existing systems**

There are existing systems for SLASH management, including the treatment of slags and ashes, and the recovery of phosphorus from sewage sludge, as well as the use of bottom ashes from municipal solid waste incineration as a source of Cu and Al. However, the effectiveness and efficiency of these systems may vary.

### **(e) Challenges**

The main challenges for SLASH may include the lack of reliable data on the composition, the limited economic value of recovered materials, and the need for further research and development to improve the recovery of SCRM data. The presence of pollutants in sewage sludge, such as heavy metals and microplastics, may add further complexity. Regulatory uncertainty surrounding the use of recovered materials, for example sewage sludge-derived fertilisers, may also hinder market uptake. Additionally, the absence of harmonised data collection on SLASH flows may remain a significant barrier to assessing the full potential for SCRM recovery.

## 4.6 Results for construction and demolition waste (CDW) for the Article 26 of the CRMA

The list of CDW from buildings to be prioritised is reported hereinafter:

- (a) Construction and demolition waste, particularly focusing on aluminium, aluminium alloys, copper, copper alloys, and cables in buildings.

### 4.6.1 Scope and background data

CDW, or Construction and Demolition Waste from buildings, can be viewed from two distinct perspectives. On the one hand, buildings can be considered as complex products composed of various components. On the other hand, unlike other waste streams, a building is not typically collected as a single product once it is demolished. Instead, the resulting waste is more akin to the SLASH waste stream, which comprises a diverse range of materials. As a result, the analysis focused on CDW waste streams from group 2, although it is acknowledged that both perspectives are relevant and were considered in the context of the FutuRaM project. **Table 32** provides an overview of the waste streams (and their corresponding EWC codes) that were included in this analysis.

**Table 32.** Waste streams and their EWC codes under CDW that were included in the analysis for the Art. 26 priority list.

| Waste code   | Description                                                                                                |
|--------------|------------------------------------------------------------------------------------------------------------|
| <b>17 01</b> | <b>Concrete, bricks, tiles and ceramics</b>                                                                |
| 17 01 01     | Concrete                                                                                                   |
| 17 01 02     | Bricks                                                                                                     |
| 17 01 03     | Tiles and ceramics                                                                                         |
| 17 01 06*    | Mixtures of, or separate fractions of concrete, bricks, tiles and ceramics containing hazardous substances |
| 17 01 07     | Mixtures of concrete, bricks, tiles and ceramics other than those mentioned in 17 01 06                    |
| <b>17 02</b> | <b>Wood, glass and plastic</b>                                                                             |
| 17 02 01     | Wood                                                                                                       |
| 17 02 02     | Glass                                                                                                      |
| 17 02 03     | Plastic                                                                                                    |
| 17 02 04*    | Glass, plastic and wood containing or contaminated with hazardous substances                               |
| <b>17 03</b> | <b>Bituminous mixtures, coal tar and tarred products</b>                                                   |
| 17 03 01*    | Bituminous mixtures containing coal tar                                                                    |
| 17 03 02     | Bituminous mixtures other than those mentioned in 17 03 01                                                 |
| 17 03 03*    | Coal tar and tarred products                                                                               |
| <b>17 04</b> | <b>Metals (including their alloys)</b>                                                                     |
| 17 04 01     | Copper, bronze, brass                                                                                      |
| 17 04 02     | Aluminium                                                                                                  |
| 17 04 03     | Lead                                                                                                       |
| 17 04 04     | Zinc                                                                                                       |
| 17 04 05     | Iron and steel                                                                                             |
| 17 04 06     | Tin                                                                                                        |

| <b>Waste code</b> | <b>Description</b>                                                                                                                                                                            |
|-------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 17 04 07          | Mixed metals                                                                                                                                                                                  |
| 17 04 09*         | Metal waste contaminated with hazardous substances                                                                                                                                            |
| 17 04 10*         | Cables containing oil, coal tar and other hazardous substances                                                                                                                                |
| 17 04 11          | Cables other than those mentioned in 17 04 10                                                                                                                                                 |
| <b>17 06</b>      | <b>Insulation materials and asbestos-containing construction materials</b>                                                                                                                    |
| 17 06 01*         | Insulation materials containing asbestos                                                                                                                                                      |
| 17 06 03*         | Other insulation materials consisting of or containing hazardous substances                                                                                                                   |
| 17 06 04          | Insulation materials other than those mentioned in 17 06 01 and 17 06 03                                                                                                                      |
| 17 06 05*         | Construction materials containing asbestos                                                                                                                                                    |
| <b>17 08</b>      | <b>Gypsum-based construction material</b>                                                                                                                                                     |
| 17 08 01*         | Gypsum-based construction materials contaminated with hazardous substances                                                                                                                    |
| 17 08 02          | Gypsum-based construction materials other than those mentioned in 17 08 01                                                                                                                    |
| <b>17 09</b>      | <b>Other construction and demolition wastes</b>                                                                                                                                               |
| 17 09 01*         | Construction and demolition wastes containing mercury                                                                                                                                         |
| 17 09 02*         | Construction and demolition wastes containing PCB (for example PCB-containing sealants, PCB-containing resin-based floorings, PCB-containing sealed glazing units, PCB-containing capacitors) |
| 17 09 03*         | Other construction and demolition wastes (including mixed wastes) containing hazardous substances                                                                                             |
| 17 09 04          | Mixed construction and demolition wastes other than those mentioned in 17 09 01, 17 09 02 and 17 09 03                                                                                        |

Source: JRC elaboration. Note: \* in the code is used for hazardous substances. Note that the overarching waste is in bold.

#### **4.6.1.1 Composition**

The collected data are based on an existing database compiled by Heeren and Fishman (MI database) (Heeren and Fishman 2019). The database was filtered to align with the geographical scope of the FutuRaM project, and the data were harmonised to meet the requirements of this study. Additionally, the terminology was adapted to conform to the FutuRaM naming conventions (code lists).

A waste classification system, referred to as the “product key”, was developed to categorise construction and demolition waste into distinct types. This system is based on the categories and terminologies employed in the MI database and comprises a general classification, dividing buildings into residential and non-residential categories, which are further subdivided into various categories and then into distinct construction types. The product key enables the identification and analysis of specific waste streams, facilitating the development of targeted strategies for waste management and reduction. Currently, the list of prioritised elements for the buildings waste stream is not presented at the component level, as the available data are insufficient. However, the product key provides a framework for future data collection and analysis, allowing for a more detailed understanding of the composition of construction and demolition waste.

#### **4.6.1.2 Stock and flow model**

The model takes into account the stocks and demolition flow of residential and non-residential buildings in the EU27 for the period 2010–2050. The current dataset encompasses wastes generated from demolition but does not include wastes arising from renovation or construction

activities. The results are highly sensitive to the availability of data in the sources used, which are incomplete for a few countries (see **Table A12** of **Annex VI** for more information).

#### 4.6.2 List of construction and demolition waste streams to be prioritised

The list of CDW from buildings to be prioritised is reported hereinafter:

- Aluminium, copper alloys, and cables contained in construction and demolition waste from buildings.

The list for CDW is obtained based on the following steps, namely:

1. Analysis of whether the respective waste stream contains CRMs.
2. Analysis of stock and waste quantities and consequently CRM quantities based on mass fractions.
3. Comparison between different waste streams for highest relevance regarding specific CRMs.

As a result, the Article 26 (7) priority list for CDW, presented in **Table 33**, comprises specific waste stream-CRM pairs. The data used to assess whether each waste stream should be included in the list are not reported in their original disaggregated form, but are instead presented as aggregated figures in **Table 35** along with the rationale underlying the determination of the waste stream's eligibility for inclusion. All waste streams that are excluded from the priority list are summarised in **Table 34** and **Table 36**.

**Table 33.** Waste stream-CRM couples to be included on the Art. 26 priority list.

| Waste sub-stream                                                          | SCRM                                                   |
|---------------------------------------------------------------------------|--------------------------------------------------------|
| Copper, bronze, brass – 17 04 01                                          | Cu, and Cu alloying element: Al                        |
| Aluminum – 17 04 02                                                       | Al and Al alloying elements: Bi, Cu, Mg, Mn, Si, Ti, V |
| Mixed metals – 17 04 07                                                   | Al, Cu                                                 |
| Cables containing oil, coal tar and other hazardous substances – 17 04 10 | Cu, Al                                                 |
| Cables other than those mentioned in 17 04 10 – 17 04 11                  | Cu, Al                                                 |

Source: JRC elaboration based on FutuRaM internal datasets.

**Table 34.** Waste streams to be excluded from the Art. 26 priority list.

| Waste sub-stream                                               | SCRM             |
|----------------------------------------------------------------|------------------|
| Concrete, bricks, tiles and ceramics – 17 01 XX                | -                |
| Wood, glass and plastic – 17 02 XX                             | -                |
| Bituminous mixtures, coal tar and tarred products – 17 03 XX   | -                |
| Lead – 17 04 03                                                | Cu, Sb           |
| Zinc – 17 04 04                                                | Cu, Mn           |
| Iron and steel – 17 04 05                                      | Cu, Mn, P, Si, V |
| Tin – 17 04 06                                                 | Cu, Sb           |
| Metal waste contaminated with hazardous substances – 17 04 09* | -                |

| Waste sub-stream                                                               | SCRM |
|--------------------------------------------------------------------------------|------|
| Insulation materials and asbestos-containing construction materials – 17 06 XX | -    |
| Gypsum-based construction material – 17 08 XX                                  | -    |
| Other construction and demolition wastes – 17 09 XX                            | -    |

Source: JRC elaboration, based on FutuRaM internal dataset. Note that hyphen (-) denotes that there is no relevant SCRM in the associated waste sub-stream.

#### 4.6.3 Rationale of the list of waste streams included and not included in the priority list – step1 of the methodology for waste streams from group 2

The rationale for including specific waste streams or code in the resulting list for the CDW stream **Table 35**) considers the different aspects as detailed in the workflow in section 4.6.2. The rationale for excluding specific waste products and components is detailed in **Table 36**.

**Table 35.** Rationale of the list of CDW included in the priority list.

| Waste sub-stream                                                           | Critical raw materials included | Rationale for inclusion                                                                                                                                                                                                                                                                                                                                                                               |
|----------------------------------------------------------------------------|---------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Copper, bronze, brass – 17 04 01                                           | Cu, Al                          | Around 9 Mt copper alloys in EU building stock (modelled for 2022), around 46 kt outflow per year (modelled for 2022). Copper alloys are currently extensively recovered in most MSs.                                                                                                                                                                                                                 |
| Aluminium – 17 04 02                                                       | Al, Bi, Cu, Mg, Mn, Si, Ti, V   | Around 23 Mt aluminium alloys in EU building stock (modelled for 2022), around 116 kt outflow per year (modelled for 2025). Aluminium alloys are currently extensively recovered in most MSs. The focus should be on alloy separation as this is still rarely done.                                                                                                                                   |
| Mixed metals – 17 04 07                                                    | Al, Cu, Bi, Mg, Mn, Si, Ti, V   | See 17 04 01 and 17 04 02. There is no data available for this stream. The model does not include mixed metals together, but they are differentiated into Al, Cu, and ferrous. These materials could be also collected as mixed metals at the construction site. Ferrous metals are also considered within this category. Ferrous metals in a mixed category are selected easily by magnetic sorting. |
| Cables containing oil, coal tar and other hazardous substances – 17 04 10* | Cu, Al                          | Cables are partly included in the around 9 Mt copper and around 23 Mt aluminium alloys in the EU building stock, as reported for the codes 17 04 01 and 17 04 02, respectively. It is assumed that more cables could be recovered, which would lead to higher amount of copper and aluminium. Specific data for cables is not available. Cables are currently extensively recovered in most MSs.      |
| Cables other than those mentioned in 17 04 10 – 17 04 11                   | Cu, Al                          | Cables are partly included in the around 9 Mt copper and around 23 Mt aluminium alloys in the EU building stock, as reported for the codes 17 04 01 and 17 04 02, respectively. It is assumed that more cables could be recovered, which would lead to higher amount of copper and aluminium. Specific data for cables is not available. Cables are currently extensively recovered in most MSs.      |

Source: JRC elaboration, based on FutuRaM internal dataset.

**Table 36.** Rationale of the list of CDW not included in the priority list.

| <b>Waste sub-stream</b>                                                        | <b>SCRM excluded</b> | <b>Rationale for exclusion</b>                                                                                                                                                                                                                                                                                                                            |
|--------------------------------------------------------------------------------|----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Concrete, bricks, tiles and ceramics – 17 01 XX                                | -                    | There could be SCRMs in tiles and ceramics. No data available for SCRMs in both categories.                                                                                                                                                                                                                                                               |
| Wood, glass and plastic – 17 02 XX                                             | -                    | There could be SCRMs in plastics, wood, and glass. No data available for SCRMs.                                                                                                                                                                                                                                                                           |
| Bituminous mixtures, coal tar and tarred products – 17 03 XX                   | -                    | No SCRMs.                                                                                                                                                                                                                                                                                                                                                 |
| Lead – 17 04 03                                                                | Cu, Sb               | Relatively small quantities of lead alloys and very small SCRM mass fractions are assumed. Cu and Sb are alloying elements. No data available.                                                                                                                                                                                                            |
| Zinc – 17 04 04                                                                | Cu, Mn               | Small quantities of zinc alloys are assumed. No data available. Cu and Mn are alloying elements. Copper alloys are a better source for Cu.                                                                                                                                                                                                                |
| Iron and steel – 17 04 05                                                      | Cu, Mn, Ni, P, Si    | Around 2,221 Mt ferrous metals in EU building stock (modelled for 2022), around 12 Mt outflow per year (modelled for 2022).<br>The majority of the SCRMs are alloying elements in steel. Mostly rebar which is in most cases carbon steel and does not contain SCRM.<br>Stainless steel which includes different SCRM is used in much smaller quantities. |
| Tin – 17 04 06                                                                 | Cu, Sb               | Small quantities of tin alloys are assumed. <u>Cu and Sb are alloying elements. No data available.</u><br>Copper alloys are a better source for Cu.                                                                                                                                                                                                       |
| Metal waste contaminated with hazardous substances – 17 04 09*                 | -                    | Priority should be on not-contaminated metal waste.                                                                                                                                                                                                                                                                                                       |
| Insulation materials and asbestos-containing construction materials – 17 06 XX | -                    | Sb (flame retardant) and B (flame retardant and preservative) could be present, but no data available.                                                                                                                                                                                                                                                    |
| Gypsum-based construction material – 17 08 XX                                  | -                    | No SCRMs.                                                                                                                                                                                                                                                                                                                                                 |
| Other construction and demolition wastes – 17 09 XX                            | -                    | Mixed waste stream is not considered as priority. Focus here should be on better separation.                                                                                                                                                                                                                                                              |

Source: JRC elaboration, based on FutuRaM internal dataset. Note that hyphen (-) denotes that there is no relevant SCRM in the associated waste sub-stream.

**Table 37** presents the numerical values of the following CDW flows for residential (R) and non-residential (NR) buildings: (i) the waste generated by reference year and (ii) the quantities of SCRMs

within the waste generated. Additionally, **Table 37** reports the quantity of recoverable SCRM, namely aluminium and aluminium alloys, and copper and copper alloys, from waste generated from buildings (both residential and non-residential) in the years 2022 and 2030.

**Table 37.** Amount of construction and demolition buildings waste generated in the EU27.

| Year | Waste stream                  | Waste generated [kt] | Amount of SCRM in waste generated [kt] | Quantities of Al & Al alloys in waste generated [kt] | Quantities of Cu&Cu alloys in waste generated [kt] |
|------|-------------------------------|----------------------|----------------------------------------|------------------------------------------------------|----------------------------------------------------|
| 2022 | CDW_generated for building_NR | 8.64E+14             | 126                                    | 96.6                                                 | 29.5                                               |
| 2022 | CDW_generated for building_R  | 4.19E+15             | 35.9                                   | 19.8                                                 | 16.1                                               |
| 2030 | CDW_generated for building_NR | 1.29E+15             | 156                                    | 119                                                  | 36.7                                               |
| 2030 | CDW_generated for building_R  | 6.40E+15             | 46.9                                   | 27.2                                                 | 19.6                                               |

Source: JRC elaboration, based on FutuRaM internal dataset. Note: R = Residential; NR= Non-residential

#### 4.6.4 Further remarks on the resulting list – step 2 of the methodology for waste streams from group 2

##### 4.6.4.1 Legal coverage and legislation gaps (sub-paragraphs b and c, respectively)

As shown in **Table 38**, there is no EU-wide legislation regarding collection and separation of CDW besides the Waste Framework Directive which only sets an overall recovery target for CDW (70% by weight by 2020). This target is met and oftentimes clearly exceeded by MSs as recovery also includes backfilling and does not specify quality of recycling.

**Table 38.** Overview of legislative coverage related to CDW flows at EU and/or national levels.

| Life cycle phase | Targeted flow – SCRM related/not related                    | Legislation coverage                                                                                                                                                                                                                                                                                                                            | National / EU                                      |
|------------------|-------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------|
| End of life      | General waste stream (excluding excavated soils - 17 05 04) | Member States shall take measures to promote selective demolition to enable removal and safe handling of hazardous substances and facilitate re-use and high-quality recycling by selective removal of materials, and to ensure the establishment of sorting systems for construction and demolition waste at least for wood, mineral fractions | Waste Framework Directive (2008/98) - Art.11, 1    |
| End of life      | General waste stream (excluding excavated soils - 17 05 04) | Preparing for reuse and recycling<br><br>11, 2(b) by 2020, the preparing for re-use, recycling and other material recovery, including                                                                                                                                                                                                           | Waste Framework Directive (2008/98) - Art.11, 2(b) |

| Life cycle phase | Targeted flow – SCRM related/not related | Legislation coverage                                                                                                                                                                                                                                            | National / EU                                               |
|------------------|------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------|
|                  |                                          | backfilling operations using waste to substitute other materials, of non-hazardous construction and demolition waste excluding naturally occurring material defined in category 17 05 04 in the list of waste shall be increased to a minimum of 70 % by weight |                                                             |
| End of life      | Use of secondary raw materials - metals  | The use of primary raw material in the construction of the building is minimised using secondary raw materials. For metals, a maximum of 30% of the total material come from primary raw material                                                               | Taxonomy Regulation criteria (EU) 2023/2486 - Annex II - 4f |

Source: JRC elaboration.

#### **4.6.4.2 Challenges and existing systems for collection and treatment (sub-paragraphs d and e, respectively)**

Challenges in collecting and treating CDW arise from the demolition method employed. A more selective demolition or deconstruction approach enhances the potential for reuse and high-quality recycling, as components remain intact, and waste streams contain fewer impurities. However, the significance of these challenges varies by material type. Organic and mineral fractions are more affected, whereas metals are less challenging to recycle, even with traditional demolition methods, as they are often separated. The primary challenge for metals lies in separating them by alloy type, which enables functional recycling and utilisation of the embedded SCRM.

As described by a study performed by the European Aluminium Association<sup>29</sup>, the deconstruction and demolition of buildings in Europe are governed by local and EU directives, focusing on hazardous material handling, recycling, and disposal. The process typically begins with the removal of hazardous materials, such as asbestos and mercury-bearing lamps, followed by semi-hazardous materials like gypsum board. Subsequently, metals like aluminium, steel, copper, and zinc are recovered from interiors before structures are dismantled. Exteriors are stripped of aluminium sheets, profiles, and cladding, while windows and doors are either resold or recycled. Once deconstruction is complete, clean concrete and brick are demolished, and any remaining metals are collected. Recovered aluminium is then reused, sent to recycling plants, or processed for further recovery.

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<sup>29</sup> European Aluminium Association 2022 - Construction of aluminium from buildings in Europe. Available at: <https://european-aluminium.eu/wp-content/uploads/2022/10/collection-of-aluminium-from-buildings-in-europe.pdf>

Copper is used in many forms in buildings including wiring, pipes and fittings, electrical outlets, switches and locks<sup>30</sup>. According to (De Simone et al. 2025), copper is already being extracted from buildings undergoing demolition for recycling, due to the high cost of the raw material, making material recovery economically viable. However, a circular economy assessment should commence by extending the life of a component or exploring potential reuse elsewhere, thereby maintaining its value for a longer period. Nevertheless, copper wire is often melted down instead of being reused, which may be justified by health and safety concerns for installers and electrical system users, as electrical design principles prioritise their safety.

As reported by (Cristóbal García et al. 2024), collection and recycling techniques for metals from CDW include selective demolition and design for deconstruction. Metals are typically separated and collected to be sent to recycling facilities, where they are processed into new materials or products.

Stakeholders suggest that up to 99% of aluminium could be collected and sent for recycling, with 10% already designated for reuse. However, effective collection and recycling depend on knowing the composition of materials in the building and the ability to effectively separate metals during the collection phase. The theoretical quantities of aluminium and copper in CDW composition from building demolition and renovation activities are relatively small, accounting for 1.8% and 0.07%, respectively. Although cables, a significant source of copper and aluminium, are currently extensively recovered in most MSs, collection and recycling practices can be optimised to maximise the recovery of these valuable metals.

#### **4.6.4.3 Further remarks on datasets availability**

Elemental composition for CDW was only considered for metals. Furthermore, components are not included in the composition data.

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<sup>30</sup> SCREEN 2023 – Factsheet copper. Available at: [https://screen.eu/wp-content/uploads/2024/01/SCREEN2\\_factsheets\\_COPPER-update.pdf](https://screen.eu/wp-content/uploads/2024/01/SCREEN2_factsheets_COPPER-update.pdf)

## **4.6.5 Key messages for CDW**

### **(a) SCRM data and elaboration**

The most SCRMs in CDW are Cu, Al, and their alloying elements. However, the current dataset only covers waste from demolition, omitting significant sources from renovation and construction activities. Notably, non-residential buildings offer higher potential for SCRMs recovery than residential buildings.

### **(b) What is covered (legislation)**

The Waste Framework Directive sets a minimum recovery target of 70% by weight for CDW by 2020. The Taxonomy Regulation encourages the use of secondary raw materials, including metals, in construction, with a maximum of 30% of total material permitted to come from primary raw materials. Emerging legislative topics, such as design-for-reuse and material passports, are gaining relevance.

### **(c) Legislation gaps**

A significant gap exists in EU-wide legislation regarding the collection and separation of CDW, except for the Waste Framework Directive, which only sets an overall recovery target. The divergent approaches adopted by MSs may hinder harmonisation and create inconsistencies.

### **(d) Existing systems**

Current CDW management systems include selective demolition and design for deconstruction. The European Aluminium Association reports that deconstruction and demolition procedures in Europe are regulated by local and EU directives, focusing on hazardous material handling, recycling, and disposal. Cables, a significant source of Cu and Al, are extensively recovered in most MSs.

### **(e) Challenges**

The challenges in CDW management include the separation of metals by alloy type, which is still rarely done. The demolition method can affect the potential for reuse and high-quality recycling. Effective collection and recycling depend on knowing the composition of materials in the building and the ability to effectively separate metals during the collection phase. The theoretical quantities of aluminium and copper in CDW composition from building demolition activities are generally small compared to other materials present in buildings. Finally, there are economic barriers due to the relatively low market value of mixed scrap compared to the high costs of advanced separation and purification technologies that often disincentivises investment in more effective recovery processes.

#### 4.7 Results for waste streams with partially available datasets for the Article 26 of the CRMA – application of the methodology for waste streams from group 3

**Table 39** shows the list and rationale for inclusion of waste streams which were not within the initial scope of the analysis but were finally included in the list because stakeholders evidenced their potential.

**Table 39.** Waste streams included in the list for which data were not available or that were out of scope of the FutuRaM project.

| Waste stream                                 | Rationale for inclusion                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|----------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Light means of transport (LMT)               | The inclusion of LMT as a priority waste stream for SCRM recovery potential is recommended by analogy to the SCRM content in motor vehicles. As outlined in section 4.4, motor vehicles are known to contain significant amounts of SCRMs, such as copper, aluminium, and rare earth elements. Similarly, LMT, including e-scooters, e-mopeds, and e-motorcycles, are likely to contain these materials, albeit in smaller quantities.                                                                                                                                                                                                                                                                                                                                                |
| Energy and telecommunications infrastructure | The inclusion of energy and telecommunications infrastructure as a priority waste stream for SCRM recovery potential is recommended by analogy to the analysis of WEEE, including wind turbines, in this study (see sections 4.2 and 4.3). The energy and telecommunications infrastructure sectors are significant consumers of SCRMs, including copper, aluminium, rare earth elements, and precious metals, which are used in a wide range of applications, such as i) transformers and cables in energy transmission and distribution systems; ii) data centres and network equipment in telecommunications infrastructure; iii) renewable energy technologies; and iv) high-voltage direct current (HVDC) systems and flexible alternating current transmission systems (FACTS). |
| Industrial pumps                             | Industrial pumps are a large category and data specific for this product group were not available for the application of the methodology. However, the inclusion of this waste stream is recommended because of the presence of relevant components such as permanent magnets in the motors and high-quality alloys, including aluminium alloys. These components and materials have been prioritised for similar waste stream under the scope of this analysis, such as motor vehicles and WEEE (sections 4.4 and 4.2, respectively). In the future, it will be important to narrow the scope and collect harmonised data for the application of the methodology.                                                                                                                    |
| Industrial catalysts                         | Industrial catalysts are a large category and data specific for this product group were not available for the application of the methodology. However, the inclusion of this waste stream is recommended because of the presence of relevant components and materials: for example, i) certain types of                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

|                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|----------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                          | <p>platinum group metal (PGM)-containing catalysts such as homogeneous catalysis (Pd, Pt) and environmental catalyst (Pt) for which relevant losses are identified; ii) rare earth-containing industrial catalysts for fluid catalytic cracking (Ce and La) for which there is no economic driver, therefore the losses were 100 % for 2020<sup>31</sup>.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Digestate and compost from separately collected biowaste | <p>Digestate and compost from separately collected biowaste has been added to the list due to its phosphorus content as critical raw material that can be recovered through different processes according to the «recovery» definition of the WFD (2008/98/EC), Article 3, point (15), i.e., <i>‘recovery’ means any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy.</i> Besides, Annex II of the WFD sets out a non-exhaustive list of recovery operations. Note that Annex II of the WFD states that <i>“Land treatment resulting in benefit to agriculture or ecological improvement” that refers to applying certain wastes (like sewage sludge, compost, or manures) to land to enhance soil health, provide nutrients for crops, or restore habitats, replacing the need for synthetic products.”</i> Compost and Digestate that complies with relevant requirements should be used directly for their phosphorus content rather than extracting phosphorus from them. One tonne of compost contains 4 kg phosphate<sup>32</sup>. Returning such phosphorus back into the cycle in a targeted manner can reduce reliance on costly synthetic fertilizers, prevent nutrient pollution in water bodies and generally support a high valorisation for the circular economy.</p> <p>The amount of separate collected waste is expected to increase, and the Waste Framework Directive is encouraging recycling, including composting and digestion, of bio-waste. Article 22(1) of the Waste Framework Directive has introduced an obligation to separately collect municipal biowaste, which constitutes the largest fraction of total municipal waste<sup>33</sup>. Efficient separate collection and recycling of biowaste is therefore essential to divert this significant waste stream from landfills and incineration, to ensure the quality of the input material, and to recover from it valuable nutrients that will be returned to the soil.</p> <p>The scope of this waste stream covers Biowaste as defined in the Waste Framework Directive “biodegradable garden and</p> |

<sup>31</sup> <https://www.umweltbundesamt.de/publikationen/recyclingpotenzial-strategischer-metalle-restra> (in German)

<sup>32</sup> European Compost Network Fact sheet 2, Soil Fertility & Productivity, 2020

<sup>33</sup> Early Warning Report 2023, COM(2023) 304 final, available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2023%3A304%3AFIN&qid=1686220362244>

|  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|--|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  | <p>park waste, food and kitchen waste from households, offices, restaurants, wholesale, canteens, caterers and retail premises and comparable waste from food processing plants". Beyond separately collected biowaste, compost and digestate can be obtained from other waste streams like agricultural residues and manure, which are also a source of phosphorus, even though they are already directly recycled in the field without further treatment. It was estimated that Europe produced approximately 31 million tonnes of digestate in dry matter in 2022, with an average phosphorus content of 0.3 million tonnes<sup>34</sup>. Digestate composition varies depending on the input feedstock, which may include agricultural residues, biowaste, manure, sewage sludge and other organic waste streams.</p> |
|--|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Source: JRC elaboration.

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<sup>34</sup> European Biogas Association (2024): Exploring digestate's contribution to healthy soils. Available at: [https://www.europeanbiogas.eu/wp-content/uploads/2024/03/Exploring-digestate-contribution-to-health-soils\\_EBA-Report.pdf](https://www.europeanbiogas.eu/wp-content/uploads/2024/03/Exploring-digestate-contribution-to-health-soils_EBA-Report.pdf)

## 5 Conclusions

The **main objective** of this study is to support the implementation of the Article 26 of the Regulation (EU) 2024/1252, which aims to promote waste prevention and to increase the reuse and repair of products and components with relevant strategic and critical raw materials potential. The study has provided insights into the prioritisation of waste streams with relevant strategic and critical raw material recovery potential, supporting the development of circularity strategies.

The study has proposed **a methodology** to process harmonised data based on composition and stock-flow, prioritising SCRMs in waste streams, products and components. The methodology accounts for essential factors, as required by the CRMA Article 26 (7), in determining the priority list such as the total amount of strategic and critical raw materials recoverable from waste streams, the extent to which these waste streams are covered by EU law, regulatory gaps, and challenges affecting collection and treatment. All the waste streams under scope are consistently processed to provide a reproducible approach, accompanied by feasibility checks supported by expert judgment. This study brings together a range of waste streams, which vary in terms of their level of data and policy coverage. For instance, some waste streams, such as batteries, are well-established and have a strong foundation of existing knowledge, whereas others, like wind turbines, are still the subject of ongoing research and development. Furthermore, the methodology employed in this study is sufficiently flexible to accommodate waste flows for which no harmonised dataset is currently available. This allows for a comprehensive assessment of various waste streams, with the possibility that data for these streams will become available, enabling a more comprehensive assessment of their potential for strategic and critical raw material recovery.

The application of the methodology led to the identification of **a list of relevant product, components and waste flows** that MSs need to consider when defining the circularity national programmes. They include batteries, electric and electronic equipment, wind turbines and related infrastructure, motor vehicles, light means of transport, energy and telecommunication infrastructure, industrial pumps, industrial catalysts, digestate and compost from separately collected biowaste, sludge and ashes, some fractions of construction and demolition waste.

Based on the findings of this study, **key messages** are provided for each waste stream analysed and for those for which data are not currently available. This work identifies substantial opportunities to enhance recovery processes for strategic and critical raw materials, highlighting the necessity for EU and MSs to address current gaps in waste management, notably through national programmes. Implementing circular economy strategies are crucial, and existing and upcoming legislative frameworks like set out by the Battery Regulation and the WEEE Directive can guide the development of measures for specific product categories.

It is also important to note that the **list may need to be reviewed and updated in the future** as new data becomes available, particularly considering technological developments. In this regard, the review clause of the CRM Act should provide a framework for revising the list to ensure it remains effective and relevant. This review process will allow for the incorporation of novel information and the adaptation of the list to changing circumstances, ultimately supporting the long-term goals of the Regulation.

The findings have significant **implications for policy and practice**. The priority list and the scientific evidence inform the development of national measures on circularity and support the transition towards a circular economy. It can also inform the development of future policies and regulations aimed at promoting the recovery and recycling of strategic and critical raw materials. It

supports ongoing efforts related to the implementation of CRM Regulation, such as Articles 28 and 29 that will come in the course of 2026, and other EU legislation (e.g., WEEE Directive revision during 2026 as well). The findings could also guide the R&D and investment efforts of both academia and industry to focus on specific waste flows. This work also demonstrates the value of FutuRaM datasets that can be adequately treated to answer a specific ambitious policy question.

**Future research** should focus on addressing the limitations of the current study, including the need for more detailed data on waste streams and SCRM recovery potential. Additionally, research should explore the application of the methodology developed in this study to other waste streams and SCRM that were not covered by the initial scope, as well as in other purposes.

Moreover, data and knowledge on flows of secondary raw materials is evolving (see e.g., Horizon Europe project FutuRaM 2026 outputs) and will require further consolidation. As the Implementing Act list of Article 26 of the CRMA comes into effect, it is anticipated that more data will become available through reporting, and the list should reflect technological advancements, remaining dynamic and adaptable to future changes in EU waste management practices.

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## List of abbreviations and definitions

### Abbreviations

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|       |                                           |
|-------|-------------------------------------------|
| BATT  | Batteries                                 |
| BAU   | Business As Usual                         |
| BEV   | Battery Electric Vehicle                  |
| CR    | Collection Rate                           |
| CRM   | Critical Raw Material                     |
| DD    | Direct Drive                              |
| EEE   | Electric and Electronic Equipment         |
| ELV   | End-of-Life Vehicles                      |
| EWC   | European Waste Catalogue                  |
| EV    | Electric Vehicle                          |
| GB    | Gear Box                                  |
| HEV   | Hybrid Electric Vehicle                   |
| LCA   | Life Cycle Assessment                     |
| LMT   | Light Means of Transport                  |
| LPG   | Liquified Petroleum Gas                   |
| MMW   | Mixed Municipal Waste                     |
| MSs   | Member States                             |
| MWIBA | Municipal Waste Incineration Bottom Ashes |
| NG    | Natural Gas                               |
| OEM   | Original Equipment Manufacturers          |
| PGM   | Platinum-Group Metals                     |

## Abbreviations

---

|       |                                            |
|-------|--------------------------------------------|
| PHEV  | Plugin Hybrid Electric Vehicle             |
| RaC   | Ranking Criteria                           |
| REE   | Rare Earth Elements                        |
| SCRM  | Strategic and Critical Raw Material        |
| SLASH | Slags, Sludges and ASHes                   |
| SLI   | Starting, Lighting, and Ignition (battery) |
| TP    | Total Potential                            |
| TRL   | Technology Readiness Level                 |
| WEEE  | Waste Electric and Electronic Equipment    |
| WT    | Wind Turbine                               |

## Definitions of waste streams

(These definitions do not have legal implications, however, are useful to clarifying the scope of the applications)

- **Batteries (BATT).** The Battery Regulation (European Union 2023) further defines battery according to Article 3 (1) as “*any device delivering electrical energy generated by direct conversion of chemical energy, having internal or external storage, and consisting of one or more non-rechargeable or rechargeable battery cells, modules or of packs of them, and includes a battery that has been subject to preparation for re-use, preparation for repurposing, repurposing or remanufacturing*”. The batteries analysed encompass all categories of batteries, namely portable batteries (Article 3 (9, 10) of the), which could be rechargeable or not (Article 3 (5, 6)), starting, lighting and ignition batteries (SLI batteries) (Article 3 (12)), light means of transport batteries (LMT batteries) (Article 3 (11)), electric vehicle batteries (EV batteries) (Article 3 (14)), and industrial batteries (Article 3 (13)), regardless of their shape, volume, weight, design, material composition, chemistry, use or purpose. Also analysed are batteries that are incorporated into or added to products or that are specifically designed to be incorporated into or added to products, according to Article 1(3). The batteries become waste, when the holder discards them, intends to do so, or is required to do so, according to Directive 2008/98/EC Article 3 (1) (European Union 2008).
- **Waste from Electrical and Electronic Equipment (WEEE).** WEEE refers to electrical and electronic equipment waste including all components, sub – assemblies and consumables which are part of the product at the time of discarding (according to Article 3 (1.e)). The WEEE Directive (European Union 2012) further defines EEE according to Article 3 (1.a) as “*equipment which is dependent on electric currents or electromagnetic fields to work properly and equipment for the generation, transfer and measurement of such currents and fields and designed for use with a voltage rating not exceeding 1 000 volts for alternating current and 1 500 volts for direct current*”.
- **End-of-Life Vehicles (ELV).** ELVs are motor vehicles as defined in the Regulation (EU) 2018/858 of the European Parliament and of the Council (European Union 2018). The legislation applies to vehicles below 3.5 tonnes, i.e. passenger vehicles and small trucks (M1 and N1 categories according to the EU vehicle classification<sup>35</sup>) but not to trucks, vintage vehicles, special-use vehicles and motorcycles. A new proposal for a Regulation on circularity requirements for vehicle design and on management of end-of-life vehicles<sup>36</sup>, motor vehicles above 3.5 tonnes used for the carriage of passengers or goods or trailers are also included in the scope. The scope of the study corresponds to the scope of the current ELV directive (M1 and N1 vehicles). We note that increasing the scope according to the new proposal would present additional challenges in terms of limited availability of official statistics on the end-of-life of such heavier vehicles.

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<sup>35</sup> <https://alternative-fuels-observatory.ec.europa.eu/general-information/vehicle-types>

<sup>36</sup> Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on circularity requirements for vehicle design and on management of end-of-life vehicles, amending Regulations (EU) 2018/858 and 2019/1020 and repealing Directives 2000/53/EC and 2005/64/EC

- **Slags, sludges, and ashes (SLASH).** SLASH refers to ‘SLAgS, sludges and ASHes’ SLASH refers to *SLAgS, sludges and ASHes*. SLASH should be considered as a heterogeneous group of materials, mainly arising from industrial, municipal waste, and wastewater treatment processes. They generally have a limited direct economic value and, unlike other waste streams, cannot be easily allocated to specific products or components. Nevertheless, certain SLASH fractions (e.g. phosphorus in sewage sludge, Cu and Al in bottom ash) can have significant recovery potential. In the FutuRaM project, selected SLASH waste streams were reported under the appropriate List of Waste (LoW) codes.
- **Construction and demolition wastes (CDW).** Construction and Demolition waste (CDW) (European Commission 2024) means waste generated by construction and demolition activities, with the following exceptions: (a) uncontaminated soil and other naturally occurring material excavated in the course of construction activities where it is guaranteed that the material will be used for the purposes of construction in its natural state on the site from which it was excavated and (b) waste waters (such as trade effluent disposed of via tankers, foul sewers, surface water drains, water courses, etc.). Construction means buildings and civil engineering works that may both be over or in the ground or water, including but not limited to roads, bridges, tunnels, pylons and other facilities for transport of electricity, communication cables, pipelines, aqueducts, dams, airports, ports, waterways, and installations which are the basis for rails of railways. In the framework of FutuRaM project only demolition waste from buildings were assessed. Other constructions/lifelines containing important quantities of CRM were not assessed in the project: power transportation, communication cables, and pipelines.
- **Wind turbines (WT).** Wind turbines are in the list of net-zero technologies as “onshore wind and offshore renewable technologies” (Article 4 (1.b) of the Regulation EU 2024/1735). Waste wind turbines refer to the decommissioned wind turbines or the remaining parts/components not being demanded on the second-hand market and considered as waste, including all parts and components, namely key components such as foundations, tower, blades, rotor blades, nacelle, hub, generator, and cables. Besides, related infrastructure of wind turbines includes the substation (with transformers, converters and inverters) and external cables.

**Definitions of waste products and/or components (these definitions do not have legal implications, however, are useful to clarifying the scope of the applications)**

- **Light means of transport (LMT).** LMT are wheeled vehicles that can be powered by an electric motor alone or by a combination of motor and human power, including type-approved vehicles of category L within the meaning of Regulation (EU) No 168/2013 of the European Parliament and of the Council. This category includes monowheels, hoverboards, e-scooters (called e-kick-scooters or e-steps in certain countries) plus larger e-mopeds (called e-scooters in certain countries) and e-motorcycles (Huisman and Bobba 2021; Bobba et al. 2024).

- **Energy and telecommunications infrastructure.** Energy infrastructure, according to the TEN-E Regulation (European Union 2022), means any physical equipment or facility falling under the energy infrastructure categories (described in Annex II of the Regulation) which is located within the Union, or linking the Union and one or more third countries.  
Telecommunication infrastructure, according to EU legislation (Directive 2018/1972, Directive 2014/61/EU, and Regulation (EU) 2024/1309—the Gigabit Infrastructure Act), means any physical installation, network element, or facility, located entirely within the Union, or serve to link the Union with third countries, that enables the conveyance or support of signals by wire, radio, optical, or other electromagnetic means. This includes (but is not limited to):
  - Active networks and systems: Fixed, mobile, satellite, fibre-optic, and other electronic communications networks.
  - Passive physical structures and associated facilities: Ducts, masts, antenna installations, towers, buildings, building entries and wiring, street cabinets, poles, conduits, manholes, street furniture such as light poles, traffic signals, billboards, and transport structures (e.g., bus stops, tramway shelters).
  - Infrastructure enabling deployment and access: High-speed-ready in-building wiring and infrastructure, shared ducts/poles, and other facilities aimed at reducing deployment cost and complexity.
- **Industrial pumps.** Industrial pump, according to EU legislative usage (e.g., Regulation (EU) 547/2012 and related directives), refers to any hydraulic machine or device that transfers liquids (such as clean water, oil, or chemicals) through mechanical or physical action, especially within an industrial setting. This encompasses rotodynamic pumps (e.g., ESOB, ESCC, MS-V, MSS) regulated under ecodesign rules, characterized by metrics like hydraulic efficiency and minimum efficiency indices (MEI). It may also include other categories—such as displacement pumps—where governed by respective EU norms (e.g., pressure equipment, machinery directives)
- **Industrial catalysts.** These are substances that increase the rate of chemical reactions in industrial processes without being consumed in the reaction. They are essential for improving efficiency, selectivity, and sustainability in large-scale chemical manufacturing.
- **Digestate and compost from separately collected biowaste.** End-products—digestate (via anaerobic digestion) and compost (via aerobic decomposition)— derived exclusively from biowaste (according to the definition in Art. 3 of the Waste Framework Directive 2018/851, that has been segregated at the source (according to Art 22), such as household food scraps, garden waste, or other comparable non-hazardous organic inputs, and that in the case of digestate is produced and processed under EU legislation (Regulation (EU) 2019/1009) with rigorous quality standards related to stability, hygiene, and contaminant thresholds.

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## **Annexes**

## Annex I. First step and second step of the methodology applied for waste streams from group 1 – associated with specific products

### Annex I.I. First step - Prioritisation of components and overarching products

This first step is the cornerstone of the methodology and tries to find and rank the components and the overarching products/waste streams based on the highest *Total Potential* ( $TP_{p-c,y}$ ), a composite indicator calculated as a function of the three ranking criteria (RaC) detailed in section I.I.1. The detailed procedure for the ranking and prioritisation is explained in section I.I.2.

#### Criteria for the prioritisation

Note that all equations are formulated with the following sub-indexes:  $p-c$  that refers to products and components, respectively;  $m-e$  that refers to the material and element, respectively;  $r$  is the region; and  $y$  is the year.

##### 1. RaC1 - Losses of critical raw material not collected

The losses of critical raw material not collected are measured through the quantity of SCRM that is lost in the collection process for each component. It accounts for the quantities of SCRM that do not reach the official collection process and are either: 1. exported for reuse, or 2. mixed with other waste streams (such as batteries of small WEEE ending up in residual waste, or metal rich WEEE or CDW not recorded or illegally treated together with metal scrap), or 3. illegally exported or treated illegally within the EU. Irrespective of the reason why they are not collected within the right channel, **higher amounts of SCRM lost in collection** represent a **higher recovery potential** whenever measures are implemented to increase the quantity collected.

Note that even if still theoretical (since the recovery process would surely lead to certain losses), this criterion is more specific than the theoretical recovery potential from the generated CRM quantities within the waste stream of each product mentioned in **Box 1**.

#### Box 1. Total theoretical potential

A commonly used criteria to prioritise products and components is the total theoretical recovery potential that accounts for the whole quantity of SCRM present in the waste generated (see **Equation 6**).

**Equation 6.** Total theoretical potential calculation.

$$Total\_Theoretical\_Potential_{p-c,y} = \sum_{m-e} \sum_r CRM\_Waste\_Generated_{m-e,p-c,r,y} \quad \forall p-c, y$$

The losses of critical raw materials not collected (in mass per year), criterion RaC1, are calculated as in **Equation 7**.

**Equation 7.** Losses of SCRMs calculation.

$$RaC1_{p-c,y} = \sum_{m-e} \sum_r CRM\_Waste\_Generated_{m-e,p-c,r,y} - \sum_{m-e} \sum_r (CRM\_Waste\_Generated_{m-e,p-c,r,y} * Collection\_Rate_{p,r,y}) \quad \forall p-c, y$$

Where the  $CRM\_Waste\_Generated_{m-e,p-c,r,y}$  is the quantity (in mass/year) of material-element  $m-e$ , in the product-component  $p-c$  within the region  $r$  and year  $y$ . And the  $Collection\_Rate$  (in %) is specific for each product  $p$  within a region  $r$  and year  $y$  and is calculated based on the total waste quantities (i.e., including the mass of other elements not classified as CRM) (see **Equation 8**).

**Equation 8.** Collection rate calculation.

$$Collection\_Rate_{p,r,y} = \frac{Total\_Waste\_Collected_{p,r,y}}{Total\_Waste\_Generated_{p,r,y}} \quad \forall p, r, y$$

## 2. RaC2 - Mass fraction of critical raw materials in waste generated

The mass fraction of critical raw material in waste generated, criterion *RaC2*, assumes that products presenting higher mass fraction of critical raw materials within the component may have higher potential for recovery. While **Equation 9** accounts for the total quantity of SCRMs in the waste generated, the recovery potential can vary significantly depending on the material and elements and their co-existence within the waste. The presence of multiple elements can pose additional challenges for recovery processes, as complex separation and extraction techniques may be required to isolate and retrieve each critical raw material efficiently. However, the co-existence is not accounted for in **Equation 9**. The mass fraction (in kg/kg), criterion *RaC2*, is calculated as in **Equation 9**.

**Equation 9.** Mass fraction of SCRMs calculation.

$$RaC2_{p-c,y} = \frac{\sum_{m-e,r} SCR\_Waste\_Generated_{m-e,p-c,r,y}}{\sum_r Total\_Waste\_Generated_{p-c,r,y}} \quad \forall p - c, y$$

## 3. RaC3 - Strategic dimension

The strategic dimension aims to prioritise products, components, and waste streams, considering three characteristics:

- SRM's content in mass within components.
- SRMs' supply risk.
- Number of SRMs in a component.

The strategic dimension considered in this methodology builds on publicly available information, as provided by the supporting documents of the (European Commission 2023) and Annexes of the EU Regulation 2024/1252. It is important to note that in the list of critical raw materials for the EU, a raw material is either critical or not. In the criticality assessment of 2023, the list of 17 strategic raw materials introduced a further differentiation for a critical raw material, of being strategic. Being strategic differentiates a critical raw material from the others providing a further characteristic enabling to focus on those critical raw materials which are essential for the EU for tackling the green and digital transition and enhancing its strategic autonomy and competitiveness. **Table A8** in Annex III details how the elements and materials embedded in the components and products have been screened as SRM. Only the screened SRMs are included in the calculation of the strategic dimension. Elements classified as CRM or OTHER are not considered.

It is important to highlight that being strategic means that only specific applications or specific purity grades of raw materials are considered and a differentiation in terms of risk of supply disruption can provide a further prioritisation among the strategic raw materials. For example, it is important to differentiate those SRM which are used in minimal quantities in the components with a higher supply risk, e.g. rare earth elements in permanent magnets, compared to other SRMs that are used in huge amounts but with a low supply risk in the latest years, e.g. copper. **Table A8** in Annex III details the supply risk considered for each screened SRM.

The strategic dimension considers the presence of different SRMs in a specific product and component. The inclusion of various SRMs in the same component or product can be advantageous for recovery but may present challenges in separating individual SRMs. For this reason, components

containing multiple SRMs are given greater weight. The intervals of occurrences are adapted from the study conducted by (S Carrara et al. 2023).

The definition of each of the characteristic of the strategic dimension has been developed also considering a coherence with data availability and the granularity of the inventories. For example, Copper alloys have been screened as strategic even if in some cases the disaggregation at the level of element was not provided.

The strategic dimension, criterion RaC3, is calculated according to **Equation 10**.

**Equation 10.** Strategic dimension calculation.

$$RaC3_{c,y} = \sum_{m-e} \sum_r SRM\_Waste\_Generated_{m-e,c,r,y} * fA_{m-e} * SR_{m-e} \quad \forall c, y$$

Where the  $SRM\_Waste\_Generated_{m-e,c,r,y}$  is the quantity (in mass/year) of material-element  $m-e$  screened as strategic raw material (SRM), in the component  $c$  within the region  $r$  and year  $y$ .  $SR_{m-e}$  is the supply risk of the material-element  $m-e$  screened as strategic raw material (SRM) (see values in **Table A8** in Annex III). Factor A ( $fA$ ) is the number of SRMs embedded in each component and counted as they appear in the inventories for each component. Based on the number of SRMs, should be used to identify the factor A ( $fA$ ) (see **Table A1**) that will be multiplied by the total amount of SRM and the SR. This process should be conducted for each component individually.

**Table A1.** Allocation of the value of factor A to be used for each component.

| Number of strategic raw materials in a component | Factor A ( $f_A$ ) |
|--------------------------------------------------|--------------------|
| 2 – 4                                            | 2                  |
| > 4                                              | 5                  |

Source: JRC elaboration.

## Procedure for the ranking and prioritisation

The *Total Potential* ( $TP_{p-c,y}$ ) composite indicator for each component and overarching product is calculated (see **Equation 11**) considering the scores obtained for each ranking criteria (after normalization) ( $RaCn_i$ ) ( $i=3$ , i.e. RaC1 = losses of critical raw materials not collected, RaC2 = mass fraction of critical raw material in waste generated, and RaC3 = strategic dimension) according to the four equations from **Equation 7** to **Equation 10** and the relative importance (i.e., weight, as  $W_i$ ) given to each ranking criteria for the final objective (i.e., recovery potential).

**Equation 11.** Total potential composite indicator.

$$TP_{p-c,y} = \sum_i RaCn_i * W_i \quad \forall p - c, y$$

Thus, the scores for each ranking criteria are normalized following the linear normalization technique max-min. Since all of the criteria are “benefit criteria” (i.e., the higher the better), **Equation 12** is used for the normalization.

**Equation 12.** Normalization calculation.

$$RaCn_i = \frac{RaC_i - RaC_{min}}{RaC_{max} - RaC_{min}}$$

The weighting factors ( $W_i$ ) attributed to each criterion differentiate each of them based on the importance to assess the recovery potential. The values for the weights are calculated using the Analytic Hierarchy Process (AHP) as proposed by Saaty (1987) and shown in **Table A2**. Further details on the AHP methodology and extended results are shown in Annex II.

**Table A2.** Weight values for the ranking criteria

|             | Weight |
|-------------|--------|
| <b>RaC1</b> | 0.65   |
| <b>RaC2</b> | 0.10   |
| <b>RaC3</b> | 0.25   |

Source: JRC elaboration.

The components and the overarching products are then ranked from the one with the highest overall score of  $TP$  to the one with the lowest for each year under assessment (i.e., 2020 and 2030). A cumulative threshold is imposed to identify the priority list, as cut-off rule. Thus, the components selected are the ones that enters in the 99 % of the total cumulative value of the sum of all  $TP$ s. This selection process is applied uniformly across all the streams and is further verified based on expert judgment. This approach ensures that the most relevant products and components are included while effectively reducing the list.

At this stage, an interaction with experts from the FutuRaM project is conducted to fine-tune results based on **feasibility checks for the possible dismantling of components**. It is common for certain components within specific products to be prioritised based on their  $TP$  value. However, if the separate dismantling process is not possible or viable, these components are treated together with the remaining fraction generated after specific dismantling in pre-treatment. In such cases, the component is duly removed from the priority list, with a justification provided for the decision. See an illustrative example in **Box 2**.

**Box 2.** Feasibility checks on dismantling for WEEE components, and duly modification of the priority list

Screws in WEEE initially resulted to be prioritised. However, according to experts, there is no viable way to separate them during pre-treatment due to the high processing time required (e.g., they are embedded in complex assemblies) and, ultimately, economic barriers. In this case, screws are removed from the priority list, as they will be treated together with the remaining fraction generated after specific dismantling in pre-treatment.

Thus, each component and overarching product has an associated  $TP$  score (Eq. 11), which allow to rank and prioritise the components according to the data for 2022 and 2030, delivering two lists of components to be prioritised. It is possible that the list of components and overarching products to be prioritised for 2022 might not be equal to the list from 2030 due to e.g., the technology evolution, product lifetime, novel product eco-design, and composition. Those two lists for the different temporal frameworks are merged within a unified list. After that, an analysis of the results is performed to provide the rationale on the resulted prioritised waste components and overarching products, and a rationale on the excluded ones.

Regarding the rationale on the excluded components and overarching products, the quantity of critical raw material within the excluded components of a product is accounted.

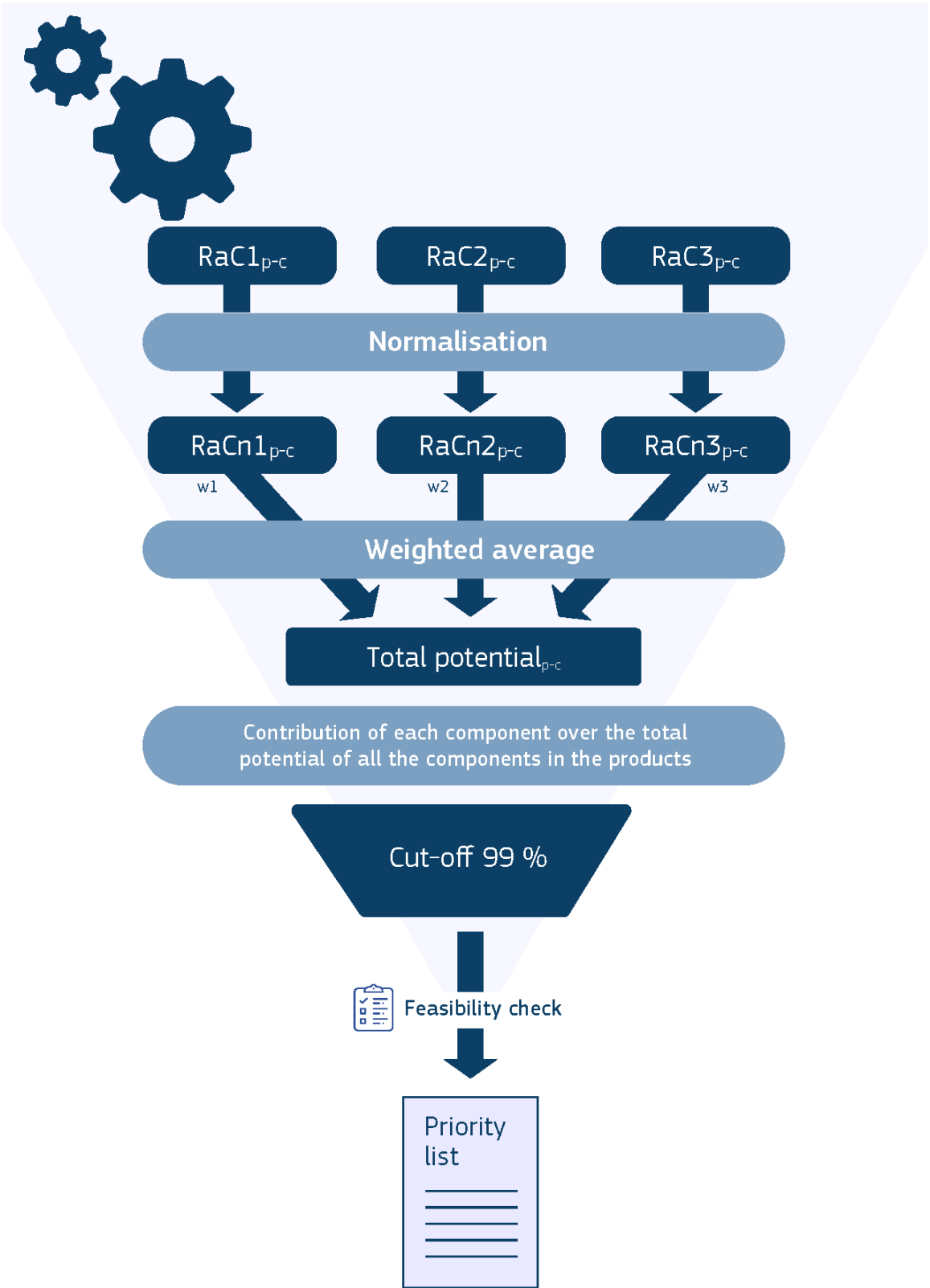
It is important to highlight that some components or products have been included in the prioritised list, even though they were initially excluded by the methodological cut-off. This decision was based

on evidence and expert judgement. More details are provided by components in the rationale of the list for each waste stream's section.

Finally, **the output of this methodology step** is a priority list of components and overarching products that aggregates the components prioritised in 2022 and 2030 according to the procedure previously explained.

An overview of the workflow to produce the priority list including the criteria for prioritisation is presented in **Figure A1**.

**Figure A1.** Overview of the workflow produce the priority list through the calculation of the total potential composite indicator, its ranking criteria, and remarks on the list. This workflow is valid for the two temporal frameworks, i.e. 2022 and 2030.



Source: JRC elaboration.

## **Annex I.II. Second step - Analysis of contextual factors, remarks and consolidation of the priority list**

An analysis of different contextual factors and remarks for the consolidation of the priority list accounting for the sub-paragraph b-e of the Art.26 (7) is conducted in this second step of the methodology. **Note that not all contextual factors are analysed for all waste streams since data might not be available or might not be needed.**

Firstly, the coverage of EU legislation on the different products, waste streams and components is analysed. The legal coverage and the legislation gap (**sub-paragraph b** and **c** respectively of the Art. 26 (7)) are two contextual factors that will help to identify and emphasise the components, products and waste streams that are less covered in the EU legislation. Note that priority should be given to products/waste streams/components that are specifically not subject to any requirement on collection, treatment, recycling or re-use under Union laws. Thus, a mapping of all legislative obligations at product, component, material or element level is done, covering all EoL steps (i.e., collection, treatment, disposal and circular strategies) and identifying both quantitative (e.g., numerical objectives with a specific timeline) and qualitative (e.g., development of standards) obligations. This mapping will result in highlighting and remarking products, waste streams and components that, while being in the priority list, are well covered within the legislation.

Secondly, to assess the challenges in collection and treatment (**sub-paragraph d** of Art. 26 (7)) experienced so far by the targeted products, components, and waste streams, an analysis of the available data regarding waste generated in 2022, and estimated for 2030, reported as **undocumented at the collection level** is performed at product level. This analysis evidences the quantities of products that are not registered within the official collection system, seen as a possible challenge faced, and allows to zoom in the possible reasons leading to the lack of collection. Waste flows that are not documented (and hence not compliantly managed) by the respective Directives in the EU illustrate losses in collection and receive herein special attention as compliance with the Directives in the EU would result in better source segregation, and registration, and hence decreasing the collection losses. **There is no available data on treatment technologies, hence the losses in compliant waste treatment could not be further quantified.** However, it is evident that some SCRM are lost in the compliant waste management. Besides, it is riskier for recyclers to prepare a business case when the composition of the products and components is unknown at material level.

At this point in the analysis, a cross check has been conducted with the experts of FutuRaM project to fine-tune results based on **feasibility checks on possible treatment technologies** and components that **have been overlooked according to the experts of FutuRaM.**

## Annex II. Analytic Hierarchy Process (AHP) – methodology and detailed results.

This methodology can be structured in five main steps that are:

1. state the decision problem/goal
2. identify the criteria/sub-criteria that influence the goal
3. structure the problem in a hierarchy of different levels
4. compare each element in the corresponding level and calibrate them on the numerical scale
5. perform consistency checks and calculations to achieve the final decision.

The methodology relies on a pairwise comparison of the relative importance of two criteria, and uses a nine-point scale for the assessment of each pair of criteria where “1” implies equal importance between two criteria and “9” indicates the absolute importance of one criterion over another (see **Table A3**).

**Table A3.** Nine-point scale for the AHP

| Intensity of importance | Definition                              |
|-------------------------|-----------------------------------------|
| 1                       | Equal importance                        |
| 3                       | Moderate importance                     |
| 5                       | Strong importance                       |
| 7                       | Very strong importance                  |
| 9                       | Absolute importance                     |
| 2, 4, 6, 8              | For compromise between the above values |

*Source: JRC elaboration.*

A pairwise comparison matrix  $C \times C$  is formed, where  $C$  is the number of elements to be compared. Note that this can be applied to both qualitative and quantitative criteria, and it is done by experts in the domain. In this case the elements to be compared are the criteria selected in section I.I.1. for the prioritisation of EU policy instruments / measures. Thus, the comparison matrix is as shown in **Table A4**.

**Table A4.** Comparison matrix overview

|      | RaC1 | RaC2 | RaC3 |
|------|------|------|------|
| RaC1 | 1    | 6    | 3    |
| RaC2 | 1/6  | 1    | 1/3  |
| RaC3 | 1/3  | 3    | 1    |

*Source: JRC elaboration.*

Then, the priority vector, i.e., the overall weighting for each criterion, is calculated. First of all, the total as the sum of the values by column is calculated as shown in **Table A5**.

**Table A5.** Total value for each criterion

|       | RaC1 | RaC2 | RaC3 |
|-------|------|------|------|
| Total | 1.5  | 10   | 4.33 |

*Source: JRC elaboration.*

And then, the normalised value is calculated by dividing each value by the total (see **Table A6**).

**Table A6.** Normalised value overview

|             | <b>RaC1</b>      | <b>RaC2</b> | <b>RaC3</b>       |
|-------------|------------------|-------------|-------------------|
| <b>RaC1</b> | 1/1.5 = 0.67     | 6/10 = 0.6  | 3/4.33 = 0.69     |
| <b>RaC2</b> | (1/6)/1.5 = 0.11 | 1/10 = 0.1  | (1/3)/4.33 = 0.08 |
| <b>RaC3</b> | (1/3)/1.5 = 0.22 | 3/10 = 0.3  | 1/4.33 = 0.23     |

Source: JRC elaboration.

Priority vector is calculated using the arithmetic mean that will be the weighted score suggested for each criterion (see **Table A7**)

**Table A7.** Weighted score for each criterion

|             | <b>Weight</b> |
|-------------|---------------|
| <b>RaC1</b> | 0.65          |
| <b>RaC2</b> | 0.10          |
| <b>RaC3</b> | 0.25          |

Source: JRC elaboration.

The AHP foresees consistency checks to assure that the consistency of the judgements is correct since it is not guaranteed due to the subjective judgements by the experts. This is mainly done through a *consistency ratio* (CR) computation (*consistency index* (CI) divided by the *random consistency index* (RI) that depends on the number of criteria being 0.58 for n=3) with a threshold of 0.1, that once it is exceeded, initial judgments must be revised by the experts:

$$CR = \frac{CI}{RI} = \frac{(\lambda - n)/(n - 1)}{0.58}$$

Where  $\lambda$  is the principal Eigen Value and is calculated through (i) a matrix multiplication of the pairwise comparison and the priority vector, and (ii) by dividing the result matrix by the priority vector's values and calculating the average of these values. In this case the  $\lambda$  equals 3.02 and the CI equals 0.0092. Thus, the CR equals  $0.02 \leq 0.1$ , being the judgement valid.

### Annex III. Classification of the elements in the waste streams.

**Table A8** is used as a reference to classify the elements in the components to run the calculations of the three criteria presented in section I.I.1. The elements are classified according to the rules defined as follows:

- PM: Precious Metal
- CRM: Critical Raw Material
- SRM: Strategic Raw Material
- OTHER: it identifies the elements which cannot be classified as above

**Table A8.** Classification of elements according to the calculation rules considering the three criteria developed for this assessment

| Element name | PM / CRM / OTHER classification                                                                                             | SRM classification                                                                    | Supply Risk of SRMs |
|--------------|-----------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------|
| Ag           | PM                                                                                                                          |                                                                                       |                     |
| Al           | Always CRM                                                                                                                  | Always SRM, also when used as Al Alloys                                               | 1.1                 |
| As           | CRM                                                                                                                         |                                                                                       |                     |
| Au           | PM                                                                                                                          |                                                                                       |                     |
| B            | CRM                                                                                                                         | B is SRM whether B is used as a metallic grade. If it is used as borate it is not SRM | 3.6                 |
| Ba           | Always CRM                                                                                                                  |                                                                                       |                     |
| Be           | Always CRM                                                                                                                  |                                                                                       |                     |
| Bi           | Always CRM                                                                                                                  | Always SRM                                                                            | 1.9                 |
| Br           | OTHER                                                                                                                       |                                                                                       |                     |
| C            | CRM if it is natural graphite. When contained in alloy it might not be natural graphite, so it shall be classified as OTHER | Natural graphite battery grade is SRM                                                 | 1.8                 |
| Ca           | OTHER                                                                                                                       |                                                                                       |                     |
| Cd           | OTHER                                                                                                                       |                                                                                       |                     |
| Ce           | Always CRM                                                                                                                  | Always SRM                                                                            | 4                   |
| Cl           | OTHER                                                                                                                       |                                                                                       |                     |
| Co           | Always CRM                                                                                                                  | Always SRM                                                                            | 2.8                 |
| Cr           | OTHER                                                                                                                       |                                                                                       |                     |
| Cu           | Always CRM.                                                                                                                 | Always SRM, also when used as Cu Alloys                                               | 0.1                 |
| Dy           | Always CRM                                                                                                                  | Always SRM                                                                            | 5.6                 |
| Er           | Always CRM                                                                                                                  |                                                                                       |                     |
| Eu           | Always CRM                                                                                                                  |                                                                                       |                     |
| F            | Always CRM                                                                                                                  |                                                                                       |                     |
| Fe           | OTHER, steel alloying elements shall be classified as OTHER                                                                 |                                                                                       |                     |

| Element name  | PM / CRM / OTHER classification                                                                                                                                                                                                                      | SRM classification                                                                                                                                  | Supply Risk of SRMs |
|---------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
|               | because they cannot be functionally recovered. Except Stainless steel where functional recycling is a common practice. Critical or Strategic raw materials used as alloying element in stainless steel shall be classified as CRM or SRM accordingly |                                                                                                                                                     |                     |
| Ga            | Always CRM                                                                                                                                                                                                                                           | Always SRM                                                                                                                                          | 3.9                 |
| Gd            | Always CRM                                                                                                                                                                                                                                           | Always SRM                                                                                                                                          | 3.3                 |
| Ge            | Always CRM                                                                                                                                                                                                                                           | Always SRM                                                                                                                                          | 1.8                 |
| H             | OTHER                                                                                                                                                                                                                                                |                                                                                                                                                     |                     |
| Hg            | OTHER                                                                                                                                                                                                                                                |                                                                                                                                                     |                     |
| I             | OTHER                                                                                                                                                                                                                                                |                                                                                                                                                     |                     |
| In            | OTHER                                                                                                                                                                                                                                                |                                                                                                                                                     |                     |
| K             | OTHER                                                                                                                                                                                                                                                |                                                                                                                                                     |                     |
| La            | Always CRM                                                                                                                                                                                                                                           |                                                                                                                                                     |                     |
| Li            | Always CRM                                                                                                                                                                                                                                           | Li battery grade is SRM                                                                                                                             | 1.9                 |
| Mg            | If Mg is used as magnesia, it shall be classified as OTHER, if used as Mg metal it shall be CRM                                                                                                                                                      | If used as Mg metal it shall be SRM. One of the main strategic uses of magnesium metals is in alloys, so it shall be classified as SRM in this case | 4.1                 |
| Mn            | Always CRM                                                                                                                                                                                                                                           | Mn battery grade is SRM                                                                                                                             | 1.2                 |
| Mo            | OTHER                                                                                                                                                                                                                                                |                                                                                                                                                     |                     |
| N             | OTHER                                                                                                                                                                                                                                                |                                                                                                                                                     |                     |
| n/a           | OTHER                                                                                                                                                                                                                                                |                                                                                                                                                     |                     |
| Na            | OTHER                                                                                                                                                                                                                                                |                                                                                                                                                     |                     |
| Nb            | Always CRM                                                                                                                                                                                                                                           |                                                                                                                                                     |                     |
| Nd            | Always CRM                                                                                                                                                                                                                                           | Always SRM                                                                                                                                          | 4.5                 |
| Ni            | Always CRM                                                                                                                                                                                                                                           | Ni battery grade is SRM                                                                                                                             | 0.5                 |
| O             | OTHER                                                                                                                                                                                                                                                |                                                                                                                                                     |                     |
| otherElements | OTHER                                                                                                                                                                                                                                                |                                                                                                                                                     |                     |
| P             | Always CRM                                                                                                                                                                                                                                           |                                                                                                                                                     |                     |
| Pb            | OTHER                                                                                                                                                                                                                                                |                                                                                                                                                     |                     |
| Pd            | Always CRM                                                                                                                                                                                                                                           | Always SRM                                                                                                                                          | 1.5                 |
| Pr            | Always CRM                                                                                                                                                                                                                                           | Always SRM                                                                                                                                          | 3.2                 |
| Pt            | Always CRM                                                                                                                                                                                                                                           | Always SRM                                                                                                                                          | 2.1                 |
| Rh            | Always CRM                                                                                                                                                                                                                                           | Always SRM                                                                                                                                          | 2.4                 |
| Ru            | Always CRM                                                                                                                                                                                                                                           | Always SRM                                                                                                                                          | 3.8                 |
| S             | OTHER                                                                                                                                                                                                                                                |                                                                                                                                                     |                     |
| Sb            | Always CRM                                                                                                                                                                                                                                           |                                                                                                                                                     |                     |

| Element name            | PM / CRM / OTHER classification                                                                      | SRM classification                                                                                                                                                                                   | Supply Risk of SRMs |
|-------------------------|------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| Sc                      | Always CRM                                                                                           |                                                                                                                                                                                                      |                     |
| Se                      | OTHER                                                                                                |                                                                                                                                                                                                      |                     |
| Si                      | If Si refers to silica sand, it shall be OTHER. Otherwise if refers to silicon metal it shall be CRM | If Si is used as silicon metal in the renewable energy (photovoltaic industry), in electronic devices, and in batteries, it shall be SRM. Otherwise it is CRM. If it is used in alloys it is not SRM | 1.4                 |
| Sm                      | Always CRM                                                                                           | Always SRM                                                                                                                                                                                           | 3.5                 |
| Sn                      | OTHER                                                                                                |                                                                                                                                                                                                      |                     |
| Sr                      | Always CRM                                                                                           |                                                                                                                                                                                                      |                     |
| Ta                      | Always CRM                                                                                           |                                                                                                                                                                                                      |                     |
| Tb                      | Always CRM                                                                                           | Always SRM                                                                                                                                                                                           | 4.9                 |
| Te                      | OTHER                                                                                                |                                                                                                                                                                                                      |                     |
| Ti                      | If used as titanium dioxide it shall be OTHER, otherwise CRM                                         | If Ti is used as titanium metal shall be SRM. Also if used in alloys, it shall be SRM                                                                                                                | 1.6                 |
| UnknownOrMissingElement | OTHER                                                                                                |                                                                                                                                                                                                      |                     |
| V                       | Always CRM                                                                                           |                                                                                                                                                                                                      |                     |
| W                       | Always CRM                                                                                           | Always SRM                                                                                                                                                                                           | 1.2                 |
| Y                       | Always CRM                                                                                           |                                                                                                                                                                                                      |                     |
| Zn                      | OTHER                                                                                                |                                                                                                                                                                                                      |                     |
| Zr                      | OTHER                                                                                                |                                                                                                                                                                                                      |                     |

Source: JRC elaboration.

## Annex IV. List of UNU-KEY within each Electric and electronic equipment (EEE) category

**Table A9.** UNU-KEY code with description of corresponding electric and electronic equipment and associated EEE category

| UNU KEY     | Description                                                                           | EU-6 Categories | EEE category under EU-6               |
|-------------|---------------------------------------------------------------------------------------|-----------------|---------------------------------------|
| <b>0001</b> | Central Heating (household installed)                                                 | 4a              | Large equipment                       |
| <b>0002</b> | Photovoltaic Panels (incl. inverters)                                                 | 4b              | Photovoltaic Panels (incl. inverters) |
| <b>0101</b> | Professional Heating & Ventilation (excl. cooling equipment)                          | 4a              | Large equipment                       |
| <b>0102</b> | Dishwashers                                                                           | 4a              | Large equipment                       |
| <b>0103</b> | Kitchen equipment (e.g. large furnaces, ovens, cooking equipment)                     | 4a              | Large equipment                       |
| <b>0104</b> | Washing Machines (incl. combined dryers)                                              | 4a              | Large equipment                       |
| <b>0105</b> | Dryers (wash dryers, centrifuges)                                                     | 4a              | Large equipment                       |
| <b>0106</b> | Household Heating & Ventilation (e.g. hoods, ventilators, space heaters)              | 4a              | Large equipment                       |
| <b>0108</b> | Fridges (incl. combi-fridges)                                                         | 1               | Temperature exchange equipment        |
| <b>0109</b> | Freezers                                                                              | 1               | Temperature exchange equipment        |
| <b>0111</b> | Air Conditioners (household installed and portable)                                   | 1               | Temperature exchange equipment        |
| <b>0112</b> | Other cooling equipment (e.g. dehumidifiers, heat pump dryers)                        | 1               | Temperature exchange equipment        |
| <b>0113</b> | Professional cooling equipment (e.g. large air conditioners, cooling displays)        | 1               | Temperature exchange equipment        |
| <b>0114</b> | Microwaves (incl. combined, excl. grills)                                             | 5               | Small equipment                       |
| <b>0201</b> | Other small household equipment (e.g. small ventilators, irons, clocks, adapters)     | 5               | Small equipment                       |
| <b>0202</b> | Equipment for food preparation (e.g. toaster, grills, food processing, frying pans)   | 5               | Small equipment                       |
| <b>0203</b> | Small household equipment for hot water preparation (e.g. coffee, tea, water cookers) | 5               | Small equipment                       |
| <b>0204</b> | Vacuum Cleaners (excl. professional)                                                  | 5               | Small equipment                       |
| <b>0205</b> | Personal Care equipment (e.g. toothbrushes, hairdryers, razors)                       | 5               | Small equipment                       |
| <b>0301</b> | Small IT equipment (e.g. routers, mice, keyboards, external drives & accessories)     | 6               | Small IT                              |
| <b>0302</b> | Desktop PCs (excl. monitors, accessories)                                             | 6               | Small IT                              |
| <b>0303</b> | Laptops (incl. tablets)                                                               | 2               | Screens and monitors                  |
| <b>0304</b> | Printers (e.g. scanners, multi-functional, faxes)                                     | 6               | Small IT                              |
| <b>0305</b> | Telecommunication equipment (e.g. cordless phones, answering machines)                | 6               | Small IT                              |
| <b>0306</b> | Mobile Phones (incl. smartphones, pagers)                                             | 6               | Small IT                              |
| <b>0307</b> | Professional IT equipment (e.g. servers, routers, data storage, copiers)              | 4a              | Large equipment                       |
| <b>0308</b> | Cathode Ray Tube Monitors                                                             | 2               | Screens and monitors                  |
| <b>0309</b> | Flat Display Panel Monitors (LCD, LED)                                                | 2               | Screens and monitors                  |
| <b>0401</b> | Small Consumer Electronics (e.g. headphones, remote controls)                         | 5               | Small equipment                       |
| <b>0402</b> | Portable Audio & Video (e.g. MP3, e-readers, car navigation)                          | 5               | Small equipment                       |

| <b>UNU KEY</b> | <b>Description</b>                                                                      | <b>EU-6 Categories</b> | <b>EEE category under EU-6</b> |
|----------------|-----------------------------------------------------------------------------------------|------------------------|--------------------------------|
| <b>0403</b>    | Music Instruments, Radio, Hi-Fi (incl. audio sets)                                      | 5                      | Small equipment                |
| <b>0404</b>    | Video (e.g. Video recorders, DVD, Blue Ray, set-top boxes) and projectors               | 5                      | Small equipment                |
| <b>0405</b>    | Speakers                                                                                | 5                      | Small equipment                |
| <b>0406</b>    | Cameras (e.g. camcorders, photo & digital still cameras)                                | 5                      | Small equipment                |
| <b>0407</b>    | Cathode Ray Tube TVs                                                                    | 2                      | Screens and monitors           |
| <b>0408</b>    | Flat Display Panel TVs (LCD, LED, Plasma)                                               | 2                      | Screens and monitors           |
| <b>0501</b>    | Small lighting equipment (excl. LED & incandescent)                                     | 5                      | Small equipment                |
| <b>0502</b>    | Compact Fluorescent Lamps (incl. retrofit & non-retrofit)                               | 3                      | Lamps                          |
| <b>0503</b>    | Straight Tube Fluorescent Lamps                                                         | 3                      | Lamps                          |
| <b>0504</b>    | Special Lamps (e.g. professional mercury, high & low-pressure sodium)                   | 3                      | Lamps                          |
| <b>0505</b>    | LED Lamps (incl. retrofit LED lamps)                                                    | 3                      | Lamps                          |
| <b>0506</b>    | Household Luminaires (incl. household incandescent fittings & household LED luminaires) | 5                      | Small equipment                |
| <b>0507</b>    | Professional Luminaires (offices, public space, industry)                               | 5                      | Small equipment                |
| <b>0601</b>    | Household Tools (e.g. drills, saws, high-pressure cleaners, lawnmowers)                 | 5                      | Small equipment                |
| <b>0602</b>    | Professional Tools (e.g. for welding, soldering, milling)                               | 4a                     | Large equipment                |
| <b>0701</b>    | Toys (e.g. car racing sets, electric trains, music toys, biking computers, drones)      | 5                      | Small equipment                |
| <b>0702</b>    | Game Consoles                                                                           | 6                      | Small IT                       |
| <b>0703</b>    | Leisure equipment (e.g. sports equipment, electric bikes, jukeboxes)                    | 4a                     | Large equipment                |
| <b>00801</b>   | Household medical equipment (e.g. thermometers, blood pressure meters)                  | 5                      | Small equipment                |
| <b>0802</b>    | Professional medical equipment (e.g. hospital, dentist, diagnostics)                    | 4a                     | Large equipment                |
| <b>0901</b>    | Household Monitoring & Control equipment (alarm, heat, smoke, excl. screens)            | 5                      | Small equipment                |
| <b>0902</b>    | Professional Monitoring & Control equipment (e.g. laboratory, control panels)           | 4a                     | Large equipment                |
| <b>1001</b>    | Non-cooled Dispensers (e.g. for vending, hot drinks, tickets, money)                    | 4a                     | Large equipment                |
| <b>1002</b>    | Cooled Dispensers (e.g. for vending, cold drinks)                                       | 1                      | Temperature exchange equipment |
| <b>9010</b>    | Large temperature exchange equipment in buildings cat 1 open scope                      | 1                      | Temperature exchange equipment |
| <b>9019</b>    | Cat 1 other open scope                                                                  | 1                      | Temperature exchange equipment |
| <b>9041</b>    | Cat 4 large central heating in building                                                 | 4a                     | Large equipment                |
| <b>9049</b>    | Cat 4 other open scope                                                                  | 4a                     | Large equipment                |

Source: JRC elaboration, adapted from (Forti, Baldé, and Kuehr 2018).

## Annex V. List of materials and components present in the total WEEE<sup>37</sup>.

**Table A10.** Materials of electric and electronic equipment

| Materials                                                                                                                                   |
|---------------------------------------------------------------------------------------------------------------------------------------------|
| additives                                                                                                                                   |
| aggregateBinderMixedMaterials                                                                                                               |
| AlAndAlAlloys                                                                                                                               |
| batteryMaterials                                                                                                                            |
| bitumen                                                                                                                                     |
| carbon                                                                                                                                      |
| composites                                                                                                                                  |
| constructionMinerals                                                                                                                        |
| CuAndCuAlloys                                                                                                                               |
| ferrousMetals                                                                                                                               |
| fluids                                                                                                                                      |
| glassAndCeramics                                                                                                                            |
| mixedMaterials                                                                                                                              |
| nonCuAndAlAlloys                                                                                                                            |
| otherMaterials                                                                                                                              |
| otherMinerals                                                                                                                               |
| otherOrganics                                                                                                                               |
| paperCarton                                                                                                                                 |
| permanentMagneticMaterials                                                                                                                  |
| plastics                                                                                                                                    |
| Rest of the materials resulted from a mass balance in our composition dataset. It consists of a mix of material not specifically identified |
| SiSemiconductor                                                                                                                             |
| Wood                                                                                                                                        |

Source: FutuRaM elaboration.

**Table A11.** Components of the electric and electronic equipment

| Components         |
|--------------------|
| Brush              |
| burnerNiobiumTube  |
| Cables             |
| cameraIntegrated   |
| capUnspecified     |
| casingPlasticBased |
| casingSteelBased   |

<sup>37</sup> Note that for some materials and components updates are expected, especially for permanent magnets since according to their characteristics are used in different components.

| <b>Components</b>                                              |
|----------------------------------------------------------------|
| casingUnspecified                                              |
| compContainHazardSubst                                         |
| compressor                                                     |
| condensator                                                    |
| CRTwhole                                                       |
| displayCRT                                                     |
| displayLCD                                                     |
| displayOther                                                   |
| displayPlasma                                                  |
| displayTFT                                                     |
| driveCDDExt                                                    |
| driveCDDInt                                                    |
| driveFDD                                                       |
| driveHDD                                                       |
| driveUnspecified                                               |
| electricEngine                                                 |
| filterFoamBased                                                |
| fluorescentPowder (rem.)                                       |
| Foil                                                           |
| Fuse                                                           |
| Gear                                                           |
| heatingCoolingAirCondenserEEE                                  |
| heatingCoolingFanEEE                                           |
| heatingCoolingHeatSinkEEE                                      |
| heatingResistor                                                |
| HgVapourInLamps (rem.)                                         |
| inductor                                                       |
| insulation                                                     |
| keyboard                                                       |
| Knob                                                           |
| lenseAssembly                                                  |
| lighting                                                       |
| magnetPermanent                                                |
| magnetron                                                      |
| magnetSensor                                                   |
| nobleGases (rem.)                                              |
| nonElectricCoil                                                |
| otherElectricCompUnspecified                                   |
| otherNonElectricCompUnspecified                                |
| passiveJunctionBox                                             |
| PCBWEEE                                                        |
| plug                                                           |
| powerSupply                                                    |
| pump                                                           |
| PVBacksheet                                                    |
| PVcellCdTe                                                     |
| PVcellCIGS                                                     |
| PVcellSi                                                       |
| PVEncapsulationEVA                                             |
| PVFrameAl                                                      |
| PVSolarGlass                                                   |
| Refrigerant                                                    |
| Remaining fraction after specific dismantling in pre-treatment |
| RemoteControl                                                  |

| <b>Components</b> |
|-------------------|
| Rotor             |
| screw             |
| sensorUnspecified |
| solenoidValve     |
| speakerEEE        |
| switch            |
| thermostat        |
| tonerCartridge    |
| touchSensor       |
| transformerEEE    |
| Transmission      |
| Transmitter       |
| Wheel             |

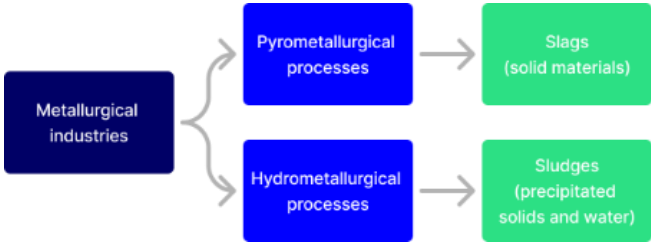
*Source: FutuRaM elaboration.*

## Annex VI. Background information on data collection and data elaboration of the different waste streams.

**Table A12.** Background information on data collection and data elaboration of the different waste streams

| Waste stream | Stream description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | List of data sources | Temporal and geographical scale | Methodology of data collection and processing             |
|--------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|---------------------------------|-----------------------------------------------------------|
| Batteries    | <p><b>Portable Batteries</b></p> <p><b>Industrial Batteries</b></p> <p>The diagram illustrates the waste management process for two types of batteries: Portable and Industrial. For Portable Batteries, the process starts with data from Eurostat and Avicenne, leading to a Stock, then Waste Generated, which is then Collected, flows into MSW, can be Exported for reuse, or becomes Losses. For Industrial Batteries, the process starts with Avicenne data, leading to a Stock, then Waste Generated, which is then Collected or becomes Losses. Both processes include detailed notes on data sources and methodologies.</p> | FutuRaM              | EU27+4 and MS, 2010-2050        | Primary data collection (complemented by literature data) |

| Waste stream                        | Stream description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | List of data sources                                                                                                          | Temporal and geographical scale                                                     | Methodology of data collection and processing                                                  |
|-------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|
|                                     | <p>Light means of transport (LMT)</p> <p><b>Waste Generated:</b></p> <ul style="list-style-type: none"> <li>- Using Weibull PDF (shape and scale parameters)</li> </ul> <p><b>Collected:</b></p> <ul style="list-style-type: none"> <li>- By expert interviews</li> <li>- Collection rate methodology according to new Battery Regulation</li> </ul> <p><b>Losses:</b></p> <ul style="list-style-type: none"> <li>- By expert interviews</li> <li>- Losses set to 5% of waste generated</li> </ul> <p><b>POM:</b></p> <ul style="list-style-type: none"> <li>- JRC – Available for collection 1</li> <li>- Country shares (eMotorcycles, eMopeds) from ACEM</li> <li>- Country shares (eBikes) mainly by CONEBI</li> <li>- Country shares (eScooters) by</li> <li>- Composition data</li> </ul> <p><b>Stock:</b></p> <ul style="list-style-type: none"> <li>- Using Weibull PDF (shape and scale parameters)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                               |                                                                                     |                                                                                                |
| Electrical and electronic equipment | <p><b>Composition</b>      <b>Stock and flow</b>      <b>EoL data (recyclability focus)</b></p> <p><b>Composition data at category level (c-m-e)</b> → <b>POM</b> → <b>Stock</b> → <b>Waste generated</b></p> <p><b>Waste generated</b> splits into:</p> <ul style="list-style-type: none"> <li>Waste exported</li> <li>Waste collected as metal scrap</li> <li>Waste collected</li> <li>Waste collected as any other complementary flow</li> <li>Waste collected as MSW</li> </ul> <p><b>Waste collected</b> leads to:</p> <ul style="list-style-type: none"> <li>RepTool &amp; other reporting systems data from PROs</li> <li>Transfer coefficients data on EoL</li> <li>Questionnaires on EoL</li> </ul> <p><b>Data used for the prioritization</b> (green box)      <b>Supplementary data supporting the rationale</b> (orange box)</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | FutuRaM (primary data from apparent consumption method, Eurostat, waste composition data, literature data, and modelled data) | composition (EU27+4), composition in stock and flow (MS in the EU27+4), 2022 - 2030 | Primary data collection (complemented by literature data), mathematical and statistical models |
| Wind turbines                       | All the details are in section 4.3 and related sub-sections                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | -                                                                                                                             | -                                                                                   | -                                                                                              |
| Vehicles                            | <p><b>New cars</b> → <b>Import of used cars</b> → <b>Fleet in use</b> → <b>Deregistered vehicles</b></p> <p><b>Deregistered vehicles</b> splits into:</p> <ul style="list-style-type: none"> <li>Vehicle gap</li> <li>End-of-Life vehicles (ELV)</li> <li>Export of used cars</li> </ul> <p><b>New cars:</b></p> <ul style="list-style-type: none"> <li>- Eurostat data</li> <li>- Complementary data from ACEA, ICCT, United Nations, OECD, VINCE</li> <li>- Compositions data from literature and industry reports</li> </ul> <p><b>Import of used cars:</b></p> <ul style="list-style-type: none"> <li>- Historical data from Convent</li> <li>- Future data constant 2022 import rate</li> </ul> <p><b>Fleet in use:</b></p> <ul style="list-style-type: none"> <li>- Historical data from Eurostat</li> <li>- Calculation of future data using stock and flow equation</li> </ul> <p><b>Deregistered vehicles:</b></p> <ul style="list-style-type: none"> <li>- Using Weibull PDF (shape and scale parameters)</li> </ul> <p><b>Vehicle gap:</b></p> <ul style="list-style-type: none"> <li>- (Deregistered vehicles) - (ELV) - (Export of used cars)</li> </ul> <p><b>End-of-Life vehicles (ELV):</b></p> <ul style="list-style-type: none"> <li>- Historical data from Eurostat and national authorities</li> <li>- Future data calculated from deregistration</li> </ul> <p><b>Export of used cars:</b></p> <ul style="list-style-type: none"> <li>- Historical data from Convent</li> <li>- Future data constant 2022 export rate</li> </ul> | Eurostat<br>ACEA<br>ICCT<br>OECD                                                                                              | EU27+4 and MS, 2010-2050                                                            | Secondary data collection                                                                      |

| Waste stream             | Stream description                                                                                                                                                                                                                                                                                                                                   | List of data sources                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Temporal and geographical scale | Methodology of data collection and processing |
|--------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------|-----------------------------------------------|
| Slags, sludge, and ashes | <p>Slugs and sludges</p>  <pre> graph LR     A[Metallurgical industries] --&gt; B[Pyrometallurgical processes]     A --&gt; C[Hydrometallurgical processes]     B --&gt; D[Slags (solid materials)]     C --&gt; E[Sludges (precipitated solids and water)] </pre> | <p>FutuRaM data elaboration based on several sources, including: Franus, W., Wiatros-Motyka, M. M., &amp; Wdowin, M. (2015), Environmental Science and Pollution Research, 22(12), 9464-9474.</p> <p>N. Moreno et al., "Physico-Chemical Characteristics of European Pulverized Coal Combustion Fly Ashes," Fuel, vol. 84, no. 11, pp. 1351 - 1363, Elsevier, Jan 2005</p> <p>Sajn et al. Secondary Deposits as a Potential REEs Source in South-Eastern Europe. Minerals 14(2) 120, 2024.</p> <p>RIS-ALiCE Registry of secondary mineral raw materials <a href="https://www.alice-registry.eu/">https://www.alice-registry.eu/</a></p> | EU27+4 and MS, 2010-2050        | Secondary data collection                     |

| Waste stream                | Stream description                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | List of data sources                                                                                                              | Temporal and geographical scale | Methodology of data collection and processing |
|-----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|---------------------------------|-----------------------------------------------|
|                             | <p>Ashes:</p> <pre> graph LR     Biomass --&gt; PP1[Power plants]     Biomass --&gt; Inc1[Incinerator]     PP1 --&gt; BA[Biomass ashes]     Inc1 --&gt; BA     Coal --&gt; PP2[Power plants]     PP2 --&gt; CA[Coal ashes]     MSW --&gt; EWI[Energy-from-waste incineration plant]     MSW --&gt; MSI[MSW incinerator]     EWI --&gt; MSA[MSW ashes]     MSI --&gt; MSA     WTS[Water treatment sludges] --&gt; Inc2[Incinerator]     Inc2 --&gt; SSA[Sewage sludge ashes] </pre> |                                                                                                                                   |                                 |                                               |
| Construction and demolition | Flow chart not available                                                                                                                                                                                                                                                                                                                                                                                                                                                           | The collected data is based on an already existing database compiled by Heeren and Fishman (MI database) (Heeren & Fishman, 2019) | EU27 2022 and 2030              | Secondary data collection                     |

Source: FutuRaM elaboration.

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