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Material Flow Analysis of Aluminium, Copper, and Iron in the EU-28

Passarini, F.

Ciacci, L.

Nuss, P.

Manfredi, S.

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Contact information
Name: Simone Manfredi
Address: DG Joint Research Centre, Sustainable Resources Directorate, Unit D3 – Land Resources, TP29, Via Enrico Fermi 2749, I - 21027 Ispra (VA) Italia
E-mail: simone.manfredi@ec.europa.eu
Tel.: +39 0332 786046

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Authors

Fabrizio Passarini, Luca Ciacci, Philip Nuss, Simone Manfredi

Abstract

The EC Raw Materials System Analysis (MSA) was carried out in 2015 for 28 materials[1]. The MSA study investigates the flows of materials through the EU economy in terms of entry into the EU, flows through the economy, stock accumulation, and end-of-life management, e.g., through disposal or recovery in the EU-28. The MSA study is a follow-up of the "Study on Data Needs for a Full Raw Materials Flow Analysis"[2] , launched by the European Commission in 2012 within the context of the European Raw Materials Initiative's (RMI) strategy. This strategy, which is a part of the Europe 2020's strategy for smart, sustainable, and inclusive growth, aims at securing and improving access to raw materials for the EU.

The MSA is a key building block of the European Union Raw Materials Knowledge Base (EURMKB). MSAs are an important data provider for a variety of raw material policy knowledge needs, as also reflected in the Raw Materials Information System (RMIS). The RMIS aims to support the broad range of EU policy knowledge needs of, e.g., the EU Raw Materials (RM) Scoreboard, EU Critical Raw Materials (CRM) assessment, and EU trade negotiations. In addition, it also aims to support broader coordination beyond these needs of other EU level data and information on raw materials. For both of these EUKBRM/RMIS roles, MSA is a vital backbone. The MSA data sets contain key, material specific data and information that will support the development of a database for the RMIS. However, currently only 28 MSA studies exist (mostly for CRMs) which are quickly becoming outdated. So far, no MSA studies exist for some of the major metals (e.g., iron, copper, aluminium, zinc, or nickel) which are important to the EU economy, e.g., due to the large quantities in which find use as well as due to their use in special application, e.g., as alloying elements.

Against this background, this report presents, firstly, detailed MSA studies for aluminium (Al), copper (Cu), and iron (Fe) and discusses, secondly, possibilities for future MSA update and maintenance in the RMIS.

Overall, the results show that the EU-28 has a well-established industrial chain for all the three metals covering the major value chain steps (from extraction to end-of-life). However, modest natural deposits make the region strongly dependent on imports to meet the domestic demand of primary material[3]. Only a small fraction of total primary metal input to processing in the EU-28 is supplied from domestic extraction ranging from 10% (Al) to 13% (Fe).

Demand-supply dynamics and product lifetime determine the accumulation of materials as in-use stocks and scrap generation at end-of-life. Iron, aluminium, and copper are used in large quantities (compared to other metals) and their major application segments have relatively long in-use lifetimes (e.g., 50-75 years for building and construction). In-use stock[4] for the three metals in EU-28 were estimated at about 5,300 Tg for iron (or around 10 t per capita), 132 Tg for aluminium (around 260 kg per capita), 73 Tg for copper (around 140 kg per capita).

A consolidated recycling industry supplements primary supply of aluminium, copper and iron with inputs from secondary sources (i.e., new scrap[5] and old scrap[6]). In particular, old scrap recycling performance attests respectable end-of-life recycling rates (EOL-RR)[7]

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[1] https://ec.europa.eu/jrc/en/scientific-tool/msa

[2] https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en/community/document/rpa-report-data-needs-full-raw-materials-flow-analysis-annexes-final-report

[3] Virgin or new materials, such as iron ore, used in making products.

[4] "In-use stock" is the amount (mass) of a given material in the antroposhere, as the result of the shift in metal stocks from the lithosphere to the anthroposphere

[5] New scraps are generated in manufacturing processes and has typical lives of weeks to months until its return to the production process. It has a known composition and origin.

[6] This is material recovered from products, and other constitute mixtures of elements alloys, plastics, and other constituents which need detailed processing to obtain recyclates for raw materials production.

[7] EOL-RR is the fraction of a given material that is recycled at the end of the material's life cycle.

for the three metals (i.e., 69% aluminium, 61% copper, 75% iron), but they are still far from "perfect" recycling.

In addition, not all old scrap collected for recycling is processed in the EU-28, with the region being a net-exporter of secondary material. Material loss in products at end-of-life and net-exports of secondary material forms constraint the closure of material cycles and prevent the implementation of a circular economy in the EU-28 requiring the adoption of resource efficiency strategies priority.

Because of its system-wide perspective on raw materials issues (encompassing all life-cycle stages of a raw material), the MSA provides an overarching data structure that could be based inside the RMIS database (DB) core to collect, store, and provide data also for other policy knowledge needs (i.e., EU CRM assessment, Circular Economy Monitoring, Trade, Minventory, RM Scoreboard). Flows/stocks parameters of the MSA can also be important to satisfy knowledge needs that may arise as a result of future policy needs, e.g., through resilience, determining urban stocks, and other emerging issues. Equally, complete MSAs can help in the quality assurance of the underlying mass balance/data and increasing harmonization of the various data sources – which cannot be guaranteed if only a partial picture exists.

Results from an assessment of data overlaps between MSA and other policy-related outputs show that current policy knowledge needs often require data on various flows related to the early stages of a raw material's life-cycle. For example, a total of 12 flows (out of 40 in total) of the MSA are also required for the 2017 CRM assessment. Data on secondary raw materials are essential for current circular economy monitoring, but generally difficult to obtain without MSAs.

Possibilities for MSA update and maintenance range from partial data updates (harvesting data synergies with current policy-related outputs, e.g., the CRM assessment, Scoreboard, and Trade module in RMIS) to carrying out full/systematic MSAs for most candidate materials of the CRM assessment (through European Commission (EC) internal research projects and outsourcing via external contracts).

Keywords: Material Flow Analysis, EU Critical Raw Materials Assessment, Data Visualizations, Network Analysis, EU Raw Materials Information System.

1 Introduction

1.1 Monitoring of Raw Materials in the EU

Europe relies on reliable and robust knowledge on materials stocks and flows to promote innovation along the entire value chain of raw materials (EC, 2012a). The European Commission (EC) promotes better monitoring of raw materials through their full supply chain (i.e., from resource extraction to materials processing to manufacturing and fabrication to use and then to collection, processing and disposal) through a variety of activities. For example, the EU Raw Materials Information System (RMIS) [8] supports the need for a European Raw Materials Knowledge Base (EURMKB), as highlighted in Action area no. II.8 of the 2013 Strategic Implementation Plan (SIP) for the European Innovation Partnership (EIP) on Raw Materials (EC, 2008, 2012b) and a specific action of the Circular Economy Communication of the EC (EC, 2017a).

The RMIS aims at providing EU level data and information on non-energy, non-food materials (e.g., metals, industrial and construction minerals, and biomass for materials purposes) from primary and secondary sources in a harmonized and standardized way and considering that supply chains are generally global. It acts as an entry point to the EU Knowledge Base on Raw Materials, facilitating the availability of data and information in a coordinated manner. Priority is given to needs of EC policy. The RMIS also includes policy-related outputs such as the EU Raw Material System Analysis (MSA) (BIO by Deloitte, 2015), EU Critical Raw Materials (CRM) assessment (EC, 2011, 2014, 2017b), EU Raw Materials Scoreboard (Vidal-Legaz et al., 2016), and others.

The RMIS includes a material flow analysis module that includes the MSA studies carried out so far (Figure 1). The MSA aims at providing a concise picture of material stocks and flows of individual materials in the EU-28 (BIO by Deloitte, 2015) using Sankey diagrams as a visualization tool (Schmidt, 2008).

[8] http://rmis.jrc.ec.europa.eu/

Figure 1 The EU Raw Materials Information System and its Material Flow Analysis (MFA) module[9].

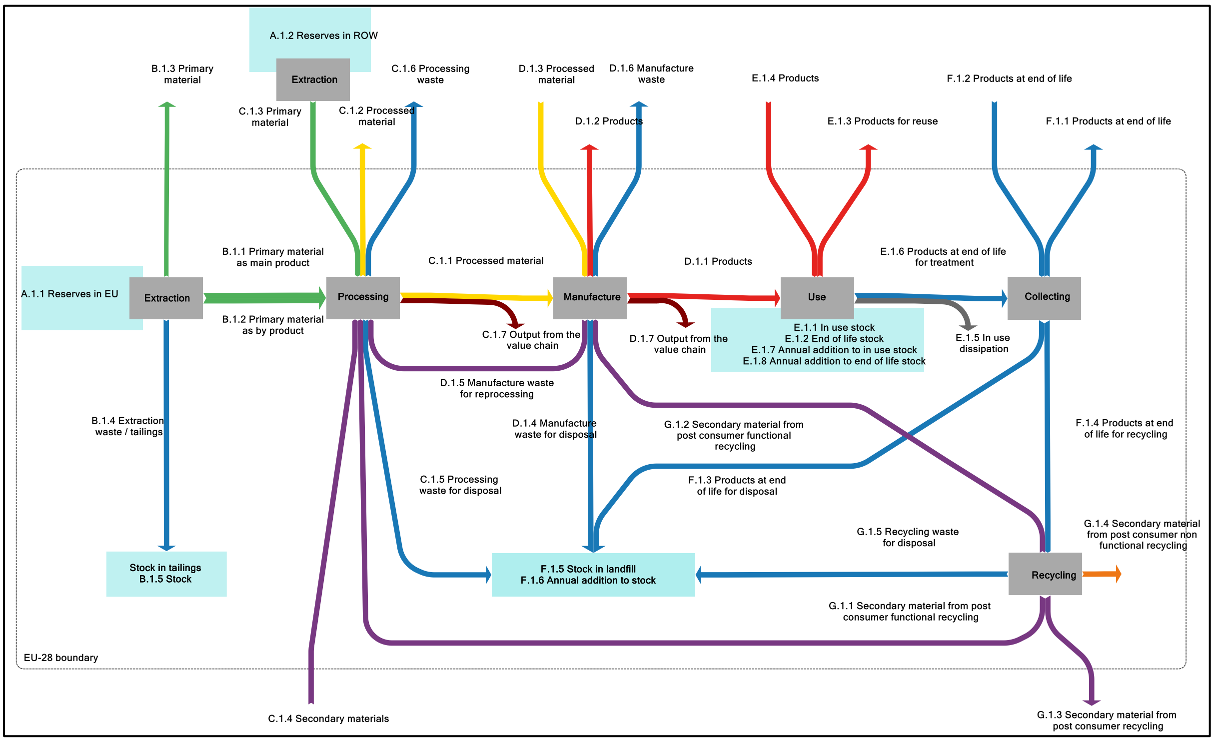
1.2 EC Raw Materials System Analysis (MSA)

The **MSA** is part of the material flow analysis (MFA) module in RMIS and investigates the flows of materials through the EU economy in terms of entry into the EU, flows through the economy, additions to stock, and end-of-life management, e.g., through disposal or recovery in the EU-28 (BIO by Deloitte, 2015) (Figure 2). The MSA study has been carried out by DG GROWTH with the consultation of expert and stakeholders. This is a follow-up of the "Study on Data Needs for a Full Raw Materials Flow Analysis" (EC, 2012a), launched by the European Commission in 2012 within the context of the European Raw Materials Initiative's (RMI) strategy. This strategy, which is a part of the Europe 2020's strategy for smart, sustainable, and inclusive growth, aims at securing and improving access to raw materials for the EU[10]. The objective of the 2015 MSA study was to provide information on material stocks and flows and to assist the EC in the development of a complete Material System Analysis (MSA) (from 'cradle-to-grave') for a selection of key raw materials used in the EU-28, some of them considered as critical for the economy of the EU-28 or the so-called "Critical Raw Materials". Given that the MSA looks at each stage of a material life-cycle, it provides a consistent data set of the

[9] http://rmis.jrc.ec.europa.eu/?page=mfa-inventory-fc6a02#/
[10] http://ec.europa.eu/growth/sectors/raw-materials/policy-strategy/index_en.htm

material stocks and flows, a comprehensive set of baseline information for EU policy knowledge needs on raw materials, and more specifically to policy-related outputs of GROWTH, some of which are currently being integrated into the RMIS.

Figure 2 MSA study framework and material flows/stocks considered[11].



[11] Source: (BIO by Deloitte, 2015)

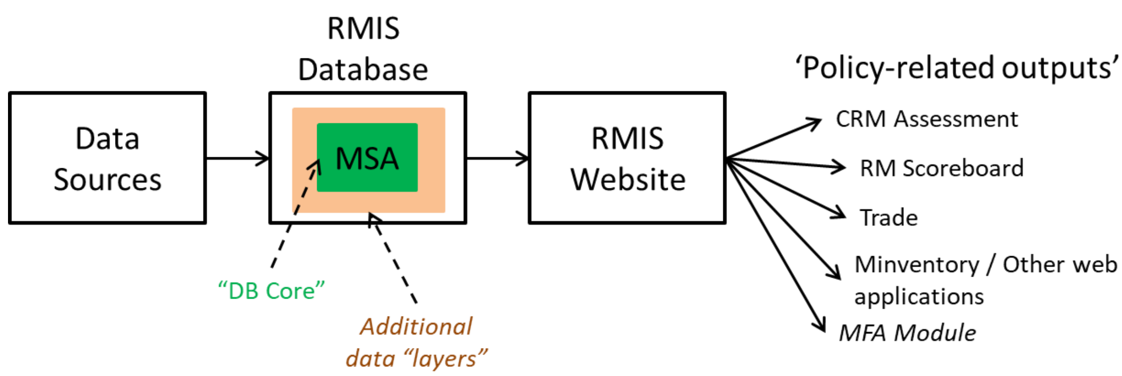
2 Goal & Scope of this Report

The objective of this report is to **expand the number of MSA studies by three materials (i.e., aluminium, copper, and iron)** and to discuss options for maintaining and updating the MSA as a more integrated part of the RMIS 2.0.

Because of its system-wide perspective on raw materials issues (encompassing all life-cycle stages of a material), the MSA provides an overarching data structure that could be based inside the RMIS database core to collect, systematically arrange (by life-cycle stage), store, and provide data for policy-related knowledge needs on raw materials. By comprehensively tracking material stocks and flows, the MSA could also be an important data provider for future policy needs that could arise, e.g., from needs for imports and exports data in trade discussions, environmental assessments of supply chains, analyses of the EU in terms of resilience, and using better estimates on in-use stocks of materials to enhance security of supply and adaptation. The data resulting from the MSA study for CRMs provide an important base of background information from which future materials criticality can be better addressed, and sustainable development pathways, on an EU-wide scope, designed.

A schematic illustration showing the MSA structure and related data (Figure 2) as the database (DB) core of the RMIS is given in Figure 3.

Figure 3 Schematic figure showing the MSA as a possible RMIS database (DB) core to structure raw materials data and partially meet the policy knowledge needs arising, e.g., from the CRM assessment, RM Scoreboard, trade module, Minventory, and other web applications shown on the RMIS website. Additional data layers implies additional data entries that would be required (in addition to the DB core) to generate the policy-related outputs.



The present study provides new MSA studies for three selected materials, namely aluminium, copper, and iron. Although the 2015 MSA study provided data for 28 materials, the focus was mostly on providing data for CRMs. As such, major metals including aluminium copper, iron, zinc, and nickel which are important for any modern economy (e.g., for use in construction, alloys, transportation, etc. (Graedel et al., 2015; Nuss et al., 2014)) were not yet included.

The second part of this report proposes ideas on how existing and future MSA studies could be integrated and mainatined into the RMIS. These range from periodical updates using frequently released data, to better integration with existing raw material-related outputs (CRM, Scoreboard, etc.), to complete updates through research and/or outsourcing to external experts.

For this, we highlight the specific data needs of the MSA study and show existing data synergies (overlaps) between the other policy-related outputs in RMIS. The CRM assessment, Scoreboard, Minventory[12] and Trade module can be seen as final *"policy-related outputs"*[13] of DG GROWTH which are partly supported by data collected in the MSA. The goal is to integrate these into a common database in RMIS 2.0 in the future, the so-called "RMIS database core". The RMIS also aims to help coordination of other EU level data and information on raw materials and could therefore also be seen as a gateway to material flow analysis (MFA) data collected by external entities (e.g., industry associations, national governments, or the academic community).

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[12] The Minventory study (https://ec.europa.eu/jrc/en/scientific-tool/minventory) collected metadata and standards employed by EU Member States and neighbouring countries of Europe in quantifying resource and reserve information related to primary and secondary mineral raw materials.

[13] The circular economy monitoring framework (http://ec.europa.eu/environment/circular-economy/pdf/monitoring-framework.pdf) also is an important policy output which uses MSA data, e.g., in the calculation of the end-of-life recycling input rate.

3 Methodology

3.1 Material Flow Analysis

The methodology used to carry out the three MSA studies (aluminium (Al), copper (Cu), and iron (Fe)) is material flow analysis (MFA) (Brunner and Rechberger, 2016; Harper et al., 2006). The overall framework and generated data sets follow the MSA data structure and flows specified in the previous MSA study for 28 raw materials (BIO by Deloitte, 2015).

Flows and stocks are accounted in mass of target metal for the most recent year possible (i.e., 2013 for aluminium, 2014 for copper, and 2015 for iron). All the quantitative results originate from calculations made by the project team and are based on several data sources. Data quality (e.g., assumptions, uncertainties, and geographical representativeness) has been assessed. The values presented here are not raw data but aggregated results.

3.2 MSA Validation Workshop

In November 2017 the JRC invited a number of external experts for a review process of the three new MSA (i.e., Al, Cu, and Fe). A MSA data validation workshop was subsequently held on 12th December in Brussels to discuss the three MSA studies in depth and fill additional data gaps. This workshop covered a brief overview to explain the EC MSA study and RMIS, followed by a presentation of the detailed pre-results (draft MSAs) for each material and a technical discussion requesting feedback from the invited experts to further improve the database. The draft MSA reports were shared in advance of the workshop with the experts for written and oral feedback during the workshop. This report presents the consolidated meeting report in which action-oriented items are included that will help to further improve the draft MSA studies and to find wide acceptance among the experts/stakeholders.

The three MSA studies were discussed and data reviewed during the MSA data validation workshop. The goal was to increase transparency of the data sources and modelling approach used and to request feedback on how data could be further improved (e.g., availability of newer data, more EU-specific datasets). Furthermore, feedback was requested on the overall MSA methodology to further align it with other data collected by the EC and increase acceptance also among the academic community. Details of the MSA validation workshop are provided in Table 1 and the list of experts that were invited in Table 2.

Workshop program

Location: DG JRC Headquarters Brussels, Room CDMA 06/144; Date: Tuesday, 12.12.2017

Table 1 Workshop agenda

Date	Time	Session Details
Tuesday, 12.12.2017	9:00 – 9:15	**Registration and Coffee**
	9:15 – 11:00	**Session I: Data validation of Aluminium**
	9:15 – 9:25	General presentation of the project: context, objectives, tasks, timeline *(Simone Manfredi and Philip Nuss, DG JRC)*
	9:25 – 9:40	Material Flow Modelling in the EU Aluminium Industry

Date	Time	Session Details
		(Djibril Rene, European Aluminium)
	9:40 – 11:00	Aluminium pre-results and discussion *(Fabrizio Passarini and Luca Ciacci, University of Bologna)*
	11:00 – 11:10	Short Break
	11:10 – 12:45	**Session II: Data validation of Copper**
	11:10 – 11:20	MSA studies in RMIS *(Philip Nuss, DG JRC)*
	11:20 – 12:45	Copper pre-results and discussion *(Fabrizio Passarini and Luca Ciacci, University of Bologna)*
	12:45 – 13:45	**Lunch**
	13:45 – 16:00	**Session III: Data validation of Iron**
	13:45 – 14:00	The MinFuture H2020 project *(Maren Lundhaug, NTNU)*
	14:00 – 14:10	Raw Materials policies in the EU *(Milan Grohol, DG GROWTH)*
	14:10 – 15:30	Iron pre-results and discussion *(Fabrizio Passarini and Luca Ciacci, University of Bologna)*
	15:30 – 15:40	Conclusions & Next steps *(Simone Manfredi, DG JRC)*

List of Experts/Stakeholders Consulted for Feedback/Comments:

Table 2 List of experts consulted for feedback and comments

No.	Institution	Contact
1	Aurubis AG	Florian Anderhuber
2	BioDeloitte	Mariane Planchon
3	British Geological Survey	Evi Petavratzi
4	Cambridge University	Jonathan Cullen
5	Deutsches Kupferinstitut Berufsverband e.V	Ladji Tikana
6	DG GROWTH	Lie Heymans
7	DG GROWTH	Marie-Theres Kuegerl
8	DG GROWTH	Milan Grohol
9	DG GROWTH	Patrice Millet
10	DG GROWTH	Rodrigo Chanez
11	DG JRC	Gadzina-Kolodziejska Agnieszka
12	DG JRC	Simone Manfredi *(Workshop Organizer)*
13	DG JRC	Philip Nuss *(Workshop Organizer)*
14	Eurogeosurveys (EGS)	Slavko Solar
15	Euromines	Mirona Coropciuc
16	European Aluminium	Djibril René
17	European Steel Association	Aurelio Braconi
18	Eurostat E2	Stephan Moll
19	Eurostat G3	Constantin-Alin Popescu
20	Fraunhofer Institute	Luis Tercero Espinoza
21	Helmholtz Institute Freiberg for Resource Technology	Markus Reuter
22	International Copper Study Group	Carlos R. Risopatron
23	LKAB	Stefan Savonen

No.	Institution	Contact
24	NTNU	Maren Lundhaug
25	University of Bologna	Fabrizio Passarini *(Project Team)*
26	University of Bologna	Luca Ciacci *(Project Team)*
27	University of Freiburg	Stefan Pauliuk
28	University of Southern Denmark	Gang Liu
29	World Aluminium	Chris Bayliss.
30	World Aluminium	Marlen Bertram

4 Results

4.1 MSA for Aluminium

4.1.1 Value chain

The main primary source of aluminium is bauxite, which contains about 29% Al on a mass basis.

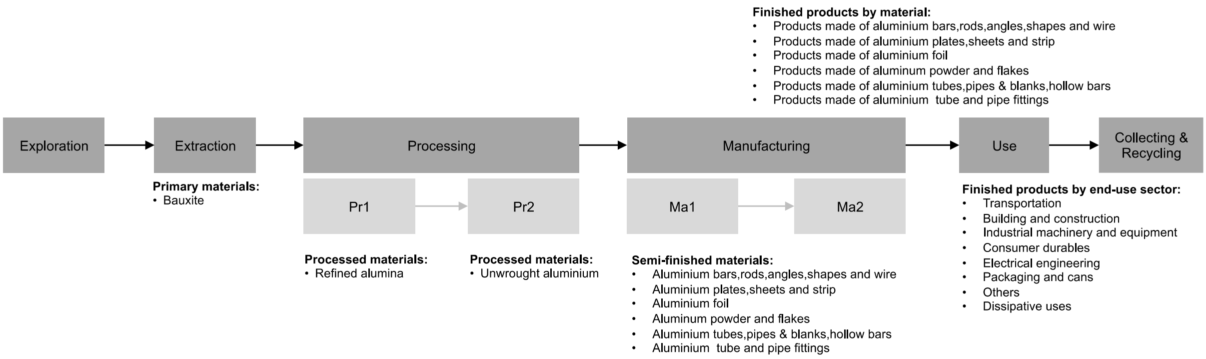
The main production route for aluminium from bauxite includes alumina refining (i.e., Bayer process) and electrolysis of alumina to aluminium metal (i.e., Hall-Héroult process). Intermediate processing stages are autoclave digestion, clarification, precipitation and calcination.

Unwrought aluminium is then wrought to produce semi-finished products such as aluminium bars, rods, angles, shapes, wires, plates, sheets, stripes, foil, tubes, pipes, blanks, hollow bars, tube fittings, powder and flakes. Part of the aluminium is remelted for adding alloying elements.

Aluminium semi-finished products are incorporated into finished products. The main end-uses of aluminium include transportation, building and construction, industrial machinery and equipment, consumer durables, electrical engineering, packaging and cans, dissipative uses (e.g., the employment of aluminium for deoxidation purposes in steelmaking) and other miscellaneous applications.

The figure below presents the value chain of aluminium and its main intermediates and end-uses.

Figure 4 Value chain of aluminium



4.1.2 Description of the main flows and stocks

Flows and stocks are accounted in mass of aluminium (Al) and are representative of the year 2013. All the quantitative results originate from calculations made by the project team and are based on several data sources. The values presented here are not raw data but aggregated results. Figure S21 in the Annex shows the complex Sankey diagram for aluminium.

Global bauxite resources are estimated at 55-75 billion tons, distributed in Africa (32%), Oceania (23%), South America and the Caribbean (21%), Asia (18%), and other countries (6%) (USGS, 2015a). Global Al reserves amount to about 5,330,000 kt of Al. In 2013, the world smelter production was 47,600 kt Al content, and the top producer country was China (46% of the global production), followed by Russia (8%) and the U.S. (4%) (USGS, 2015b).

In the EU, Al reserves are estimated at about 120,000 kt (USGS, 2015b). In 2013, around 682 kt Al (BGS, 2016; Reichl et al., 2017) were extracted mainly from Greece, which represents about 85% of total bauxite production in the region. Extraction of bauxite was also supplemented from Hungary and France. Of that amount, 496 kt Al were sold in EU to alumina refining, 98 kt were exported and 89 kt were disposed in tailings. A detailed representation of aluminium flows within the processing and manufacture phases is reported in the Annex (see Figure S22).

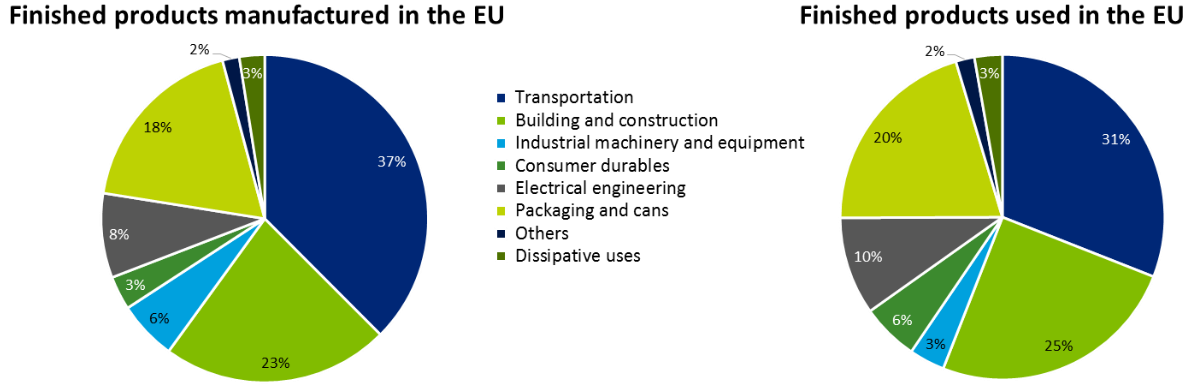
Input to alumina refining was supplemented with imports of bauxite (3,360 kt Al) from outside the EU. Total refined alumina production in the EU amounted to 3,161 kt Al, of which 1,217 kt Al were sold in EU while 1,944 kt were exported. Al in waste from EU production of refined alumina sent to disposal resulted in 694 kt.

Imports of refined alumina (1,099 kt Al content) supplemented the input to primary Al smelting from domestic production, resulting in 2,032 kt Al. Input to secondary Al smelting production was 8,190 kt, consisting of 2,209 kt from domestic old scrap, 268 kt Al imported as waste and scrap from outside the EU, 4,200 kt Al new scrap from semi-finished products fabrication and 1,513 kt Al new scrap from finished products manufacturing. Total (i.e., primary + secondary) Al production resulted in 9,408 kt. About 60% of unwrought Al (i.e., 5,448 kt) was sold in the EU, while 4,876 kt were exported. About 21 kt Al were stocked at production facilities. Processing waste disposed in the EU was 162 kt.

Imports of unwrought Al in the EU supplemented the input to semi-finished products manufacture with 8,882 kt, which resulted in 14,330 kt Al input. Of this amount, 329 kt were stockpiled at semis production facilities, while 4,200 kt were sent to secondary smelting production as new scrap. Exports of semis product from the EU were 1,308 kt. The amount of Al in semis products sold to manufacturing of finished products in the EU resulted in 8,493 kt.

Input to EU manufacturing was supplemented with imports of semi-finished products (1,596 kt Al content) and resulted in 10,089 kt. The main end-use segments of Al include transportation, building and construction, industrial machinery and equipment, consumer durables, electrical engineering, packaging and cans, dissipative uses and other miscellaneous applications. New scrap generated from finished goods manufacturing (about 1,513 kt Al) was sent to secondary aluminium production. The export of finished products (2,185 kt Al) from the EU reduced the total input to use at about 5,464 kt Al. Figure 5 shows the distribution by end-use sector of Al-containing finished products manufactured (pie-chart on left-hand side) and used (pie chart on right-hand side) in the EU-28.

Figure 5 Shares of finished-products containing aluminium manufactured in the EU and shares of finished-products containing aluminium used in the EU (taking into account exports and imports of products).



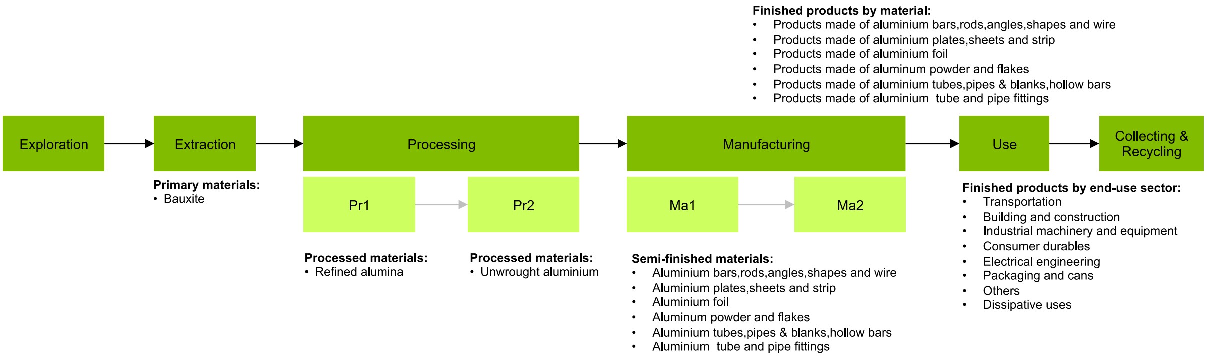
On the basis of the total Al inflow to use and lifespan distributions assumed for the main end-use segments of aluminium (Table S8 in the Annex), about 3,361 kt Al were accumulated in the European in-use stock in 2013. The total stock of products in-use is quantified at about 132 Mt Al.

The total output from use amounted at 4,338 kt Al, of which more than 70% was collected and sorted for functional recycling. Overall, about 1,352 kt Al were lost due to inefficiency at end-of-life. The export of about 777 kt Al old scrap and waste reduced the total amount of secondary Al domestically processed at 2,209 kt Al in 2013.

4.1.3 Value chain distinguishing steps occurring or not within the EU

Figure 6 shows the value chain steps that take place within and outside the EU-28.

Figure 6 Value chain of aluminium, steps in green occur in the EU, steps in orange occur only outside of the EU.



4.1.4 Data sources, assumptions and reliability of results

The main sources of production and trade data are the U.S. Geological Survey (USGS, 2015a, 2015b)[14], the International Organizing Committee for the World Mining Congresses (Reichl et al., 2017), the British Geological Survey (BGS, 2016), the European Aluminium (EAA, 2013), the World Bureau of Metal Statistics (WBMS, 2010), and the United Nations Commodity Trade Statistics database (UN, 2018). Additional information including a list of commodities containing aluminium (Table S9 in the Annex), process efficiency, collection and separation efficiency of aluminium at end-of-life (Table S10 in the Annex) was gathered from peer-reviewed papers and reports in literature (Bertram et al., 2017; Chen et al., 2010; Ciacci et al., 2013, 2015; Liu and Müller, 2013; Løvik et al., 2014; UNEP, 2013; World Aluminium, 2017). Overall, basic extrapolation was applied to primary data to compute reliable estimates of aluminium flows and stock in the EU.

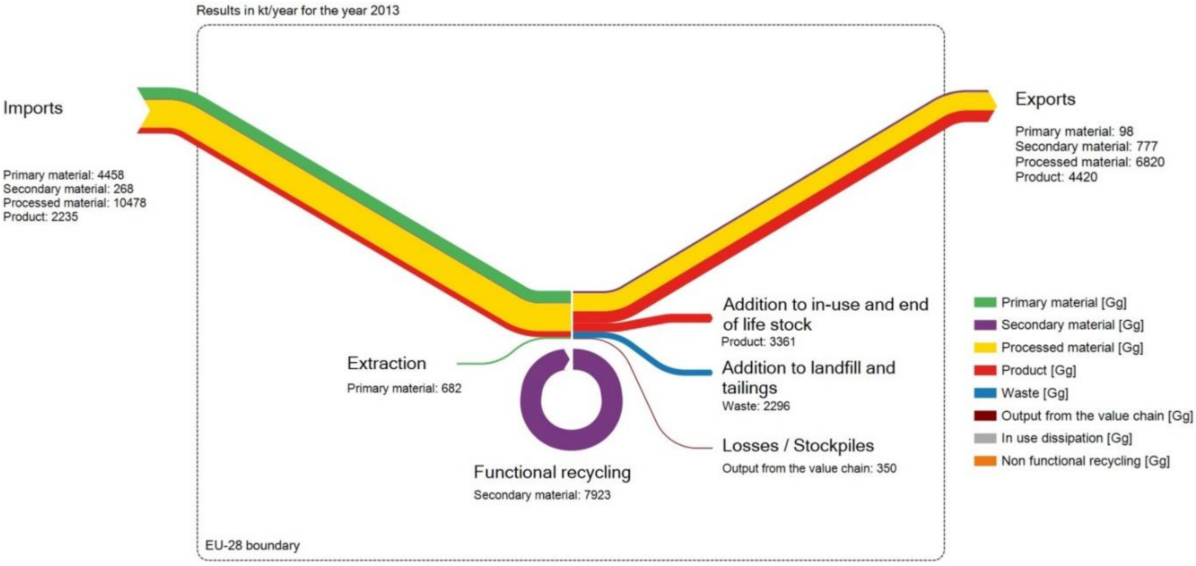
Due to lack of information, some assumptions based on average knowledge were made for evaluating the share of aluminium-containing products at end-of-life hold by users and flows of aluminium contained in obsolete products traded for reuse.

[14] For trade data, SITC codes for commodities containing aluminium were identified in literature. Considering the limited timeframe to finalize this study, the same decoded list was applied. A comparison with ComExt statistics for a selection of commodities showed no major differences between the two databases.

4.1.5 Simplified Sankey Diagram

Finally, Figure 7 shows the simplified Sankey diagram for aluminium.

Figure 7 Simplified Sankey diagram for aluminium.



A consolidated aluminium industry is established in the EU-28, with all value chain steps taking place in the region. The demand for primary aluminium cannot be met by domestic supply and requires strong imports of primary materials from outside the EU-28. Overall, about 10% of total primary aluminium input was sourced domestically in 2013.

Input to aluminium processing is supplemented by secondary aluminium forms including both new scrap and old scrap. Manufacture waste (i.e., new scrap) sent to domestic reprocessing constitutes the greatest source of secondary aluminium, representing more than 70% of secondary material input.

Of the total amount of aluminium old scrap generated at end-of-life (i.e., 4,338 kt Al), about 2,986 kt Al were collected for recycling, resulting in an end-of-life recycling rate (EOL-RR) of 69%[15].

A considerable fraction of secondary aluminium at end-of-life collected for recycling is actually exported from the EU-28. In case that fraction (G1.3) is excluded from the calculation, EOL-RR becomes 51%[16].

The ratio of recycling from old scrap to European demand for aluminium (end-of-life recycling input rate (EOL-RIR)[17]) results in 12%. If the EU-28 had processed domestically the flow of aluminium waste and scrap exported in 2015, EOL-RIR would have increased to 16%. Different options to calculate recycling rates are summarized in Table 3.

Table 3 Different recycling rate calculations for Aluminium.

Recycling Rate Formula	%
EOL-RIR=(G.1.1+G.1.2)/(B.1.1+B.1.2+C.1.3+D.1.3+C.1.4+G.1.1+G.1.2)	12%

[15] Computed as (G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)
[16] Computed as (G.1.1 + G.1.2)/(E.1.6+F.1.2-F1.1)

[17] EOL-RIR=(G.1.1+G.1.2)/(B.1.1+B.1.2+C.1.3+D.1.3+C.1.4+G.1.1+G.1.2)

EOL-RR=(G1.1 + G1.2)/(E1.6+F1.2)	51%
EOL-RR=(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	69%
EOL-RR=(G1.1+G1.2)/(E1.6+F1.2-F1.1)	51%

Aluminium loss in end-of-life product for disposal and net-export of aluminium waste and scrap collected for recycling prevent the closure of material flows in the EU-28. In addition, despite respectable end-of-life recycling rates, the presence of alloying elements in aluminium alloys has been indicated as a major hinder to future recycling (Løvik et al., 2014), requiring the adoption of resource efficiency strategies priority (UNEP, 2013).

4.2 MSA for Copper

4.2.1 Value chain

The main primary sources of copper are copper sulfide and copper oxide ores.

Copper containing minerals are commonly pyrometallurgically processed to the metal form. The main steps include extraction, comminution, roasting and smelting. Copper anodes resulting from smelting are then electrolytically refined to increase the grade of copper cathodes. The alternative route (i.e., hydrometallurgy) bypasses smelting and encompasses leaching and solvent extraction followed by electrowinning.

Copper cathodes are then wrought to produce semi-finished products such as copper bars, rods, wires, plates, sheets, tubes, pipes, powder and flakes. Part of the refined copper is remelted for adding alloying elements and obtaining alloys such as brasses and bronzes.

Copper semi-finished products are incorporated into finished products. The main end-uses of copper include electrical and electronic products (e.g., power utilities, telecommunications, lighting and wiring devices), building and construction (e.g., plumbing and heating, building wire, air conditioning and commercial refrigerator), industrial machinery and equipment (e.g., in-plant equipment, industrial valves and fittings), transportation equipment (e.g., automobile, truck and buses, railroad, marine and aerospace), consumer and general goods (appliances, cord sets, and consumer electronics) (Copper Development Association, 2018; Thomson Reuters GFMS, 2016).

The two figures below present the value chain of copper and its main intermediates and end-uses.

Figure 8 Value chain of copper.

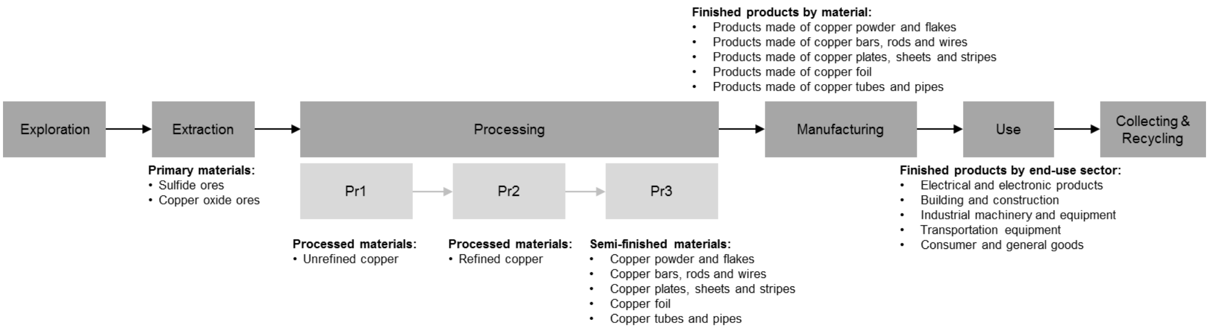
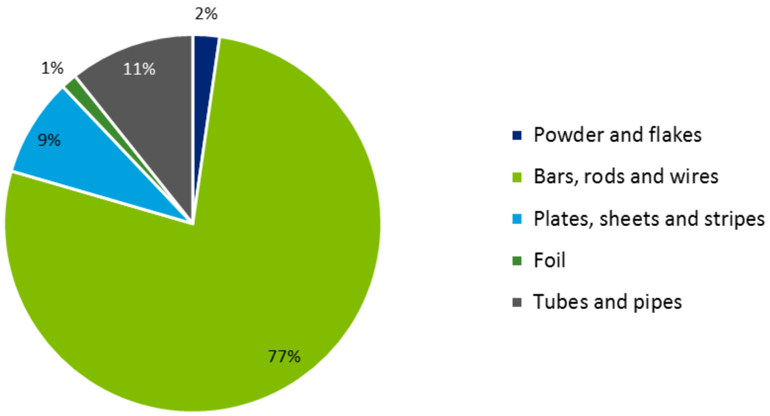


Figure 9 Copper used in the EU industry for manufacture of finished products per type of material.



4.2.2 Description of the main flows and stocks

Flows and stocks are accounted in mass of copper (Cu) and are representative of the year 2014. All the quantitative results originate from calculations made by the project team and are based on the material flow analysis (MFA) model developed in (Ciacci et al., 2017). The values presented here are not raw data but aggregated results. However, all raw data are provided in the accompanying excel file and Annex. Figure S24 in the Annex shows the complex Sankey diagram for copper.

World copper resources are estimated at about 2.1 billion tons of copper, with around 720,000 kt Cu of Cu reserves worldwide. Additional undiscovered resources are expected to contain around 3.5 billion tons Cu. In 2014, the world mine production was 18,500 kt Cu content, and the top three main producer countries were Chile (31% of the global production), China (10%) and Peru (7%) (USGS, 2017a).

In the EU, Cu reserves are estimated at about 48,000 kt (USGS, 2017a). The EU criticality factsheets provide additional EU reserve data collected in the Minerals4EU project (EU, 2017). In 2014, around 810 kt of copper were extracted mainly from Poland, Bulgaria, Spain, Sweden and Portugal, which together accounted for about 85% of total copper production in the EU-28 (Reichl et al., 2017, p. 20).

About 494 kt of the copper extracted in the EU were exported, while 356 kt Cu were processed in European smelters. This amount was supplemented with 1,565 kt Cu from imports of primary copper ores and concentrates and with the supply of 305 kt Cu from secondary sources (i.e., copper scrap). Total copper smelter production amounted to 2,594 kt Cu in 2014, of which 21 kt Cu were exported while 2,573 kt were sent to domestic refining. The additional import of 87 kt Cu resulted in 2,660 kt Cu entering the refining phase. A detailed representation of copper flows within the processing and manufacture phases is reported in the Annex (see Figure S25).

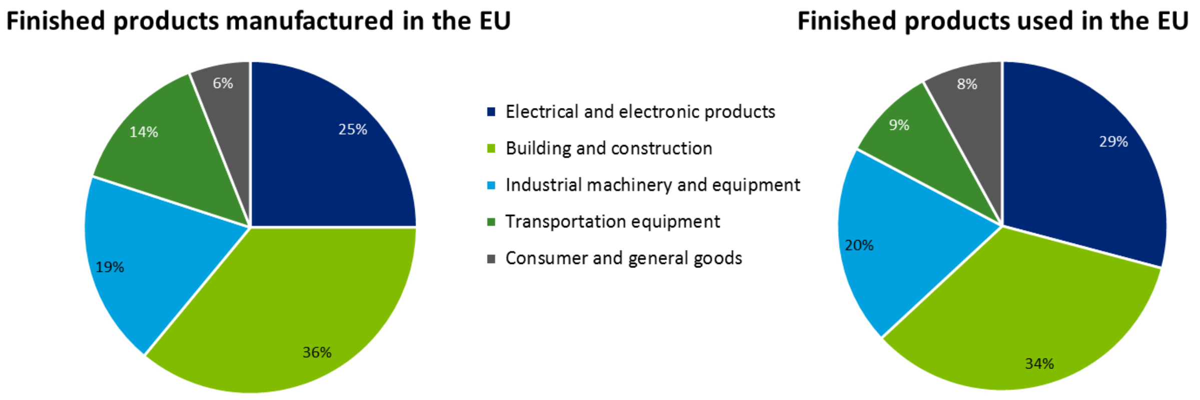
Exports of refined Cu from the EU amounted at 464 kt Cu, while imports were 970 kt Cu. Consequently, the domestic apparent consumption (i.e., production – export + import) of refined Cu amounted to 2,196 kt. Total input to fabrication of semi-finished Cu-containing products was supplemented with 1,042 kt Cu scrap directly melted by fabricators. Total copper contained in semi-finished products amounted to 4,208 kt Cu. As depicted in Figure 11, bars, rods and wires were the main first-use of copper, followed by tubes and pipes, plates, sheets, stripes, foil, copper powder and flakes.

About 792 kt Cu in semi-finished products created in the EU was exported, with the production of semi-finished products sent to manufacture in the EU (3,396 kt Cu) that was increased by additional 300 kt Cu from imports. Total Cu entering the manufacturing stage (3,696 kt Cu) was utilized for the creation of finished goods employed in the main end-use segments. The distribution by end-use sector of all finished copper-containing products manufactured in the EU is shown in figure 10 (pie-chart on left hand side). Exports of manufactured products from the EU amounted to 1,120 kt Cu, while imports were 1,345 kt Cu. Thus, a net-import of about 225 kt Cu contained in manufactured products increased the total input to use in the EU to about 3,000 kt Cu. The distribution of Cu contained in finished products used in the region is shown in Figure 10 (pie-chart on right hand side).

On the basis of the total Cu inflow to use and lifespan distributions assumed for the main end-use segments of copper (Table S11 in the Annex), about 336 kt Cu were accumulated in the European in-use stock in 2014. The total stock of products in-use is quantified at about 73,000 kt Cu. Loss of copper during use (i.e., in-use dissipation) was estimated at 36 kt in 2014.

The total output from use amounted to about 2,625 kt Cu, of which more than 60% was collected for sorting and recycling. Overall, about 1,022 kt Cu were lost due to inefficiency at end-of-life. The net-export of 873 kt Cu old scrap (mainly to Asian countries) (Ciacci et al., 2017) reduced the total amount of secondary Cu domestically processed to 730 kt Cu in 2014. Of this amount, about 612 kt Cu were sent to secondary cathodes production, while 118 kt Cu were directly melted by European fabricators. Based on the mass flow model created, about 107 kt Cu were assumed to be stockpiled in 2014.

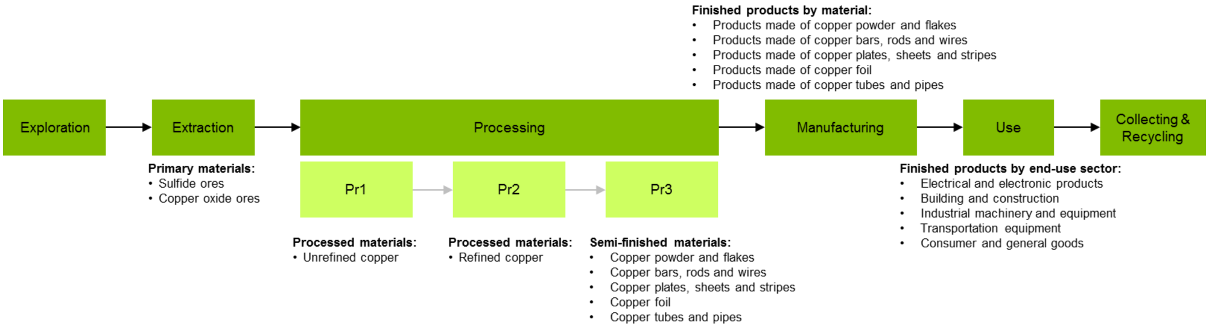
Figure 10 Shares of finished-products containing copper manufactured in the EU and shares of finished-products containing copper used in the EU (taking into account exports and imports of products).



4.2.3 Value chain distinguishing steps occurring or not within the EU

Figure 11 shows the value chain steps that take place within and outside the EU-28.

Figure 11 Value chain of copper, steps in green occur in the EU, steps in orange occur only outside of the EU.



4.2.4 Data sources, assumptions and reliability of results

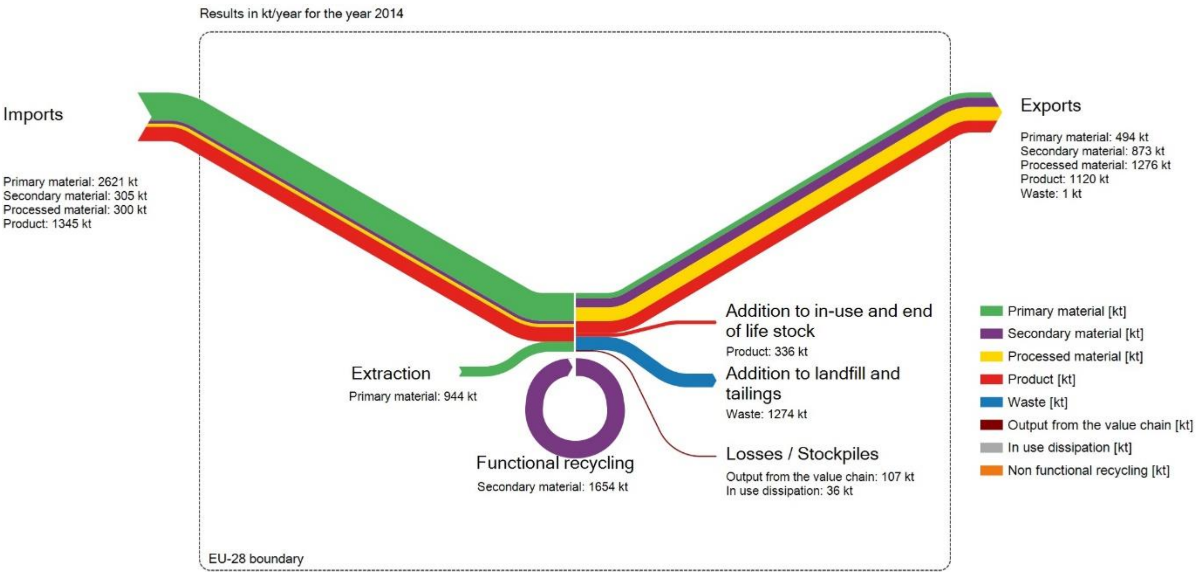
The main sources of production and trade data are: Copper Development Association, 2018; International Copper Study Group, 2010, 2016; Reichl et al., 2017; Thomson Reuters GFMS, 2016; UN, 2018; USGS, 2017a; WBMS, 2010. Additional information including process efficiency, collection and separation efficiency of copper at end-of-life was gathered from peer-reviewed papers and reports in literature (Baldè et al., 2016; Ciacci et al., 2015; Glöser et al., 2013; Graedel et al., 2015; Northey et al., 2; Ruhrberg, 8; Schlesinger et al., 2011a, 2011b; Soulier et al., 2018). Overall, basic extrapolation was applied to primary data to compute reliable estimates of copper flows and stock in the EU.

Due to lack of information, some assumptions based on average knowledge and expert opinion were made for evaluating the share of copper-containing products at end-of-life hold by users and flows of copper contained in obsolete products traded for reuse.

4.2.5 Simplified Sankey Diagram

Finally, Figure 12 shows the simplified Sankey diagram for aluminium.

Figure 12 Simplified Sankey diagram for copper.



The results show that a consolidated network of copper industries that cover the entire metal life cycle is established in the EU-28. However, the modest natural deposits of copper in the region determine a strong reliance on imports of primary forms to meet the domestic demand. In 2014, primary copper extracted domestically amounted to about 12%[18] of total primary copper input to Processing in the EU-28.

Secondary copper forms (i.e., new scrap and old scrap) constitute a significant input to Processing, but only old scrap has the potential to relief the dependence on primary sources. Of the total amount of copper old scrap generated at end-of-life (i.e., 2,625 kt Cu), about 1,603 kt Cu were collected for recycling, with EOL-RR resulting in 61%[19]. Not all copper old scrap collected for recycling is processed in the EU-28. Excluding the flow of copper waste and scrap exported (G1.3), EOL-RR reduces to 28%[20]. The amount of secondary copper sent to domestic processing is supplemented by imports of copper waste and scrap. However, in absolute terms, the EU-28 is a net-exporter of secondary copper forms.

The ratio of recycling from old scrap to European demand for copper (EOL-RIR[21]) results in 17%. If the EU-28 had processed domestically the flow of copper waste and scrap exported in 2014, EOL-RIR would have amounted to 31%. Different options to calculate recycling rates are summarized in Table 4.

Table 4 Different recycling rate calculations for Copper

Recycling Rate Formula	%
EOL-RIR=(G.1.1+G.1.2)/(B.1.1+B.1.2+C.1.3+D.1.3+C.1.4+G.1.1+G.1.2)	17%
EOL-RR=(G1.1 + G1.2)/(E1.6+F1.2)	28%
EOL-RR=(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	61%
EOL-RR=(G1.1+G1.2)/(E1.6+F1.2-F1.1)	28%

18 Computed as (B.1.1 + B1.2)/(B.1.1 + B1.2 + C.1.3)
19 Computed as (G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)
20 Computed as (G.1.1 + G.1.2)/(E.1.6 + F.1.2-F1.1)

21 EOL-RIR=(G.1.1+G.1.2)/(B.1.1+B.1.2+C.1.3+D.1.3+C.1.4+G.1.1+G.1.2)

Overall, the EU-28 shows a better recycling performance at end-of-life than global averages, (Glöser et al., 2013) but far from "perfect" recycling, with about 40% copper old scrap being unrecovered and lost. The amount of old scrap collected for recycling is further reduced by net-exports, a feature that contrasts with the EU's goal of implementing a circular economy in the region (EC, 2017c).

4.3 MSA for Iron

4.3.1 Value chain

The main primary sources of iron are iron oxide ores, among which hematite, magnetite and limonite are of worldwide importance (Oeters et al., 2011).

Crude iron ores are pyrometallurgically processed to the metal form. Most iron is used in iron and steel processing, which consists of three steps: iron making, steel-making and casting.

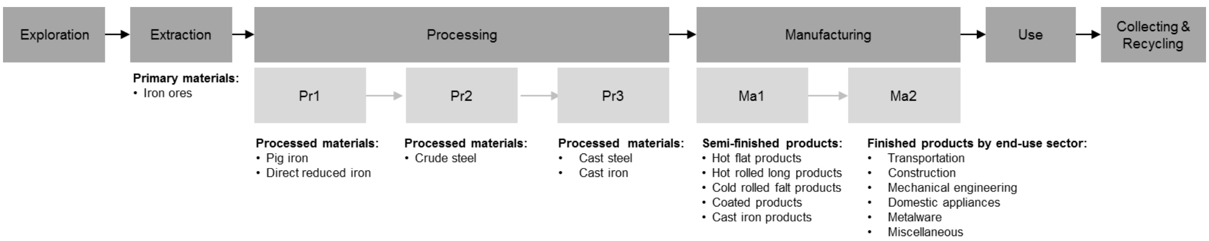
In the iron-making step, iron ores can be directly reduced to iron metal with natural gas or reduced to molten pig iron with carbon as a reducing agent in blast furnace. In the second step (steel-making), impurities are removed and iron is upgraded to steel. In Europe, basic oxygen-blown converter is the main steel-making technology followed by electric arc furnace. Direct reduced iron is generally sent to electric arc furnace, while pig iron is mainly utilized in oxygen-blown converters. Secondary iron forms (i.e., iron scrap and steel scrap) is the major material input in electric arc furnaces. The old-fashioned open hearth furnace is no longer utilized in the region (Cullen et al., 2012; Wang et al., 2007; World Steel Association, 2016).

In the third step (casting), liquid steel is fabricated into semi-finished products as billets, blooms and slabs. Part of pig iron is remelted in foundries to produce cast iron products. Castings and mill products enter the manufacture phase in which they are transformed into finished steel products such as hot or cold rolled coils and coated coils, beams, reinforcing bars, plates and similar.

Intermediate products are then incorporated into finished end products. The main end-uses of iron and steel include transportation, construction, mechanical engineering, domestic appliances, metalware, and other miscellaneous uses (Cullen et al., 2012; World Steel Association, 2016).

The figure below presents the value chain of iron and its main intermediates and uses.

Figure 13 Value chain of iron.



4.3.2 Description of the main flows and stocks

Flows and stocks are accounted in mass of iron (Fe) and are representative of the year 2015. All the quantitative results originate from calculations made by the project team. The values presented here are not raw data but aggregated results. Figure S27 in the Annex shows the complex Sankey diagram for iron.

World iron resources are estimated to be greater than 800 billion tons of iron ore containing about 230 billion tons of iron. Fe reserves worldwide amounts to 82,000,000 kt Fe. In 2015, the world mine production was 1,400,000 kt Fe content, and the top three main producer countries were Australia (35% of the global production), Brazil (18%) and China (16%) (USGS, 2017b).

In the EU, iron reserves are estimated at about 2,200,000 kt Fe. (USGS 2017) In 2015, around 19,000 kt Fe were extracted mainly from Sweden (Reichl et al., 2017). About 12,625 kt Fe were sent to domestic iron making, with 4,024 kt Fe being exported from the EU. Primary Fe ore imports were 76,416 kt Fe. The greatest part (88,418 kt Fe) of the resulting Fe input to processing entered the blast furnace to produce pig iron, while the remaining amount (624 kt Fe) was processed through direct reduction. A detailed representation of iron flows within the processing and manufacture phases is reported in the Annex (see Figure S28).

The amount of directly reduced Fe sold to domestic production (i.e., 524 kt) was supplemented with 2,624 kt Fe net-imported, resulting in 3,148 kt sent to electric arc furnace production.

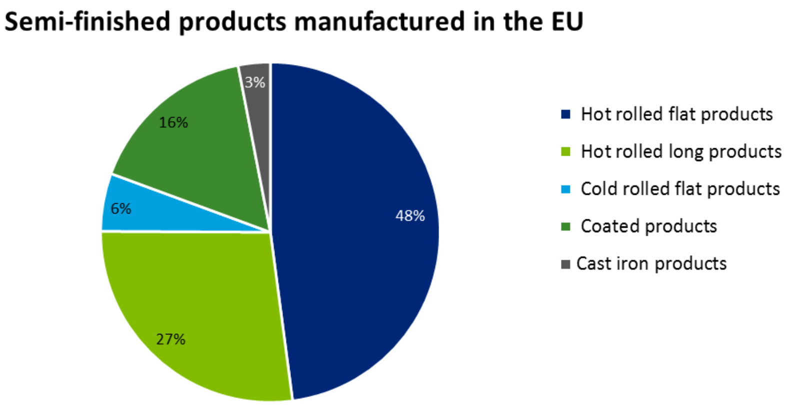
Total pig iron produced in the EU amounted to 87,799 kt Fe. The net-import of pig iron from outside the EU (2,882 kt) resulted in 90,640 kt Fe sent to domestic production. Of that amount, 87,495 (corresponding to more than 96% on a mass basis) entered oxygen-blown converters to produced crude steel. The remaining fraction was split between foundries (1,899 kt Fe) to cast iron products and electric arc furnaces (1,246 kt Fe) for additional steel-making.

Domestic electric arc furnaces were supplemented with 64,445 kt Fe from secondary sources (iron and steel scrap), resulting in 65,497 kt of crude steel produced. [4] Input of Fe scrap to oxygen-blown converters were significantly lower (21,874 kt), corresponding to about 20% Fe input. Total crude steel production from oxygen-blown converters amounted to 100,619 kt Fe (World Steel Association, 2016). About 65% of Fe input to iron casting (i.e., 3,528 kt Fe) was sourced from scrap.

Overall, cast steel production in the EU amounted to 166,114 kt Fe, of which 5,581 kt were exported while 160,533 kt were sent to domestic manufacture. Cast iron produced in the EU resulted in 5,400 kt Fe, of which 157 kt were exported while 5,243 kt were sent to manufacture. Total Fe input to domestic manufacture of semi-finished products was supplemented with 21,831 kt Fe from cast steel and cast iron imports, resulting in 187,607 kt Fe in 2015..

Figure 14 shows Fe used in the EU industry for manufacture of semi-finished products per type of material.

Figure 14 Iron used in the EU industry for manufacture of semi-finished products per type of material.

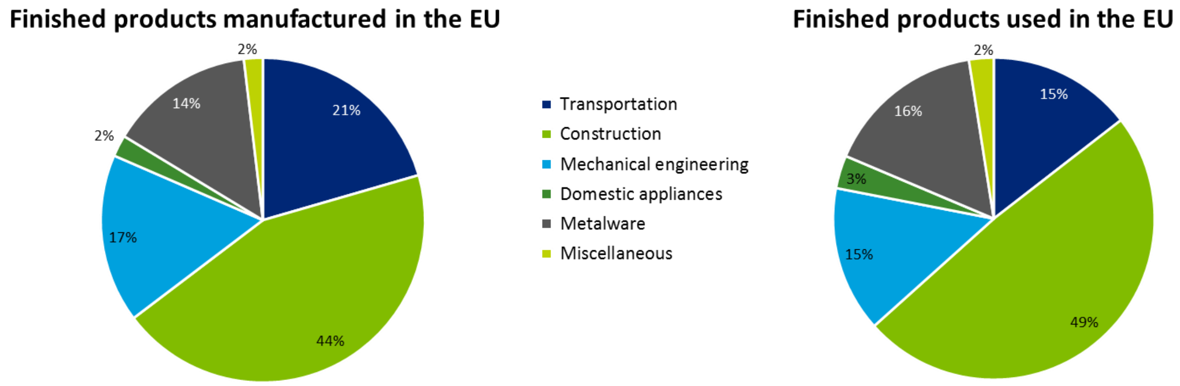


New scrap generated from semi-finished products manufacture (13,133 kt Fe) and total losses (15,009 kt Fe) reduced to 159,466 kt the amount of iron contained in semi-finished products fabricated in the EU. Of this amount, 5,472 kt were net-exported, while 127,694 kt Fe were sent to domestic manufacture and incorporated into finished products. The distribution by end-use sector of all finished Fe-containing products manufactured in the EU is shown in figure 15 (pie-chart on left hand side). Total Fe new scrap generated from the manufacture of finished products resulted in 25,088 kt Fe.

The domestic apparent consumption (i.e., production – export + import) of Fe contained in finished products that entered the use phase in 2015 amounted to 116,062 kt Fe. The distribution of Fe contained in finished products used in the region is shown in figure 15 (pie-chart on right hand side).

On the basis of lifespan distributions assumed for each main end-use segments of iron (Table S17 in the Annex), about 7,981 kt Fe were accumulated in the European in-use stock in 2015. The total stock of products in-use is quantified at more than 5,329,000 kt Fe. In-use dissipation amounted to 7 kt, while the total output from use resulted in 108,075 kt. More than 70% of end-of-life iron was collected and processed for recycling. The net-export of about 10,913 kt Fe waste and scrap (EUROFER, 2016) and losses from scrap preparation reduced the total secondary material input to domestic processing at 66,894 kt Fe.

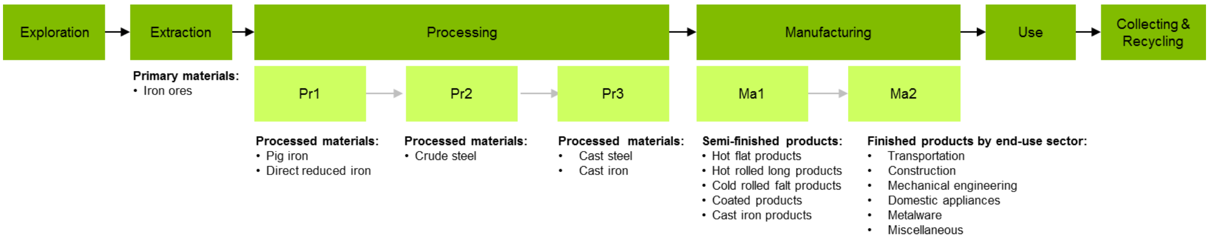
Figure 15 Shares of finished products containing iron manufactured in the EU and shares of finished products containing iron used in the EU (taking into account exports and imports of products).



4.3.3 Value chain distinguishing steps occurring or not within the EU

Figure 16 shows the value chain steps that take place within and outside the EU-28.

Figure 16 Value chain of iron steps in green occur in the EU, steps in orange occur only outside of the EU.



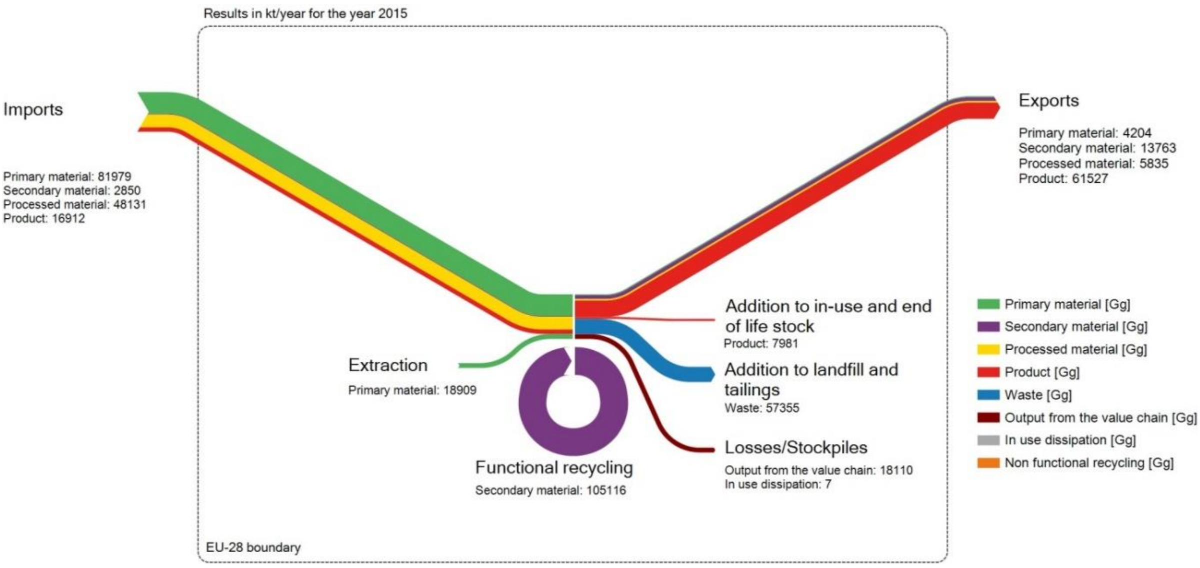
4.3.4 Data sources, assumptions and reliability of results

The main sources of production and trade data are the Ullmann's Encyclopedia of Industrial Chemistry (Oeters et al., 2011), the World Steel Association (World Steel Association, 2016), the U.S. Geological Survey (USGS, 2017b), the International Organizing Committee for the World Mining Congresses (Reichl et al., 2017) the European Steel Association (EUROFER, 2016), the European Foundry Association (CAEF, 2012), and the United Nations Commodity Trade Statistics database (UN, 2018). Additional information including process efficiency, in-use dissipation rates, collection and separation efficiency of iron at end-of-life was gathered from peer-reviewed papers in literature (Ciacci et al., 2015; Cullen et al., 2012; Dahlström et al., 2004; Müller et al., 2011; Pauliuk et al., 2013; Wang et al., 2007). Overall, basic extrapolation were applied to primary data to compute reliable estimates of iron flows and stock in the EU. Overall, basic extrapolations were applied to primary data to compute reliable estimates of iron flows and stock in the EU (Table S17 to Table S20).

4.3.5 Simplified Sankey Diagram

Finally, Figure 17 shows the simplified Sankey diagram for iron.

Figure 17 Simplified Sankey diagram for iron



The EU-28 has a well-established iron and steel industry covering the entire material value chain. However, in 2015, only about 13% of total primary iron input to Processing was extracted domestically, with the EU-28 relying on imports to meet the domestic demand for primary iron.

The recycling industry of iron and steel supplies a great part of material input to production with old scrap almost doubling the amount of new scrap sent to reprocessing. Of the total amount of iron old scrap generated at end-of-life (i.e., 108,075 kt Fe), about 81,333 kt Fe were collected for recycling, resulting in EOL-RR of 75%[22].

[22] Computed as (G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)

Not all iron old scrap collected for recycling is processed in the EU-28, with the region being a net-exporter of secondary iron forms. Excluding the flow of iron and steel waste and scrap exported (G1.3) decreases EOL-RR to 62%[23].

The ratio of recycling from old scrap to European demand for iron (i.e., (EOL-RIR[24]) results in 31%. Different options to calculate recycling rates are summarized in Table 3.

Table 5 Different recycling rate calculations for iron

Recycling Rate Formula	%
EOL-RIR=(G.1.1+G.1.2)/(B.1.1+B.1.2+C.1.3+D.1.3+C.1.4+G.1.1+G.1.2)	31%
EOL-RR=(G1.1 + G1.2)/(E1.6+F1.2)	62%
EOL-RR=(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	75%
EOL-RR=(G1.1+G1.2)/(E1.6+F1.2-F1.1)	62%

Similarly to aluminium and copper cycles, a respectable end-of-life recycling performance for iron and steel is shown for the EU-28. However, material losses cover a relevant fraction of products at end-of-life sent to disposal and the amount of old scrap collected for recycling is further reduced by net-exports. Both features contrast with the circular economy approach and are major constraints to the efficient closure of iron and steel cycle in the EU-28.

4.4 Validation of MSA results

The following sections include a summary of the main points and comments that emerged from the three working sessions of the MSA validation workshop (December 11-12, 2017, Brussels), as well as the written feedback received from experts. It should be noticed that these feedback do not represent the views or opinions of the authors, but represent instead a summary of all feedback received by stakeholders.

Not all comments and suggestions could be taken into account in the revision of the MSA studies for aluminium, copper, and iron. However, we report all feedback received in the subsequent sections because some of it could be further considered in possible future MSA studies.

4.4.1 Overarching Points and Comments

- The project team highlighted that the MSA methodology puts some constraints on how the MFA data are structured as process steps and data availability might vary depending on the material examined. However, the MSA framework was followed for consistency reasons and to allow for better comparability between materials and previous MSA studies.

- For better comparability of material flows/stocks data, all estimates are displayed in metal content in the Sankey diagrams. However, several stakeholders might be more familiar with official statistics which are not generally reported in metal content (e.g., the amount of bauxite extracted in the EU is known but this cannot be directly compared with the MSA flow from domestic extraction which assumes that the metal content in aluminium ores is 29%). Therefore, it can be difficult to directly compare the MSA estimates with official statistics collected. It was

[23] Computed as (G.1.1 + G.1.2)/(E.1.6 + F.1.2-F1.1)

[24] EOL-RIR=(G.1.1+G.1.2)/(B.1.1+B.1.2+C.1.3+D.1.3+C.1.4+G.1.1+G.1.2)

suggested to report the individual metal contents used in the calculations always together with the MSA data shown, e.g., in a comment cell in the underlying excel files.

- The estimate 'Stocks in Landfills' does not allow for a distinction between different types and qualities of metal-containing waste products. However, this information is generally useful in order to know in what form the metal is present in the landfill and to approximate possible recycling potentials. Therefore, it was recommended to provide, where possible, additional information on the waste types making up the "Stocks in Landfill". This could also help to increasingly connect the MSA to related discussions on urban mining.

- Following the 2015 MSA study, an 'Exploration' box reflected by the reserve estimates should be added before the extraction box for both EU and ROW[25]. The assessment deals with the entire value chain which begins with Exploration up to Recycling and Waste Treatment.

- The project team pointed out that the MSA framework does not allow for material stockpiling. Material stockpiling at production facility could be relevant for balancing flows in years of oversupply, with aluminium, copper and iron being an example. As far as the MSA framework is conceived, there is no possibility to account for material stockpiling at the 'Production' and/or 'Manufacture' process. The project team recommended including flows and stocks for modelling material stockpiling in the revised MSA framework.

- It was recommended to include a 'Fabrication' process between 'Processing' and 'Manufacture' which would lower aggregation of data for the three materials and allow for a higher level of detail. This is also supported by the need to include additional sub-Sankey diagrams which can help to provide additional details for complex processes such as, e.g., the processing and manufacturing phases for iron and steel making. Visually, this could be included as pop-up images in the RMIS webpage when a user clicks on the respective process in the complex Sankey diagram. Such a higher level of detail would also enable a better visualisation of secondary material flows sent to recycling distinguishing the fate of new scrap and old scrap. The project team recommended including a 'Fabrication' process (displayed as a grey box in the complex Sankey diagram) between 'Processing' and 'Manufacture' in future studies. Material flows accounting for processed material input, processed material output, waste for disposal, manufacture waste for reprocessing (e.g., direct melting of Cu) and secondary material from post-consumer functional recycling could be defined according to the new framework.

- Currently, in-use dissipation is calculated as a function of annual inflow into use instead as a function of the total stock in use. In-use dissipation can occur from all products in use in the reference year. Accounting for in-use dissipation as function of the annual input flow to use underestimates material losses from all those end-uses having lifespans longer than 1 year. In first approximation, in-use dissipation could be estimated as product of the total stock in use times by in-use dissipation factor. However, in-use dissipation can be non-linear over time (e.g., corrosion phenomena) so that developing a dynamic material flow model is a more accurate way to account for in-use dissipation.

- Regarding trade flows it was recommended to account for trade flows (import and export) in the same process. This would also help to avoid possible negative values. A possible solution could also be to include market processes in-between

[25] Rest of the world.

each process. Currently, trade flows are considered in separate processes. If possible, trade flows should be taken from similar sources (e.g., (1) Eurostat Comext, then UN Comtrade) and using the same classification (e.g., Harmonized System vs. SITC). This would also help to increasingly align them with the RMIS trade module[26]. Given the limited time available to finalize the three MSA studies, this feedback could be considered in future MSA studies.

- Redundant definition/overlap for 'Waste' and 'Output from the value chain'. In the 2015 MSA final report, 'Output from the value chain' is defined as 'annual quantity of the element exiting the value chain (as impurities, non-functional by product, dissipation…)'. This definition overlaps with that of 'waste' in some cases, for instance when material losses due to process inefficiency are considered, or with 'in-use dissipation'. In addition, the term 'Waste' can create confusion with the 'Waste and scrap' flow that is instead processed for recovery and recycling. A possible action can be to use a more neutral term 'Loss' for the three flows mentioned above. Eventually, a distinction on the basis of the fate could be maintained (e.g., 'Loss to disposal', 'in-use dissipation loss'…).

- Some stakeholders highlighted that World Mining Data 2017[27] provides a reliable source of public information for the world wide minerals production and could be used if relevant data from this source exists.

- It was suggested to increasingly align the MSA study and underlying data collected with the tri-annual EC Criticality Raw Materials (CRM) Assessment[28], Raw Materials Scoreboard[29], and Trade Module[30] in RMIS (e.g., by firstly developing a data collection sheet that accounts for the data overlaps and synergies among the three raw materials files).

4.4.2 Specific Feedback by Material

The following sections provide feedback received by material. Firstly, it provides a summary of all feedback received by material and, secondly, a number of specific action items that describe the feedback that was considered (also considering the timeframe to finalize the three studies until the end of February 2018) in the finalization of the three MSA studies.

Session I: Aluminium

Aluminium	
Participants	*European Commission* Constantin-Alin Popescu (ESTAT) Philip Nuss (DG JRC) *Project Team* Fabrizio Passarini (UNIBO) Luca Ciacci (UNIBO)

[26] http://rmis.jrc.ec.europa.eu/?page=raw-materials-trade-flows-ddaaaf
[27] http://www.wmc.org.pl/?q=node/49
[28] http://rmis.jrc.ec.europa.eu/?page=crm-list-2017-09abb4
[29] http://rmis.jrc.ec.europa.eu/?page=scoreboard
[30] http://rmis.jrc.ec.europa.eu/?page=raw-materials-trade-flows-ddaaaf

	Experts Mirona Coropciuc (Euromines) Djibril René (European Aluminium) Maren Lundhaug (NTNU)

(a) Remarks about data, parameters, and methodology

- The draft Aluminium MSA study was developed for year 2013. However, several data sources are outdated (i.e., more recent reports (e.g., by European Aluminium) are available and should be incorporated). It was recommended to update the MSA study to the most recent year possible (e.g., 2014 or 2015). For example, the Environmental Profile Report is not referring the latest version available online.

- The Global Aluminium Flow Model[31] forms the basis for data on manufactured and finished products containing Aluminium. It was pointed out that the data for Europe includes Norway and Iceland and does not strictly represent the EU-28 (focus of the MSA study).

- Industry stakeholders confirmed that the order of magnitude of the calculated results seems to be correct.

- The MSA approach for assessing the aluminium end-uses is different / complementary from the European Aluminium method (European Aluminium relies on direct data / shipments from members (i.e. semi production), while the EC MSA relies on an estimate of aluminium content per application (e.g. Al content of road tractors for tractor trailer combinations: 4%) and on trade data (i.e. for semi production and / or final products). The order of magnitude of final aggregated results seems good (e.g. 38% for transport, 23% for B&C and 18% for packaging) in 2013.

- All data are presented in Aluminium content (e.g. bauxite and alumina production) which doesn't allow a quick and easy check for the industry.

- The "Complex Sankey diagram" is aggregating the data which doesn't allow a quick and easy check for the industry (e.g. processing includes alumina and primary; manufacturing includes semi production and production of final products).

- Confusion between pre- and post-consumer scrap (e.g. for exports). All scrap exports are considered as old scrap / post consumer scrap…

- Details should be available for main Aluminium segment (e.g. primary, alumina, rolling, extrusion).

- Refer to more recent data (analysis is based on 2013 and some data are based on old publications). The Aluminium demand is growing constantly, 2013 picture is no longer meaningful.

- Refer to Aluminium waste and scrap instead of only "waste" (c.f. Complex Sankey diagram)

[31] http://www.world-aluminium.org/publications/

- The functional recycling rate of 41% could be misleading as it refers to new and old scrap.
- The quantity of Aluminium stocked in tailings is largely unknown (only annual value exists).

(b) General recommendations on the MSA methodology

- MSA does not allow for new scrap exports. Details could be increased.
- Trade data (from UN COMTRADE SITC) should be better linked with HS nomenclature and ideally Eurostat Comext.
- Absolute value (in kg of output) should be available for allowing industry double checking

(c) Possible future collaborations/developments in RMIS

- The EC MSA study on Aluminium has multiple synergies with the work carried out by European Aluminium and the Global Aluminium Association. In fact, the existing MFA models developed by the industry can inform various parameters of the EC MSA study (see comments above).
- It was suggested to further strengthen collaborations with industry associations, e.g., through a regular review process of MSA data and increasing linkages to the models developed by industry for cross-checking / data gap filling.

(d) Action Points to finalize the MSA study for Aluminium

- Use/compare the World Data Mining 2017 for the world wide minerals production.
- Update references (e.g., Environmental Profile report).
- Compute Al in-use dissipation as product of in-use stock by in-use dissipation factor (to be defined based on (Ciacci et al., 2015).
- Compute Al in tailings based on historic records and constant extraction efficiency (first-order estimate).
- Compare Comtrade with Eurostat (Comext) records – To be defined if for all commodities or a selection of them.
- Provide additional information, when possible, on the type waste making up the 'Stock in Landifll', but preserving the initial MSA framework and nomenclature for consistency.
- Other comments, especially on the methodology will be further discussed and will inform planning of future MSA studies and to possibly further align these with related policy outputs of the Commission.

Session II: Copper

Copper	
Participants	*European Commission* Constantin-Alin Popescu (ESTAT) Philip Nuss (DG JRC) *Project Team* Fabrizio Passarini (UNIBO) Luca Ciacci (UNIBO) *Experts* Mirona Coropciuc (Euromines) Djibril René (European Aluminium) Maren Lundhaug (NTNU) *Experts (Written Feedback)* Carlos Risopatron (ICSG)

(a) Remarks about data, parameters, and methodology

- It was observed that the production of smelted and refined copper in different EU member states needs to be corrected. The International Copper Study Group (ICSG) provided estimates on refined copper from recycled sources, denominated as "secondary refined production" for the year 2014. Statistics available on blister and anode cathode coming from scrap are limited in some EU countries, therefore there is limited information of secondary smelter production and estimates were provided from ICSG data for 2014.

- Some discrepancies between the estimates for Copper and Copper allow scrap directly melted by EU fabricators in the MSA study and the ICSG data sets were highlighted as a possible source.

- In Figure S25, showing the copper flows to smelting, refining and fabrication, is not clear if imports of copper scrap to the region are included or not.

- It was recommended to carry out a comparison of trade data used from Comtrade with Eurostat (Comext) data to see if they match.

- There are small differences between the new scrap generation rates used in the scientific papers by Ciacci and Soulier paper. However, overall the results of both studies are well aligned.

(b) Possible future collaborations/developments in RMIS

- The ICSG highlighted several possibilities for cooperation on the Copper MSA study (and future updates) related to: (a) Structure and Status of the European Union Copper Fabrication Industry, (b) Composition of Copper Concentrate in EU Inflows and Outflows, and (c) Improving Recycled Copper Market Transparency in the European Union.

(c) Action Points to finalize the MSA study for Copper

- Use/compare the World Data Mining 2017 for the world wide minerals production.
- Revise imports and exports of Cu waste and scrap using UN Comtrade records and Cu content in (Soulier et al., 2018) instead of WBMS records.
- Include direct melting within 'Processing' and revise material flows D.1.5, G.1.1, and G.1.2, in the complex Sankey diagram accordingly.
- Apply the European average of new scrap generation rate (across all Cu applications) as defined in (Soulier et al., 2018).
- ICSG experts reported 620-810 Gg refined Cu from recycled sources in the EU28. Adjust the mass balance accordingly.
- Compare Comtrade with Eurostat (Comext) records – To be defined if for all commodities or a selection of them.
- Compute Cu in-use dissipation as product of in-use stock by in-use dissipation factor (to be defined based on (Ciacci et al., 2015).
- Compute Cu in tailings based on historic records and constant extraction efficiency (first-order estimate).
- Provide additional information, if possible, on the type waste making up the 'Stock in Landifll', but preserving the initial MSA framework and nomenclature for consistency
- Other comments, especially on the methodology will be further discussed and will inform planning of future MSA studies and to possibly further align these with related policy outputs of the Commission.

Session III: Iron

Iron	
Participants	*European Commission* Milan Grohol (DG GROW) Marie-Theres Kuegerl (DG GROW) Constantin-Alin Popescu (ESTAT) Simone Manfredi (DG JRC) Philip Nuss (DG JRC) *Project Team* Fabrizio Passarini (UNIBO) Luca Ciacci (UNIBO) *Experts* Mirona Coropciuc (Euromines)

	Djibril René (European Aluminium) Maren Lundhaug (NTNU) *Experts (Written Feedback)* Aurelio (EUROFER) Stefan Savonen (LKAB) Stefan Pauliuk (Uni Freiburg)

(a) Remarks about data, parameters, and methodology

- Several suggestions for improvements of the terminologies used in the iron processing and steel making steps were made by industry.
- Suggestions for the improvement of trade data were made and it was highlighted that in the draft study there might be some double-counting for Iron trade flows. It was recommended to cross-check data with the Eurostat Comext trade statistics.
- It was suggested to revise some of the figures based on Worldsteel data with data coming from EUROFER as there might be some inaccuracies in the figures dealing with scrap trade.
- The figure of second-hand products cannot be easily found. Firstly, it will be necessary discussing whether it is an EoL product then reconditioned or a product just changing ownership... however, the consumption of ferrous scrap should be corrected first.
- All numbers should be rounded to two of three significant digits (reflecting various uncertainties introduced in the model and calculations).
- The products in-use estimate should be reconsidered as it might be too small.
- In cases where comprehensive statistics for iron scrap are present, those and not the results of the lifetime model should be used. The difference will thus remain in use or part of it may have been transformed to obsolete stocks.
- Further data were provided by industry to improve the estimates of the iron reserves, iron ore production, and primary import estimates.
- Iron ores exports are larger than iron extraction in EU (corrected by using BGS data). Is this an issue of stocks? (average of 5 years used in the EC CRM assessment).
- If different data are available multiple data should be recorded and displayed clearly which data value should be used.
- Public available data from WMD are reliable. Includes production for countries worldwide including iron data.

(b) Possible future collaborations/developments in RMIS

- Trade markets could be located in between processes.
- Locate secondary material exports next to functional recycling flow

- Interconnections of cycles (linkages) should be considered in the future (e.g., copper ore comes with various companion metals).

(c) Action Points to finalize the MSA study for Iron

- Use/compare the World Data Mining 2017 for the world wide minerals production.
- Correct terminology used in iron processing and steel making according to industry experts.
- Revise data for mine extraction, imports and exports of iron in ores according to LKAB feedback.
- Double-check the stock and flow model parameters and, if possible, see if other values than those used would lead the in-use stock to approach estimates by S. Pauliuk.
- If possible, revise annual growth rates of historic shipments of iron in finished products based on EU28 averages rather than UK proxy.
- Compare Comtrade with Eurostat (Comext) records – To be defined if for all commodities or a selection of them.
- Compute Fe in-use dissipation as product of in-use stock by in-use dissipation factor (to be defined based on (Ciacci et al., 2015).
- Compute Fe in tailings based on historic records and constant extraction efficiency (first-order estimate).
- Provide additional information, if possible, on the type waste making up the 'Stock in Landifll', but preserving the initial MSA framework and nomenclature for consistency.
- Other comments, especially on the methodology will be further discussed and will inform planning of future MSA studies and to possibly further align these with related policy outputs of the Commission.

4.5 Suggestions on the overall MSA methodology

Additional suggestions by some stakeholders on the overall methodology were received that can guide the EC when planning for future MSA studies.

- The purpose and intended uses of MSA studies should be made very clear. The information available at present that explains the exact aims and objectives of the MSA studies and the associated questions attempted to be answered might not be sufficient. Stakeholders also highlighted that it might be unclear what the reasons are behind the selected materials. If for example, the aim is to understand how these materials flow through our society and develop policy, strategy and indicators on the basis of the data and methodology developed in the MSA studies, then the studies might not be adequately detailed. Although they are based on the same methodology, in reality the underlying understanding of each material cycle is highly complex, varies for different materials and requires individual material specific system definitions. Some stakeholder, therefore, favour a bottom-up approach, rather than the current top-down approach to enhance the understanding of raw material cycles.

- The underlying data used and the system developed needs to be transparent. The data and the system for each MFA model needs to be robust, and transparency is key for this robustness. Stakeholder emphasized that the data, methodology and calculations undertaken during the model development needs to be accessible not only to the EC but to all stakeholders and the public. This way the work developed is defensible and it is possible to improve the MSA studies further by utilising the best possible knowledge available from the wider stakeholder community. Transparency can further promote synergies between data providers, data users, industry and researchers amongst others which can all contribute to elevate the quality and relevance of the MSA studies.

- The EC has a good approach with the aim of visualizing all materials in the MSA studies using the same generic system definition. Nevertheless, the aggregation level that is presented to the general public through the simplified Sankey diagrams hides gaps and neglects several aspects that several stakeholders believe is of high importance for future raw material strategies and policies. For example, the MinFuture project[32] works with raw materials in 4 dimensions (1) Stages, (2) Trade, (3) Linkages and (4) Time. It was proposed that some aspects of these dimensions are considered in the MSA studies, especially the stages dimension, the trade dimension and the linkages dimension. Materials go through different stages through their lifetime, these stages needs to be integrated and understood properly to be able to develop comprehensive material cycles. The stages of the material cycles are not clearly defined in the simplified Sankey diagrams and this can make it very hard to apprehend what happens with materials within the EU, which could impact adversely our understanding of supply and demand dynamics. No material cycle exists in isolation and the linkages of the different materials through production and use is very important to highlight. How materials are linked to each other will have implications for the potential for recycling and future availability of the materials in in-use stocks. Europe is highly reliant on imports of most metals and as such the trade dimension of the MSA studies should be looked into more detail to enhance our understanding of the influence of trade on material cycles. These dimensions are of major importance when developing policy, strategy and indicators aimed at amongst others securing supply of raw materials.

- Past research efforts should be utilised adequately in future MSA studies. Relationships towards current experts on the different materials can be established which might create even stronger synergies with other relevant stakeholders and therefore increase the overall robustness of the MSA studies.

- Terminology used should be clearly defined. When collecting data across a variety of disciplines one should be aware of the fact that these disciplines may use alternative terminology to describe the same item, or a particular term may have multiple meanings depending on who is using it. We suggest that the terminology used in the MSA studies is clearly defined and published together with the studies to avoid potential misconceptions.

- The approach of incorporating reserves figures in the MSA studies should be revised or avoided altogether. Reserves are not static and the current reserves represent only a small portion of the mineral resources in the earth's crust. It is incorrect to use the reserves figures as a proxy to geological stocks. The use of

[32] http://minfuture.eu/

“reserves” in the MSA figures and visualisations, as a measure of the actual minerals resources in the earth’s crust, is in our view misleading. Reserves are not a static measure of the minerals available, but instead a dynamic measure of the minerals potentially available for recovery based on a financial price for the mineral. Therefore, reserves represent only a small portion of the mineral resources in the earth’s crust, which is discovered and financially viable for extraction. It is therefore incorrect to use the reserves figures as a proxy to geological stocks. For future MSA studies some stakeholders emphasized the importance to go beyond the current level of aggregation to be able to adequately inform decision makers. This way, the MSA studies could be used as a more comprehensive tool to identify challenges and interventions that lead to decision support for criticality studies, the circular economy, climate change mitigation, and the sustainable development goals to name a few.

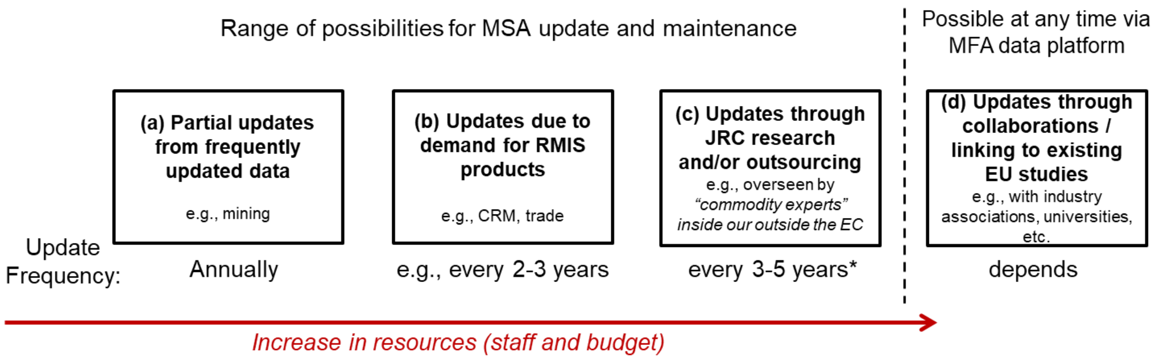
5 Maintaining and Updating MSAs in RMIS 2.0

5.1 Range of possibilities for future updates

The MSA carried out in 2015 (BIO by Deloitte, 2015) refer to the EU-28 economy in 2012/2013 and the three new MSAs described in this report to 2013/2015, although a number of parameters considered might refer also to other years due to a lack of specific data. Recommendations from the MSA project consortium were made in 2015 and included a proposal for update of MSA data periodically every 3 to 5 years mainly because of the significant research efforts required in full updates and new studies (BIO by Deloitte, 2015).

Possibilities for updating the MSA data sets range from partial updates of frequently updated data (e.g., annual mining statistics) to updates as a result of data needs for other policy-related outputs (CRM assessment, Scoreboard, Trade, etc.) to scientific research undertakings inside or outside the EC (Figure 18).

Figure 18 Possibilities for MSA update and maintenance.



*Based on the MSA study recommendation for updates of the full MSA.

(a) Partial updates from frequently updated data sources

Partial updates from frequently updated data sources (e.g., geological surveys or trade statistics) could capture a small subset of flows/stocks captured in the MSA, mostly related to the first stages of a material supply chain (e.g., estimates on mineral reserves in ground, mining and processing) (Table 6). This would, thus, meet the needs of, e.g., the Circular Economy Action Plan to only a limited extent.

Table 6 MSA material flow/stock parameters which rely on frequently updates data sources (direct link to data providers, no or minor modifications required to adapt data sets into the MSA).

MSA Material Flow/Stock Parameter	LC-Stage	Possible Data Source
A.1.1 Reserves in EU	Exploration	BRGM, BGS, USGS
A.1.2 Reserves in ROW	Exploration	BRGM, BGS, USGS
B.1.1 Production of primary material as main product in EU sent to processing in EU	Extraction	BRGM, BGS, USGS
B.1.2 Production of primary material as by product in EU sent to processing in EU	Extraction	BRGM, BGS, USGS
B.1.3 Exports from EU of primary material	Extraction	UN Comtrade, ComExt
C.1.2 Exports from EU of processed material	Processing	UN Comtrade, ComExt
C.1.3 Imports to EU of primary material	Processing	UN Comtrade, ComExt
C.1.4 Imports to EU of secondary material	Processing	UN Comtrade, ComExt

For these data, no or only minor modifications/research would be required to use them in the MSA data sets. An example for a possible adaptation of data could be to convert mine data from gross weight into metal content by multiplying with respective material content factors that would be stored in a separate data file (mine-site specific or averaged). In the future, updates could be automatized by directly linking RMIS to the relevant data providers (e.g., through an application programming interface (API)). For example, a link (both on the IT-side as well as through a formal data sharing agreement) could be established between the RMIS and providers of annually updated data (e.g., UN COMTRADE, selected Eurostat statistics, mine data from geological surveys) which would allow the RMIS to automatically update data records whenever the source data (in this example the trade data provided) is updated. By doing so, it would be ensured that the RMIS always shows the latest available data through its user interface.

(b) Updates due to existing policy knowledge needs on raw materials

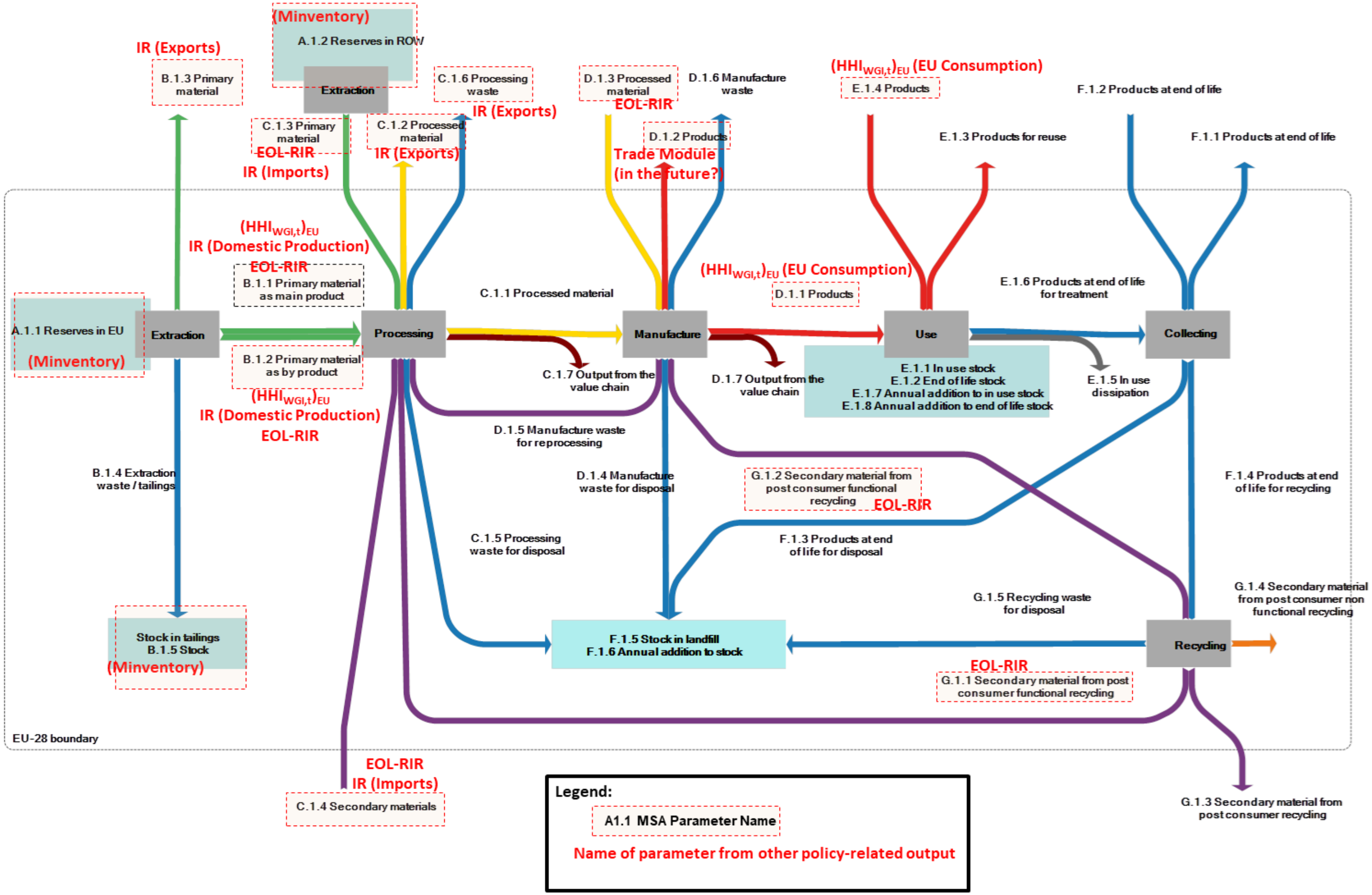
The policy need for providing assessments and analysis, e.g., through the reoccurring CRM assessment (every 3 years), Scoreboard (every 2 years), and trade analysis (frequency to be determined), implies raw materials-related data collection by the EC or though external contractors. Because the objective of the MSA study is to provide information on material stocks and flows throughout a material's full life-cycle (i.e., from extraction to end-of-life management), substantial overlaps of data collected for an MSA with the other policy-related outputs on raw materials exist.

For example, MSA requires information and data related to each life-cycle stage, e.g., data on domestic and foreign extraction, EU consumption, imports and exports at each life-cycle stage, end-use information, and recycling figures (Figure 2). The majority of EC raw material outputs, in contrast, focus on specific parts of the material life-cycle, e.g., extraction and processing stage (supply risk in the CRM assessment) or the trade flows between the EU and external partners in the extraction and processing stages (Trade module).

Due to this overlap, there is a clear potential for synergies. Depending on the way of work organization, this can basically be carried out in both ways, i.e., using data from policy-related outputs as an input for the MSA, or the other way around. Better harmonization of data and a common data structure are of key importance for utilizing this synergy potential.

Figure 19 and Table 7 look at each parameter of the MSA study and potential data overlaps/synergies with the above-mentioned additional policy-related outputs of GROW (CRM assessment, Scoreboard, Trade module, Minventory). It should be noted that the lack of systematic data for, e.g., secondary raw materials can be one of the reasons why this could not be appropriately taken into consideration, analogous to primary data in, e.g., the critical raw materials analyses. Hence, improving the quality and availability of such data could also enhance the policy support assessments beyond current usage.

Figure 19 The Material System Analysis (MSA) modelling framework (BIO by Deloitte, 2015) and data overlaps with other policy-related outputs (i.e., critical raw materials (CRM) assessment, EU RM Scoreboard, Minventory, and RMIS trade module).



IR: Import Reliance. EOL-RIR: End-of-Life Recycling Input Rate. HHI: Herfindahl Hirschman Index. WGI: World Governance Index. GS: Global Supply Mix.

Table 7 Data overlaps between the MSA study and other policy-related outputs of the RMIS. Green = Confirmed data overlaps; Red = Possible data overlap (tbc). SR: Supply Risk. EI: Economic Importance. Scoreboard (Scbd) numbers represent the number of the indicator. Minv. = Minventory More details are provided in Table S21 of the annex.

MSA Study (RMIS Overarching Structure)		CRM	Trade	Scbd	Minv.
Material Flow/Stock Parameter	LC-Stage				
A.1.1 Reserves in EU	Exploration			12	
A.1.2 Reserves in ROW	Exploration				
B.1.1 Production of primary material as main product in EU sent to processing in EU	Extraction	SR		6,16	
B.1.2 Production of primary material as by product in EU sent to processing in EU	Extraction	SR		3,6,16	
B.1.3 Exports from EU of primary material	Extraction	SR	?		
B.1.4 Extraction waste disposed in situ/tailings in EU	Extraction				
B.1.5 Stock in tailings in EU	Extraction				
C.1.1 Production of processed material in EU sent to manufacture in EU	Processing				
C.1.2 Exports from EU of processed material	Processing	SR	?		
C.1.3 Imports to EU of primary material	Processing	SR	?	3,16	
C.1.4 Imports to EU of secondary material	Processing	SR	?	3,16	
C.1.5 Processing waste in EU sent for disposal in EU	Processing				
C.1.6 Exports from EU of processing waste	Processing	SR	?	3,18	
C.1.7 Output from the value chain	Processing				
D.1.1 Production of manufactured products in EU sent to use in EU	Manufacture	SR			
D.1.2 Exports from EU of manufactured products	Manufacture		?		
D.1.3 Imports to EU of processed material	Manufacture	SR	?	16	
D.1.4 Manufacture waste in EU sent for disposal in EU	Manufacture				
D.1.5 Manufacture waste in EU sent for reprocessing in EU	Manufacture				
D.1.6 Exports from EU of manufacture waste	Manufacture		?	18	
D.1.7 Output from the value chain	Manufacture				
E.1.1 Stock of manufactured products in use in EU	Use				
E.1.2 Stock of manufactured products at end of life that are kept by users in EU	Use				
E.1.3 Exports from EU of manufactured products for reuse	Use		?		
E.1.4 Imports to EU of manufactured products	Use	SR	?		
E.1.5 In use dissipation in EU	Use				
E.1.6 Products at end of life in EU collected for treatment	Use				
E.1.7 Annual addition to in-use stock of manufactured products in EU	Use				
E.1.8 Annual addition to end-of life stock of manufactured products at end of life that are kept by users in EU	Use				
F.1.1 Exports from EU of manufactured products at end of life	Collection		?		
F.1.2 Imports to EU of manufactured products at end of life	Collection		?		
F.1.3 Manufactured products at end of life in EU sent for disposal in EU	Collection				
F.1.4 Manufactured products at end of life in EU sent for recycling in EU	Collection				
F.1.5 Stock in landfill in EU	Collection				
F.1.6 Annual addition to stock in landfill in EU	Collection				
G.1.1 Production of secondary material from post consumer functional recycling in EU sent to processing in EU	Recycling	SR		16	
G.1.2 Production of secondary material from post consumer functional recycling in EU sent to manufacture in EU	Recycling	SR		16	
G.1.3 Exports from EU of secondary material from post consumer recycling	Recycling		?		
G.1.4 Production of secondary material from post consumer non-functional recycling	Recycling				
G.1.5 Recycling waste in EU sent for disposal in EU	Recycling				

The **CRM assessment** aims at estimating the EU's supply risk and economic importance for a range of candidate materials. For this, the CRM assessment[33] requires data on a variety of flows related mostly to the early stages of a raw material's life-cycle (detailed assessment related to secondary raw material flows was not feasible due to data availability; hence having better MSA data on this could enhance the assessments). For example, a total of 12 flows (out of 40 in total) of the MSA are included in a typical CRM assessment. This includes data, e.g., on domestic production (B1.1 and B.1.2), imports and exports (mostly at the stages of extraction and processing), and flows that are required in the calculation of the "end-of-life recycling input rate" (EOL-RIR) which is used as a risk-reducing measure in the SR calculation. Resilience is not currently

[33] https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

addressed in these assessments, which focus on risk and economic consequence indicators in the context of supply disruptions; resilience analyses could also increase the need of stocks/reserves data and better knowledge on how the different MSA studies (currently treated separately from each other) are interconnected with other raw materials (e.g., metal-metal linkages due to co/by-production). Similarly, monitoring the circular economy in terms of, e.g., potential for recycling could similarly enhance the need for robust data in-use stocks, current recycle rates, etc.

The **trade module** currently focuses on capturing data on the imports and exports as well as domestic production of materials for the extraction and processing stages in the MSA framework. However, in several cases such data would need to be transformed into metal contents in order to be used for the MSA.

Data needs from MSAs also exist with the **Scoreboard**. For example, the EOL-RIR (indicator 16) theoretically implies the need for data for seven flows (G1.1, G1.2, B1.1, B1.2, C1.3, C1.4, and D1.3), while, in practice (e.g., in the 2017 CRM assessment), data from other one-off sources, e.g., (UNEP, 2011) are widely used. The importance of collecting better EU data on EOL-RIR may increase in light of the ongoing discussion on circular economy monitoring and the Action Plan; complementing needs of criticality assessments that remained simplified in current practice. Other data overlaps with the Scoreboard are domestic production figures (indicator 6).

The **Minventory study** to date provides only metadata and standards employed by EU Member States and neighbouring countries of Europe in quantifying resource and reserve information related to primary and secondary mineral raw materials (see also deliverable 8.2). If this study would be continued to collect data it would have overlaps with the MSA stock parameters A1.1 "Reserves in the EU", B 1.5 "Stock in tailings in the EU", and partial overlaps with A1.3 "Reserves in ROW" (for the countries that are included outside the EU).

It should be noted that all data overlaps are subject to change due to changing policy demand and further improvements, e.g., the CRM methodology could be further revised in the future, or new versions of the Scoreboard may look at modified indicators and/or completely new indicators. Improved MSAs could help improve also existing analyses, as well as to support new assessments for emerging policy interests (such as on resilience and circular economy monitoring). A common data structure and data collection procedure would also help to increase the efficiency in generating the various policy-related outputs.

Another important challenge relates to the fact that data collection for parameters must be well described. For example, data on import reliance collected for the 2017 CRM assessment represents a 5-year average and it is sometimes unclear what underlying method and which statistics and trade codes were involved. In order to further support raw-materials related policy knowledge needs and be prepared for emerging policy interests, the EC should re-examine selected parameters in more detail and develop internal time-series data to be able to provide relevant raw materials knowledge and expertise in the future.

(c) Other updates though JRC internal research and/or outsourcing

While some parameters of the MSA overlap with data collected for other policy-related outputs (Figure 3 and Table 7), it is obvious that the EC would also need to coordinate additional data collection to fill data gaps and ensure data consistency and harmonization. The 2015 study (BIO by Deloitte, 2015), clearly states that the availability of large parts of the MSA data depends on scientific research or data provided by industry (often with confidentiality issues).

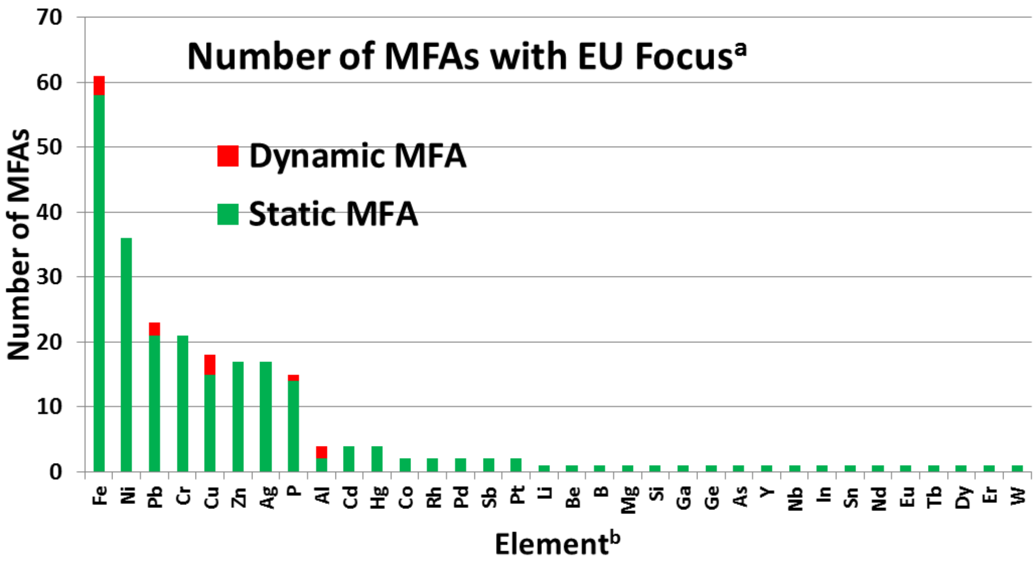
A possible approach would be to put aside an annual **separate budget** to target specific materials to be updated or added to the MSA database (e.g., based on the new list of CRMs or other policy needs). These could then be either developed inside the EC and/or through outsourcing to external contractors. A *reasonable target* might be for the EC, via the RMIS, to provide full and up-to-date (updated every 3-5 years) MSAs for all CRMs as well as for a selected number of major metals (e.g., aluminium, iron, copper, zinc, nickel) which form the basis of any industrial society. For prioritization of actions, policy demands should be explicitly prioritized. The minimum frequency of updates, but also the comprehensiveness of the coverage of materials, depends strongly on the final uses of the MSA.

Given that material supply chains can significantly differ between each other and that it takes time to become familiar with a single material, a possible strategy could be to introduce **"EC commodity experts"** (alternatively, a network of external "commodity experts" in Europe could be established) that gain knowledge for a small number of specific raw materials and oversee/peer-review related EC raw material outputs, including the MSA and future updates. The advantage of this approach would be that the number of raw materials followed by a single person would become more manageable than having a small number of people designated to MSA cover all possible materials included in RMIS.

(d) Other updates by establishing collaborations / linking to existing EU studies

The MFA module in RMIS aims to provide a gateway to external MFA data and studies with EU scope undertaken, e.g., by industry associations, governments, or the academic community. Furthermore, RMIS attempts to also link to global MFA studies and for other world regions. A preliminary review shows that a number of static (describes a "snapshot" of a system in time) and dynamic (describes the behaviour of a system over time) MFAs have been carried for some EU member states or the EU as a whole (Figure 20).

Figure 20 Number of static or dynamic MFAs of the elements[34].



The **MFA module in RMIS** can increasingly link to these studies, further review existing literature, and approach authors about the possibilities to provide related data directly in RMIS. For the moment, the MSA framework published in 2015 provides a starting point for carrying out additional MSA studies in the EU. Recognizing that MFA methodologies and approaches somewhat differ (e.g., in system boundaries chosen or data sources used), in the medium- to longer-term also the development of more detailed guidelines at EU level for carrying out MFA/MSA studies could be developed by the EC together with relevant stakeholders. For the moment, a review of existing MFA studies in the EU would serve as a starting point and would also allow the EC to establish a network of potential external and independent "commodity specialists" that could be approached for raw material specific questions. For experts at universities, collaborations could be initiated using, e.g., EC expert contracts which can run over a period of 4 years[35]. For industry associations with EU scope, it would need to be discussed on a case by case basis if these would directly provide their MFA related data into the RMIS (analogous to e.g. how many already provide material specific Life Cycle Assessments into the European Life Cycle Database – ELCD). In many cases, the collected data/published studies might not directly fit into the MSA data structure and additional work might be required; particularly initially to agree on a common structure.

5.2 Complementary work

The following items are based on recommendations given in the 2015 MSA study as well as based on discussions that took place as part of developing the current report. These are complementary to the recommended option discussed in section 4 and are partly incorporated also into Tables 3 and 4.

- **Development of time-series data for selected parameters used in MSA, CRM, Scoreboard, and Trade analysis**

As mentioned earlier in this report, an important challenge relates to the fact that data collection for parameters of the various raw material-related knowledge needs (e.g.,

[34] Source: (Nuss et al., 2017)
[35] https://ec.europa.eu/research/participants/portal/desktop/en/home.html

CRM assessment and MSA study) must be better explained. For example, data on import reliance for the 2017 CRM assessment represents a 5-year average and it is sometimes unclear with respect to the underlying method and the statistics and trade codes that were used. In order to build up good knowledge on raw materials in the EU, the EC will need to re-examine selected parameter in more detail (those with relevance to multiple policy needs) and develop its own internal time-series data to be able to provide raw materials knowledge and expertise in the future. Starting to view the CRM assessment, MSA study, Trade module, and Raw Materials Scoreboard in a more integrated fashion and targeting data sets important for all of these policy-related outputs provides a starting point for developing a better data base that could in the future then also be useful to provide knowledge to emerging policy demands.

- **Improvement of EU databases**

The 2015 MSA study highlighted a number of specific data challenges and needs in regard to frequently used EU databases, including ComExt, PRODCOM, and the Eurostat waste database. These include issues encountered in regard to data accuracy, units, clarity of name of trade codes, missing updates of trade codes, issues regarding the combination of materials in the same trade codes, missing material contents, differences in data availability in PRODCOM and Comext, and others.

Taking these ideas and suggestions as a starting point, the EC is well positioned to follow up with a more detailed report of recommendations on how EU statistics could be more aligned with the data needs of the MSA and other policy-related outputs in general. These should then be discussed with relevant DGs.

As an example, a first proposal on PRODCOM from DG GROW C2 to Eurostat was sent. It could be reviewed and commented on by JRC. NACE codes statistics can also be improved. Based on its experience in using EUROSTAT statistics, new suggestions for improving could be sent by JRC to C2.

- **Review of MSA against global MFA harmonization and inter-operability**

Given recent developments in harmonization, standardization, and sharing of MFA data at national, regional, and global level (e.g., MinFuture project[36] and ISIE Task Force on data transparency[37]), the MSA framework and model structure should be reviewed towards providing an EU stocks and flows database compatible with externally ongoing efforts. The EC already started following the MinFuture project and the JRC has recently joined as an advisory board member. Furthermore, it is currently being explored if the MSA data for selected materials can also be reviewed by the MinFuture consortium to ensure compatibility with a global MFA framework possibly proposed by the consortium in the future.

- **Definition of data quality requirements (minimum requirements) for MFA data platform**

Transforming the RMIS into a possible gateway for EU MFA data and information requires linkages to external data providers of such data. At the same time (and in order to become an authoritative source of raw materials data/information), the RMIS will need

[36] http://cordis.europa.eu/project/rcn/206335_en.html

[37] The goal of the International Society for Industrial Ecology (ISIE) Task Force is to develop proposals for how to increase the transparency and data availability of industrial ecology research, including MFA.

to ensure that any data/information provided by the RMIS (including its MFA module) follow certain data quality standards. Towards this end, a set of minimum data quality requirements (e.g., similar to the Life-Cycle Data Network[38] and/or the 2015 MSA study[39]) could be established, as well as a number of criteria (ideally of quantitative nature) to be used for assessing data quality. This remains a task for the future and would be based on, firstly, a review of existing MFA studies in the EU and an agreement with external experts on the best MFA framework at EU level to be promoted by the EC.

[38] http://eplca.jrc.ec.europa.eu/LCDN/

[39] BIO by Deloitte, 2015. Study on Data for a Raw Material System Analysis: Roadmap and Test of the Fully Operational MSA for Raw Materials. Prepared for the European Commission, DG GROW

6 Conclusions

This report presented three new MSA studies for aluminium, copper, and iron. Even though not among the list of critical raw materials in the EU, these materials are of high importance due to the large magnitude by which they are used in the EU economy. While recycling at end-of-life (EOL-RR) for these materials is relatively high, secondary raw materials generally make up a relatively small share of overall material inputs to the EU (EOL-RIR) mainly because demand is higher than what can currently be met by recycling.

Results from an assessment of data overlaps between MSA and other policy-related outputs show that current policy knowledge needs often require data on various flows related to the early stages of a raw material's life-cycle. For example, a total of 12 flows (out of 40 in total) of the MSA are also required for the 2017 CRM assessment. Possibilities for MSA update and maintenance range from partial data updates (harvesting data synergies with current policy-related outputs, e.g., the CRM assessment, Scoreboard, and Trade module in RMIS) to carrying out full/systematic MSAs for most candidate materials of the CRM assessment (through European Commission (EC) internal research projects and outsourcing via external contracts).

In a next step, these studies will be integrated into the RMIS website. In order to increase data harmonization between the different raw material files handled by JRC.D.3, future research efforts should focus on developing an overarching data collection procedure (encompassing MSA, Trade, Critical Raw Materials, RM Scoreboard, etc.) and decide on a good mix of in-house data collection and outsourcing.

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8 Annex

8.1 Aluminium

Figure S21 Complex Sankey diagram for aluminium (2013). Values are in Gg Al.

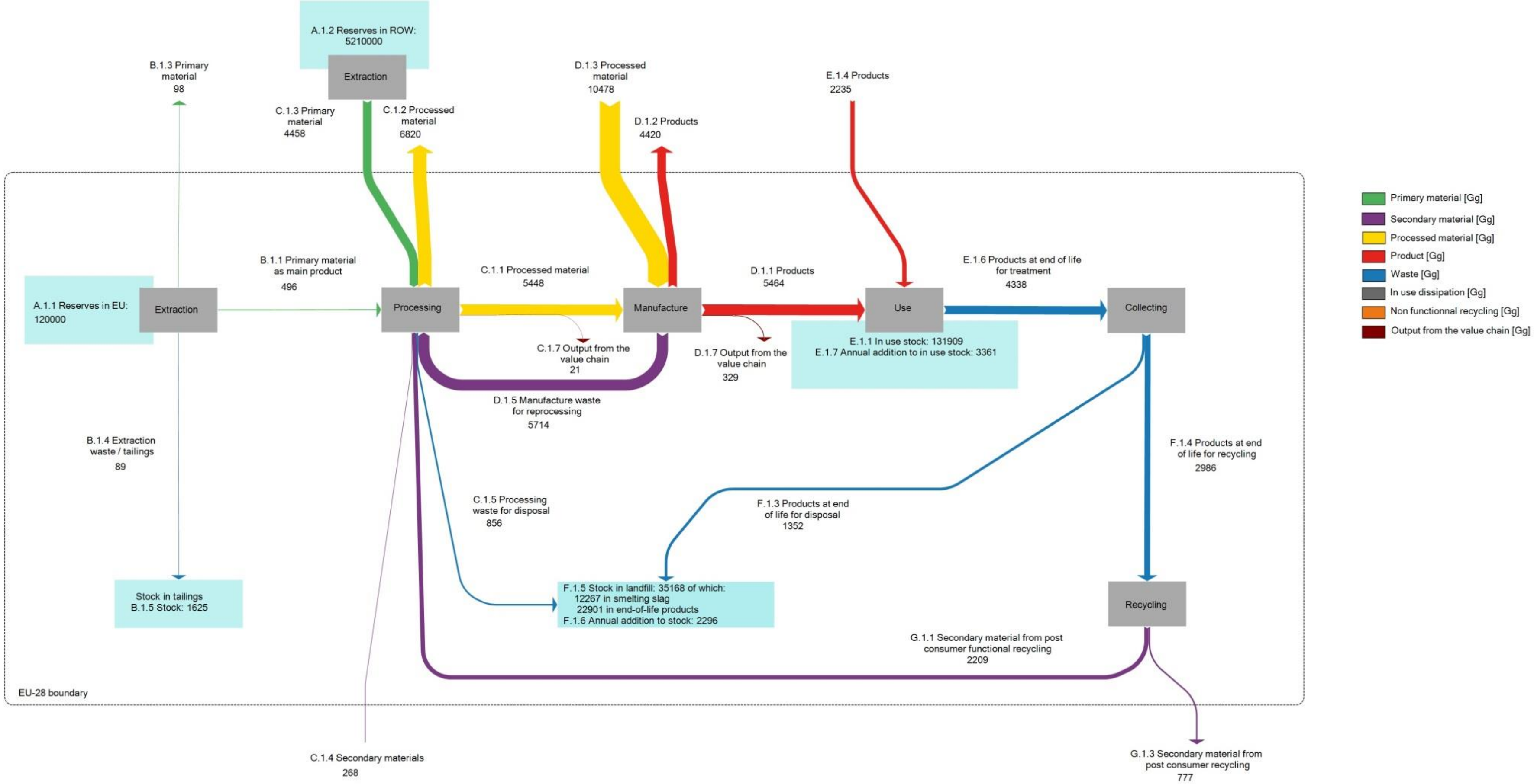

Figure S22 Disaggregation of aluminium flows within the processing and manufacture phases. Values are in Gg Al.

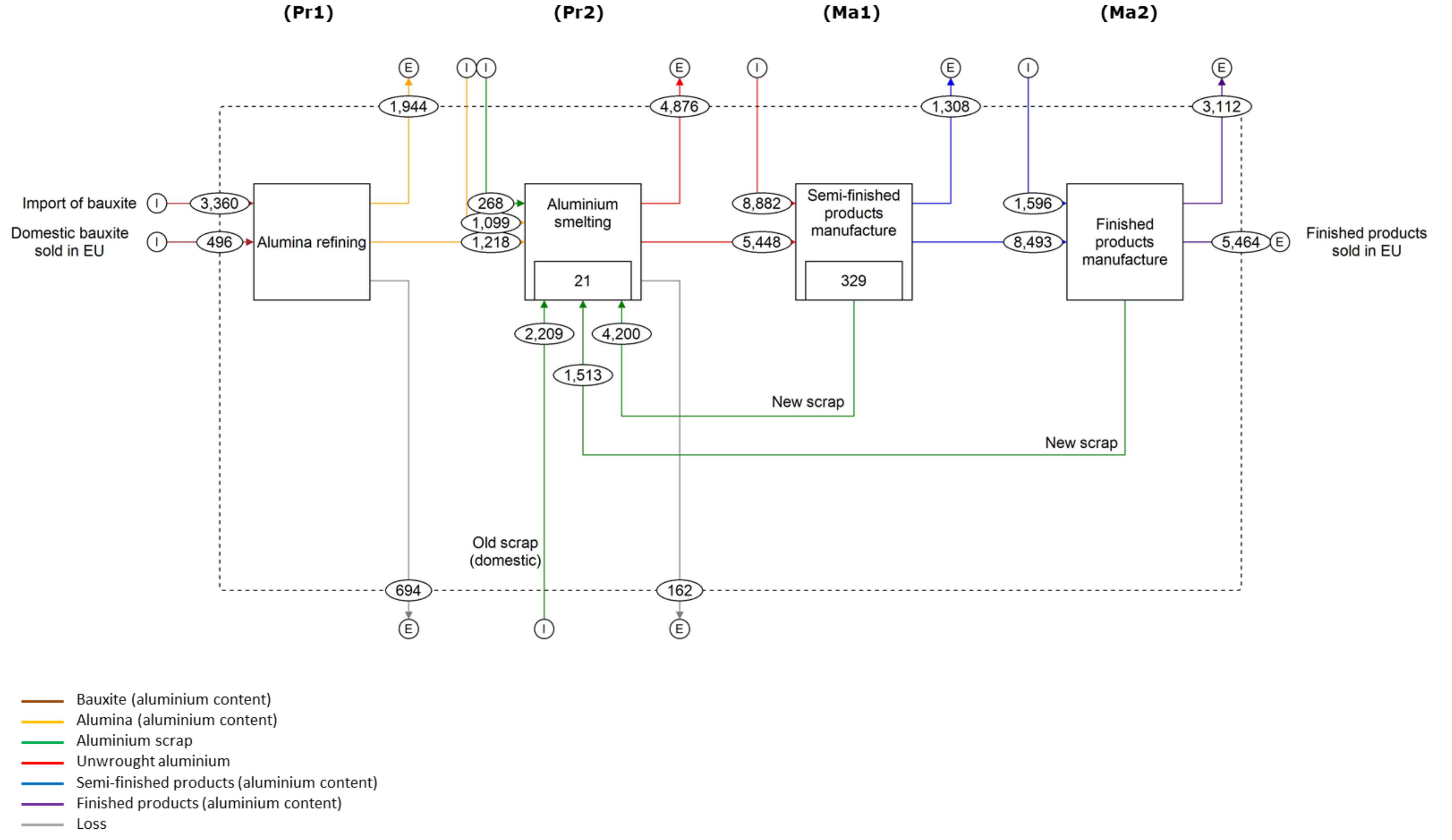

Figure S23 Historical end-uses of aluminium in the EU. Own calculation based on [1, 3].

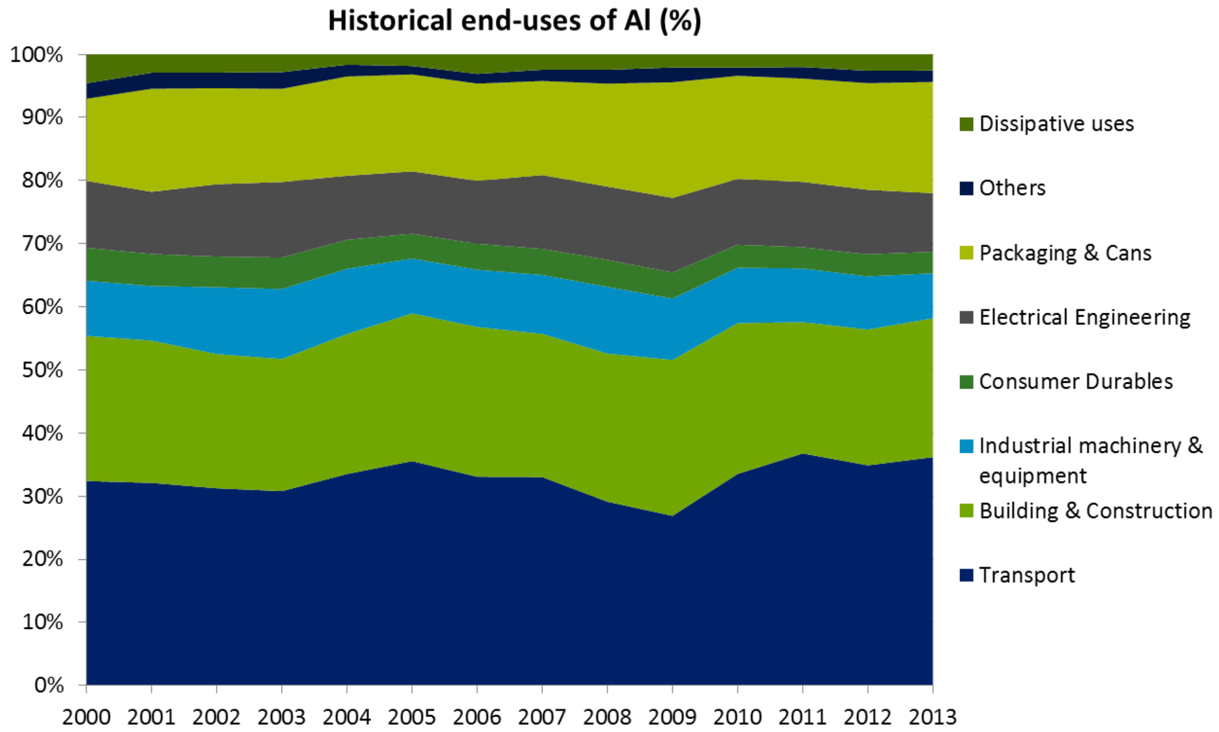

Table S8 Stock and flow model parameters, and results for each main end-use application segment.

Flow	Transportation	Year	Unit	Value
	Imports of Al in Transportation to EU	2013	Gg	959
	Input of Al in Transportation use	2013	Gg	2,383
	EU Annual Growth of Al consumption in Transportation in EU	2013	%	2.4%[1]
	In use dissipation rate in Transportation	2013	%/year	0%[2]
	Life span of Transportation	2013	Year	22[1]
	Share of Transportation at end of life kept by users	2013	%	0%
	Time during Transportation at end of life are kept by users	2013	Year	0
	Share of Transportation exported for reuse	2013	%	0%
E.1.1 Stock of manufactured products in use in EU	*Al in stocks of Transportation in EU*	2013	Gg	41,339
E.1.2 Stock of manufactured products at end-of-life that are kept by users in EU	*Al in stocks of Transportation at end of life kept by users in EU*	2013	Gg	0
E.1.3 Exports from EU of manufactured products for reuse	*Al in exports for reuse of Transportation*	2013	Gg	0
E.1.4 Imports to EU of manufactured products	*Al in imports of Transportation in EU*	2013	Gg	959
E.1.5 In use dissipation in EU	*In use dissipation of Al in Transportation*	2013	Gg	0
E.1.6 Products at end of life in EU collected for treatment	*Al in Transportation collected for treatment*	2013	Gg	1,414
E.1.7 Annual Addition to in-use stock of manufactured products in EU	*Al in Annual addition on stocks of Transportation in use in the EU*	2013	Gg	969
E.1.8 Annual addition to end-of life stock of manufactured products at end of life that are kept by users in EU	*Al in Annual addition on stocks of Transportation in the EU at end of life kept by users*	2013	Gg	0

[1]Based on historic aluminium industry net-production shipments in Europe. [1]

[2] Negligible loss. [2] To be computed from total in use stock.

Flow	Building and construction	Year	Unit	Value
	Imports of Al in Building and construction to EU	2013	Gg	145
	Input of Al in Building and construction use	2013	Gg	1,925
	EU Annual Growth of Al consumption in Building and construction in EU	2013	%	3.5%[1]
	In use dissipation rate in Building and construction	2013	%/year	0%[2]
	Life span of Building and construction	2013	Year	60[1]
	Share of Building and construction at end of life kept by users	2013	%	0%
	Time during Building and construction at end of life are kept by users	2013	Year	0
	Share of Building and construction exported for reuse	2013	%	0%
E.1.1 Stock of manufactured products in use in EU	*Al in stocks of Building and construction in EU*	2013	Gg	49,690
E.1.2 Stock of manufactured products at end-of-life that are kept by users in EU	*Al in stocks of Building and construction at end of life kept by users in EU*	2013	Gg	0
E.1.3 Exports from EU of manufactured products for reuse	*Al in exports for reuse of Building and construction*	2013	Gg	0
E.1.4 Imports to EU of manufactured products	*Al in imports of Building and construction in EU*	2013	Gg	145
E.1.5 In use dissipation in EU	*In use dissipation of Al in Building and construction*	2013	Gg	0
E.1.6 Products at end of life in EU collected for treatment	*Al in Building and construction collected for treatment*	2013	Gg	244
E.1.7 Annual Addition to in-use stock of manufactured products in EU	*Al in Annual addition on stocks of Building and construction in use in the EU*	2013	Gg	1,680
E.1.8 Annual addition to end-of life stock of manufactured products at end of life that are kept by users in EU	*Al in Annual addition on stocks of Building and construction in the EU at end of life kept by users*	2013	Gg	0

[1]Based on historic aluminium industry net-production shipments in Europe. [1]

[2] Negligible loss. [2] To be computed from total in use stock.

Flow	Industrial machinery and equipment	Year	Unit	Value
	Imports of Al in Industrial machinery and equipment to EU	2013	Gg	226
	Input of Al in Industrial machinery and equipment use	2013	Gg	273
	EU Annual Growth of Al consumption in Industrial machinery and equipment in EU	2013	%	2.0%[1]

Flow	Industrial machinery and equipment	Year	Unit	Value
	In use dissipation rate in Industrial machinery and equipment	2013	%/year	0%[2]
	Life span of Industrial machinery and equipment	2013	Year	40[1]
	Share of Industrial machinery and equipment at end of life kept by users	2013	%	0%
	Time during Industrial machinery and equipment at end of life are kept by users	2013	Year	0
	Share of Industrial machinery and equipment exported for reuse	2013	%	0%
E.1.1 Stock of manufactured products in use in EU	*Al in stocks of Industrial machinery and equipment in EU*	2013	Gg	7,631
E.1.2 Stock of manufactured products at end-of-life that are kept by users in EU	*Al in stocks of Industrial machinery and equipment at end of life kept by users in EU*	2013	Gg	0
E.1.3 Exports from EU of manufactured products for reuse	*Al in exports for reuse of Industrial machinery and equipment*	2013	Gg	0
E.1.4 Imports to EU of manufactured products	*Al in imports of Industrial machinery and equipment in EU*	2013	Gg	226
E.1.5 In use dissipation in EU	*In use dissipation of Al in Industrial machinery and equipment*	2013	Gg	0
E.1.6 Products at end of life in EU collected for treatment	*Al in Industrial machinery and equipment collected for treatment*	2013	Gg	124
E.1.7 Annual Addition to in-use stock of manufactured products in EU	*Al in Annual addition on stocks of Industrial machinery and equipment in use in the EU*	2013	Gg	150
E.1.8 Annual addition to end-of life stock of manufactured products at end of life that are kept by users in EU	*Al in Annual addition on stocks of Industrial machinery and equipment in the EU at end of life kept by users*	2013	Gg	0

[1]Based on historic aluminium industry net-production shipments in Europe. [1]

[2] Negligible loss. [2] To be computed from total in use stock.

Flow	Consumer durables	Year	Unit	Value
	Imports of Al in Consumer durables to EU	2013	Gg	418
	Input of Al in Consumer durables use	2013	Gg	438
	EU Annual Growth of Al consumption in Consumer durables in EU	2013	%	1.0%[1]
	In use dissipation rate in Consumer durables	2013	%/year	0%[2]
	Life span of Consumer durables	2013	Year	20[1]
	Share of Consumer durables at end of life kept by users	2013	%	0%
	Time during Consumer durables at end of life are kept by users	2013	Year	0
	Share of Consumer durables exported for reuse	2013	%	0%
E.1.1 Stock of manufactured products in use in EU	*Al in stocks of Consumer durables in EU*	2013	Gg	7,988
E.1.2 Stock of manufactured products at end-of-life that are kept by users in EU	*Al in stocks of Consumer durables at end of life kept by users in EU*	2013	Gg	0
E.1.3 Exports from EU of manufactured products for reuse	*Al in exports for reuse of Consumer durables*	2013	Gg	0
E.1.4 Imports to EU of manufactured products	*Al in imports of Consumer durables in EU*	2013	Gg	418
E.1.5 In use dissipation in EU	*In use dissipation of Al in Consumer durables*	2013	Gg	0
E.1.6 Products at end of life in EU collected for treatment	*Al in Consumer durables collected for treatment*	2013	Gg	359
E.1.7 Annual Addition to in-use stock of manufactured products in EU	*Al in Annual addition on stocks of Consumer durables in use in the EU*	2013	Gg	79
E.1.8 Annual addition to end-of life stock of manufactured products at end of life that are kept by users in EU	*Al in Annual addition on stocks of Consumer durables in the EU at end of life kept by users*	2013	Gg	0

[1]Based on historic aluminium industry net-production shipments in Europe. [1]

[2] Negligible loss. [2] To be computed from total in use stock.

Flow	Electrical engineering	Year	Unit	Value
	Imports of Al in Electrical engineering to EU	2013	Gg	486
	Input of Al in Electrical engineering use	2013	Gg	750
	EU Annual Growth of Al consumption in Electrical engineering in EU	2013	%	2.0%[1]
	In use dissipation rate in Electrical engineering	2013	%/year	0%[2]
	Life span of Electrical engineering	2013	Year	40[1]
	Share of Electrical engineering at end of life kept by users	2013	%	0%

Flow	Electrical engineering	Year	Unit	Value
	Time during Electrical engineering at end of life are kept by users	2013	Year	0
	Share of Electrical engineering exported for reuse	2013	%	0%
E.1.1 Stock of manufactured products in use in EU	*Al in stocks of Electrical engineering in EU*	2013	Gg	20,917
E.1.2 Stock of manufactured products at end-of-life that are kept by users in EU	*Al in stocks of Electrical engineering at end of life kept by users in EU*	2013	Gg	0
E.1.3 Exports from EU of manufactured products for reuse	*Al in exports for reuse of Electrical engineering*	2013	Gg	0
E.1.4 Imports to EU of manufactured products	*Al in imports of Electrical engineering in EU*	2013	Gg	486
E.1.5 In use dissipation in EU	*In use dissipation of Al in Electrical engineering*	2013	Gg	0
E.1.6 Products at end of life in EU collected for treatment	*Al in Electrical engineering collected for treatment*	2013	Gg	340
E.1.7 Annual Addition to in-use stock of manufactured products in EU	*Al in Annual addition on stocks of Electrical engineering in use in the EU*	2013	Gg	410
E.1.8 Annual addition to end-of life stock of manufactured products at end of life that are kept by users in EU	*Al in Annual addition on stocks of Electrical engineering in the EU at end of life kept by users*	2013	Gg	0

[1]Based on historic aluminium industry net-production shipments in Europe. [1]

[2] Negligible loss. [2] To be computed from total in use stock.

Flow	Packaging and cans	Year	Unit	Value
	Imports of Al in Packaging and cans to EU	2013	Gg	0
	Input of Al in Packaging and cans use	2013	Gg	1,572
	EU Annual Growth of Al consumption in Packaging and cans in EU	2013	%	2.8%[1]
	In use dissipation rate in Packaging and cans	2013	%/year	0%[2]
	Life span of Packaging and cans	2013	Year	1[1]
	Share of Packaging and cans at end of life kept by users	2013	%	0%
	Time during Packaging and cans at end of life are kept by users	2013	Year	0
	Share of Packaging and cans exported for reuse	2013	%	0%
E.1.1 Stock of manufactured products in use in EU	*Al in stocks of Packaging and cans in EU*	2013	Gg	1,572
E.1.2 Stock of manufactured products at end-of-life that are kept by users in EU	*Al in stocks of Packaging and cans at end of life kept by users in EU*	2013	Gg	0
E.1.3 Exports from EU of manufactured products for reuse	*Al in exports for reuse of Packaging and cans*	2013	Gg	0
E.1.4 Imports to EU of manufactured products	*Al in imports of Packaging and cans in EU*	2013	Gg	0
E.1.5 In use dissipation in EU	*In use dissipation of Al in Packaging and cans*	2013	Gg	0
E.1.6 Products at end of life in EU collected for treatment	*Al in Packaging and cans collected for treatment*	2013	Gg	1,529
E.1.7 Annual Addition to in-use stock of manufactured products in EU	*Al in Annual addition on stocks of Packaging and cans in use in the EU*	2013	Gg	43
E.1.8 Annual addition to end-of life stock of manufactured products at end of life that are kept by users in EU	*Al in Annual addition on stocks of Packaging and cans in the EU at end of life kept by users*	2013	Gg	0

[1]Based on historic aluminium industry net-production shipments in Europe. [1]

[2] Negligible loss. [2] To be computed from total in use stock.

Flow	Others	Year	Unit	Value
	Imports of Al in Others to EU	2013	Gg	0
	Input of Al in Others use	2013	Gg	143
	EU Annual Growth of Al consumption in Others in EU	2013	%	1.2%[1]
	In use dissipation rate in Others	2013	%/year	0%[2]
	Life span of Others	2013	Year	20[1]
	Share of Others at end of life kept by users	2013	%	0%
	Time during Others at end of life are kept by users	2013	Year	0
	Share of Others exported for reuse	2013	%	0%
E.1.1 Stock of manufactured products in use in EU	*Al in stocks of Others in EU*	2013	Gg	2,558
E.1.2 Stock of manufactured products at end-of-life that are kept by users in EU	*Al in stocks of Others at end of life kept by users in EU*	2013	Gg	0

Flow	Others	Year	Unit	Value
E.1.3 Exports from EU of manufactured products for reuse	*Al in exports for reuse of Others*	2013	Gg	0
E.1.4 Imports to EU of manufactured products	*Al in imports of Others in EU*	2013	Gg	0
E.1.5 In use dissipation in EU	*In use dissipation of Al in Others*	2013	Gg	0
E.1.6 Products at end of life in EU collected for treatment	*Al in Others collected for treatment*	2013	Gg	113
E.1.7 Annual Addition to in-use stock of manufactured products in EU	*Al in Annual addition on stocks of Others in use in the EU*	2013	Gg	30
E.1.8 Annual addition to end-of life stock of manufactured products at end of life that are kept by users in EU	*Al in Annual addition on stocks of Others in the EU at end of life kept by users*	2013	Gg	0

[1]Based on historic aluminium industry net-production shipments in Europe. [1]

[2] Negligible loss. [2] To be computed from total in use stock.

Flow	Dissipative uses	Year	Unit	Value
	Imports of Al in Dissipative uses to EU	2013	Gg	0
	Input of Al in Dissipative uses use	2013	Gg	199
	EU Annual Growth of Al consumption in Dissipative uses in EU	2013	%	-0.1%[1]
	In use dissipation rate in Dissipative uses	2013	%/year	0%[2]
	Life span of Dissipative uses	2013	Year	1[1]
	Share of Dissipative uses at end of life kept by users	2013	%	0%
	Time during Dissipative uses at end of life are kept by users	2013	Year	0
	Share of Dissipative uses exported for reuse	2013	%	0%
E.1.1 Stock of manufactured products in use in EU	*Al in stocks of Dissipative uses in EU*	2013	Gg	199
E.1.2 Stock of manufactured products at end-of-life that are kept by users in EU	*Al in stocks of Dissipative uses at end of life kept by users in EU*	2013	Gg	0
E.1.3 Exports from EU of manufactured products for reuse	*Al in exports for reuse of Dissipative uses*	2013	Gg	0
E.1.4 Imports to EU of manufactured products	*Al in imports of Dissipative uses in EU*	2013	Gg	0
E.1.5 In use dissipation in EU	*In use dissipation of Al in Dissipative uses*	2013	Gg	0
E.1.6 Products at end of life in EU collected for treatment	*Al in Dissipative uses collected for treatment*	2013	Gg	200
E.1.7 Annual Addition to in-use stock of manufactured products in EU	*Al in Annual addition on stocks of Dissipative uses in use in the EU*	2013	Gg	0
E.1.8 Annual addition to end-of life stock of manufactured products at end of life that are kept by users in EU	*Al in Annual addition on stocks of Dissipative uses in the EU at end of life kept by users*	2013	Gg	0

[1]Based on historic aluminium industry net-production shipments in Europe. [1]

[2] Negligible loss. [2] To be computed from total in use stock.

Table S9 List of commodities containing aluminium. . Based on [4-6, 8].

Code	Description	Aluminium content (%)	Aluminium cycle phase
S1-68421	Bars, rods, angles, shapes and wire of aluminium	98,5%	Semi-finished products
S1-68422	Plates, sheets and strip of aluminium	95,0%	
S1-68423	Aluminium foil	99,0%	
S1-68424	Aluminium powders and flakes	95,0%	
S1-68425	Tubes, pipes & blanks, hollow bars of aluminium	98,0%	
S1-68426	Tube and pipe fittings of aluminium	98,0%	
S1-7113	Steam engines and steam turbines	2,0%	Transportation (parts of and finished products)
S1-7114	Aircraft incl. jet propulsion engines	3,0%	
S1-7115	Internal combustion engines, not for aircraft	25,0%	
S1-7294	Automotive electrical equipment	5,0%	
S1-7312	Electric railway locomotives, not self generat.	1,0%	
S1-7313	Railway locomotives, not steam or electric	1,0%	
S1-7314	Mechanically propelled railway and tramway cars	1,0%	
S1-7315	Rail & tram passenger cars not mech propelled	1,0%	
S1-7316	Rail.&tram. freight cars, not mechanically propd.	1,0%	
S1-7317	Parts of railway locomotives & rolling stock	1,0%	
S1-7321	Passenger motor cars, other than buses	5,0%	
S1-7322	Buses, including trolleybuses	8,0%	
S1-7323	Lorries and trucks, including ambulances, etc.	6,0%	
S1-7324	Special purpose lorries, trucks and vans	6,0%	
S1-7325	Road tractors for tractor trailer combinations	4,0%	
S1-7327	Other chassis with engines mounted	1,0%	
S1-7328	Bodies & parts motor vehicles ex motorcycles	10,0%	
S1-73291	Motorcycles, auto cycles, etc.& side cars	10,0%	
S1-73311	Cycles, not motorized	20,0%	
S1-73312	Parts of vehicles of heading 733 11 & 733 4	20,0%	
S1-7333	Trailers & oth vehicles not motorized, & parts	8,0%	
S1-7334	Invalid carriages	5,0%	
S1-7341	Aircraft, heavier than air	70,0%	
S1-73492	Parts of aircraft, airships, etc.	70,0%	
S1-7351	Warships of all kinds	1,0%	
S1-7353	Ships and boats, other than warships	2,0%	
S1-7358	Ships, boats and other vessels for breaking up	2,0%	
S1-7359	Special purpose ships and boats	1,0%	
S1-6912	Fin, structural parts & structures of aluminium	90,0%	Building and construction (parts of and finished products)
S1-72505	Electric space heating equipment etc.	3,0%	
S1-8121	Central heating apparatus and parts	2,0%	
S1-81242	Lamps & lighting fittings & parts thereof	2,0%	
S1-69213	Tanks, etc. for storage of manuf. use of aluminium	80,0%	Industrial machinery and equipment (parts of and finished products)
S1-69222	Casks, drums, etc .used for transport of aluminium	80,0%	
S1-69232	Compressed gas cylinders of aluminium	80,0%	
S1-7111	Steam generating boilers	1,0%	
S1-7112	Boiler house plant	1,0%	
S1-7116	Gas turbines, other than for aircraft	2,0%	
S1-7117	Nuclear reactors	0,1%	
S1-7118	Engines, nes	4,0%	
S1-7121	Agricultural machinery for cultivating the soil	1,0%	
S1-7122	Agricultural machinery for harvesting, threshing	1,0%	
S1-7123	Milking machines, cream separators, dairy farm eq	1,0%	
S1-7125	Tractors, other than road tractors	1,0%	
S1-7129	Agricultural machinery and appliances, nes	1,0%	
S1-715	Metalworking machinery	2,0%	
S1-717	Textile and leather machinery	2,0%	
S1-718	Machines for special industries	2,0%	
S1-7191	Heating and cooling equipment	3,0%	
S1-7192	Pumps and centrifuges	3,0%	
S1-7193	Mechanical handling equipment	2,0%	
S1-7195	Powered tools, nes	3,0%	
S1-7196	Other non electrical machines	2,0%	
S1-7197	Ball, roller or needle roller bearings	1,0%	
S1-7198	Machinery and mechanical appliances, nes	1,0%	
S1-7199	Parts and accessories of machinery, nes	2,0%	
S1-7296	Electro mechanical hand tools	3,0%	
S1-7297	Electron and proton accelerators	3,0%	
S1-7299	Electrical machinery and apparatus, nes	3,0%	
S1-861	Scientific, medical, optical, meas./contr. instrum.	3,0%	
S1-89999	Catapults and sim. aircraft launching gear, etc.	8,0%	

Code	Description	Aluminium content (%)	Aluminium cycle phase
S1-95101	Armoured fighting vehicles	1,0%	
S1-95102	Artillery weapons, mach. guns and arms, n.e.s.	2,0%	
S1-95103	Parts of military ordnance	2,0%	
S1-95104	Sidearms and parts thereof	2,0%	
S1-95105	Revolvers and pistols	2,0%	
S1-95106	Projectiles and ammunition, n.e.s.	2,0%	
S1-69723	Domestic utensils of aluminium	75,0%	Consumer durables (parts of and finished products)
S1-6979	Other household equipment of base metals	6,0%	
S1-6981	Locksmiths wares	3,0%	
S1-6982	Safes, strong rooms, strong room fittings etc.	2,0%	
S1-6988	Miscell. articles of base metal	2,0%	
S1-69894	Artricles of aluminium, n.e.s.	90,0%	
S1-7141	Typewriters and cheque writing machines	2,0%	
S1-7142	Calculating & accounting machines etc	2,0%	
S1-7143	Statistical machines cards or tapes	2,0%	
S1-7149	Office machines, nes	2,0%	
S1-7194	Domestic appliances, non electrical	2,0%	
S1-72501	Domestic refrigerators, electrical	2,0%	
S1-72502	Domestic washing machines whether or not elec.	3,0%	
S1-72503	Electro mechanical domestic appliances nes	2,0%	
S1-72504	Electric shavers & hair clippers	1,0%	
S1-81243	Portable electric battery lamps	3,0%	
S1-8210	Furniture	1,0%	
S1-82101	Chairs/seats and parts thereof	1,0%	
S1-82102	Medical furniture, etc. parts thereof	1,0%	
S1-82103	Mattreses, mattress supports and similar furn.	1,0%	
S1-82109	Furniture and parts thereof, n.e.s.	1,0%	
S1-8310	Travel goods, handbags & similar articles	1,0%	
S1-8310	Travel goods, handbags & similar articles	1,0%	
S1-864	Watches and clocks	3,0%	
S1-8911	Phonographs, tape & other sound recorders etc.	1,0%	
S1-8914	Pianos and other string musical instruments	1,0%	
S1-8918	Musical instruments, nes	1,0%	
S1-8919	Parts and accessories of musical instruments	1,0%	
S1-894	Perambulators, toys, games and sporting goods	2,0%	
S1-8951	Office and stationery supplies of base metals	1,0%	
S1-69313	Wire, cables, ropes etc. not insulated, aluminium	90,0%	Electrical engineering (parts of and finished products)
S1-7221	Electric power machinery	5,0%	
S1-7222	Apparatus for electrical circuits	5,0%	
S1-7231	Insulated wire and cable	40,0%	
S1-7232	Electrical insulating equipment	5,0%	
S1-7241	Television broadcast receivers	1,0%	
S1-7242	Radio broadcast receivers	2,0%	
S1-7249	Telecommunications equipment nes	2,0%	
S1-726	Elec. apparatus for medic.purp.,radiological ap.	2,0%	
S1-7291	Batteries and accumulators	1,0%	
S1-7292	Electric lamps	1,0%	
S1-7293	Thermionic valves and tubes, transistors, etc.	1,0%	
S1-7295	Electrical measuring & controlling instruments	3,0%	
S1-28404	Aluminium waste and scrap	84%	Waste and scrap

Table S10 Process efficiency rates.

Process	Rate (%)	Year of reference	Source
Bauxite extraction	87.0%	2008	[7]
Alumina refining	83.0%	2008	[7]
Primary Al smelting	98.9%	2009	[4-5]
Secondary Al smelting	97.0%	2009	[3]
New scrap melting / Direct remelting	99.0%	2014	[3]
New scrap from semi-finished products manufacture (generation rate)	30.0%	2014	Own assumption based on [3]
New scrap from finished products manufacture (generation rate)	15.0%	2014	Own assumption based on [3]
End-of-life collection and sorting			
Transportation	92.0%	2013	[1]
Building and construction	95.0%	2013	[1]
Industrial machinery and equipment	80.0%	2013	[1]
Consumer durables	50.0%	2013	[1]
Electrical engineering	70.0%	2013	[1]
Packaging ad cans	59.0%	2013	[1]
Others	30.0%	2013	[1]
Dissipative uses	0.0%	2013	[1]

Table S8 EU-28 production [9], import [6] and export [6] of bauxite used in the study. Values in Gg of bauxite.

Year	Production	Import	Export
2010	2,682		
2011	2,160	11,220	520
2012	2,046	11,887	437
2013	1,967	11,585	337
2014	1,922		

Table S9 EU-28 production [10], import [6] and export [6] of alumina used in the study. Values in Gg of alumina.

Year	Production	Import	Export
2010	5,207		
2011	5,318		
2012	4,959		
2013	5,231	2,107	3,728
2014	5,109	3,279	5,634

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8.2 Copper

Figure S24 Complex Sankey diagram for copper (2014). Values are in Gg Cu.

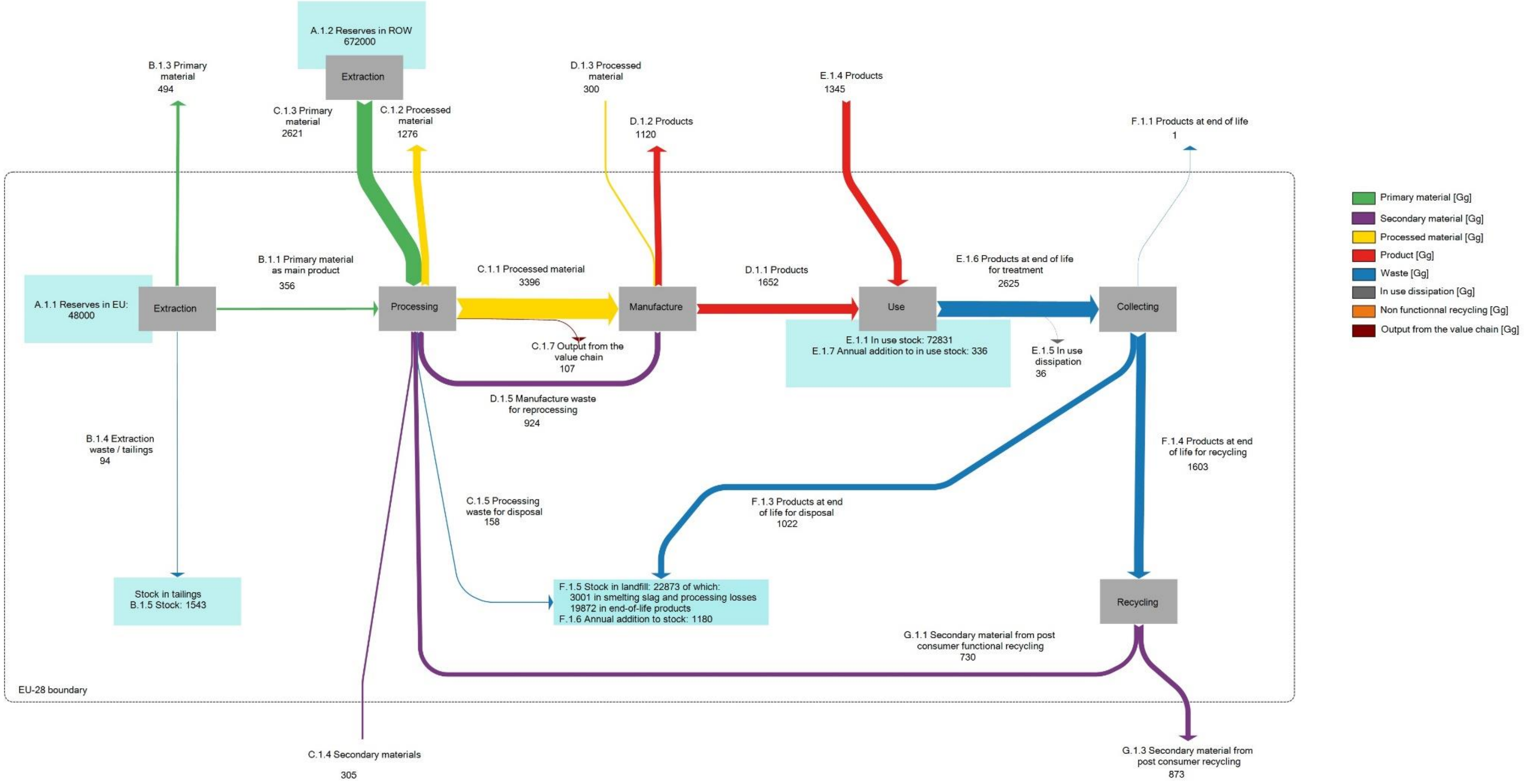

Figure S25 Disaggregation of copper flows within the processing and manufacture phases. Values are in Gg Cu.

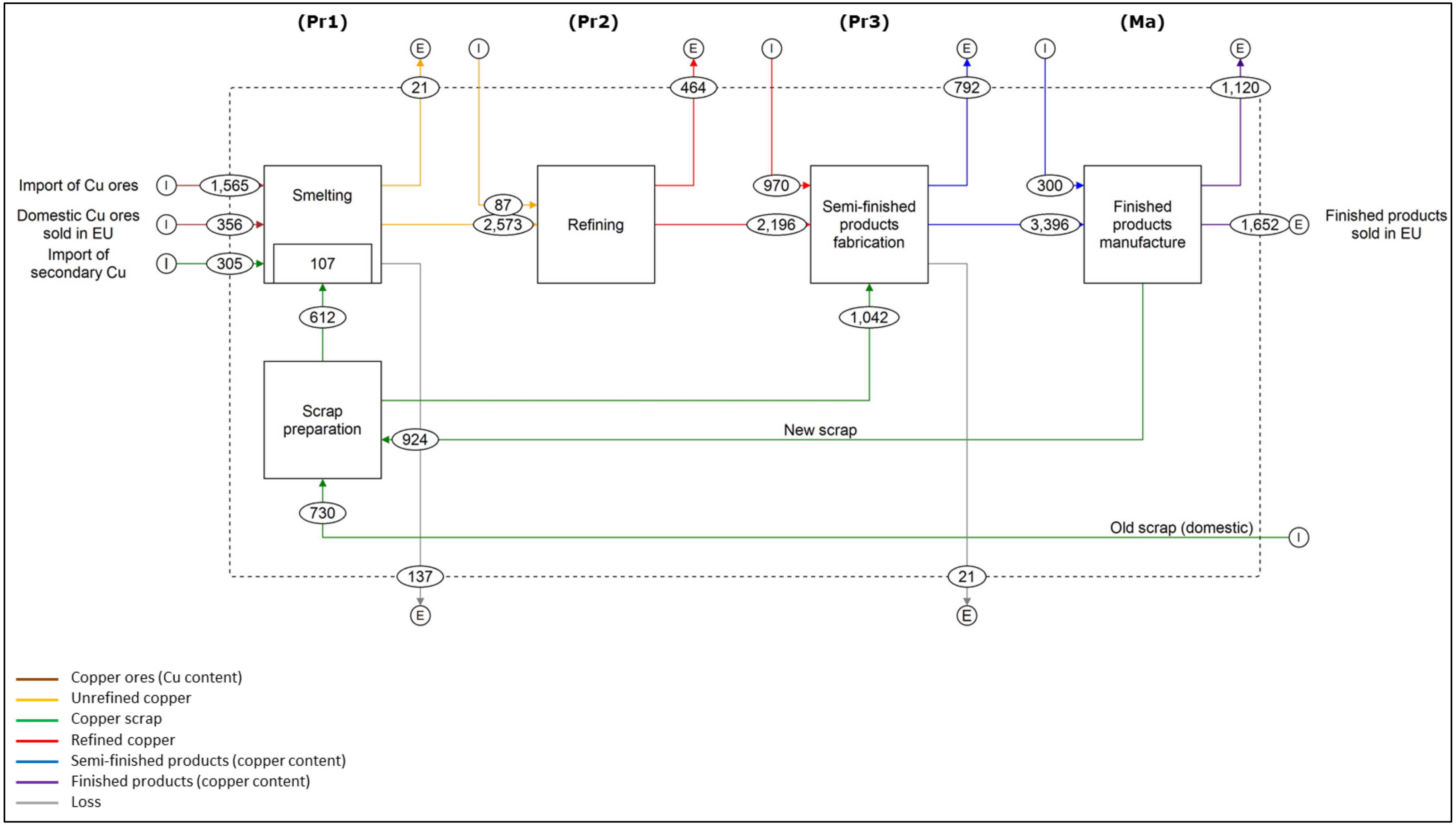

Figure S26 Historical end-uses of copper in the EU. Own calculation based on [1, 2].

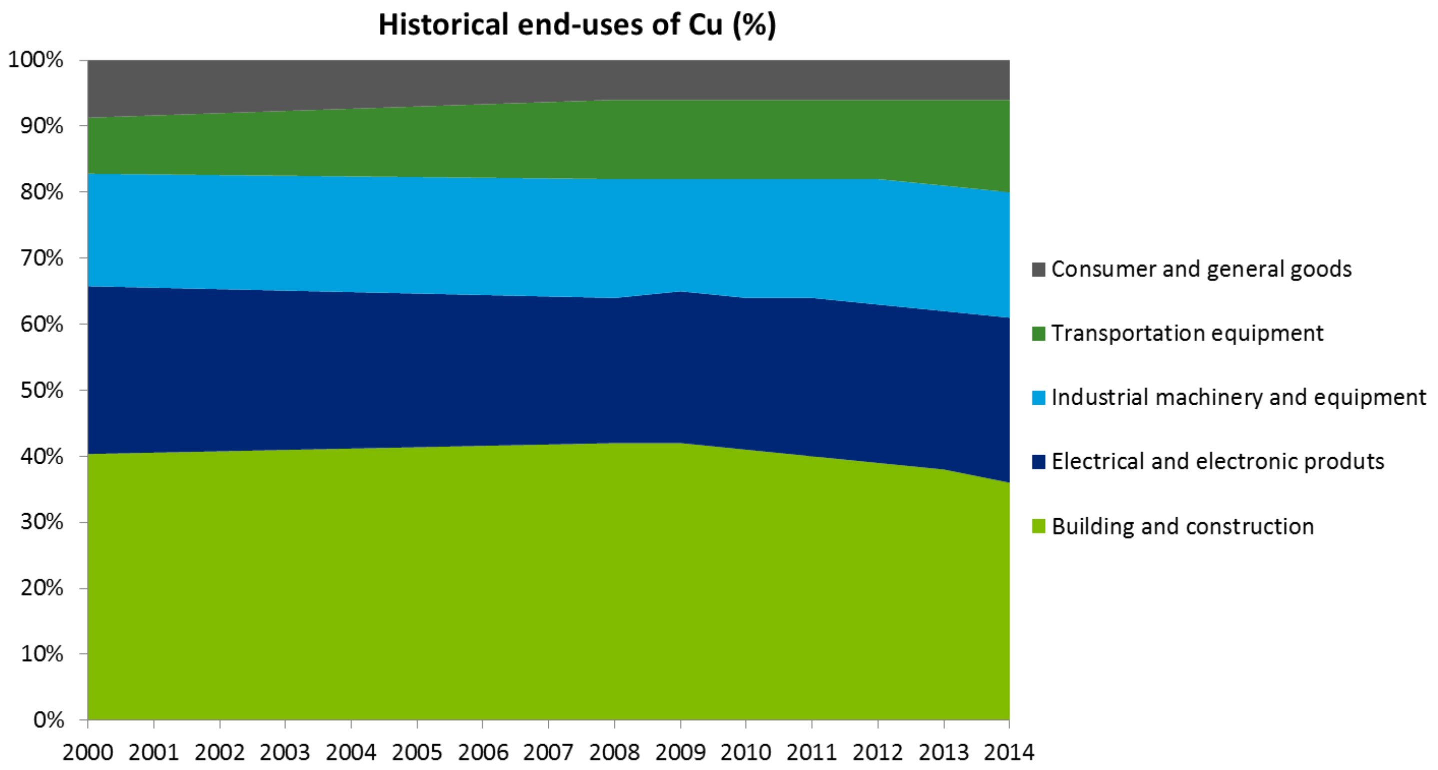

Table S11 Stock and flow model parameters, and results for each main end-use application segment.

Flow	Electrical and electronic products	Year	Unit	Value
	Imports of Cu in Electrical and electronic products to EU	2014	Gg	455
	Input of Cu in Electrical and electronic products use	2014	Gg	873
	EU Annual Growth of Cu consumption in Electrical and electronic products in EU	2014	%	0.4%[1]
	In use dissipation rate in Electrical and electronic products	2014	%/year	0%[2]
	Life span of Electrical and electronic products	2014	Year	25[3]
	Share of Electrical and electronic products at end of life kept by users	2014	%	0%
	Time during Electrical and electronic products at end of life are kept by users	2014	Year	0
	Share of Electrical and electronic products exported for reuse	2014	%	0%
E.1.1 Stock of manufactured products in use in EU	*Cu in stocks of Electrical and electronic products in EU*	2014	Gg	20,815
E.1.2 Stock of manufactured products at end-of-life that are kept by users in EU	*Cu in stocks of Electrical and electronic products at end of life kept by users in EU*	2014	Gg	0
E.1.3 Exports from EU of manufactured products for reuse	*Cu in exports for reuse of Electrical and electronic products*	2014	Gg	0
E.1.4 Imports to EU of manufactured products	*Cu in imports of Electrical and electronic products in EU*	2014	Gg	455
E.1.5 In use dissipation in EU	*In use dissipation of Cu in Electrical and electronic products*	2014	Gg	0
E.1.6 Products at end of life in EU collected for treatment	*Cu in Electrical and electronic products collected for treatment*	2014	Gg	790
E.1.7 Annual Addition to in-use stock of manufactured products in EU	*Cu in Annual addition on stocks of Electrical and electronic products in use in the EU*	2014	Gg	83
E.1.8 Annual addition to end-of life stock of manufactured products at end of life that are kept by users in EU	*Cu in Annual addition on stocks of Electrical and electronic products in the EU at end of life kept by users*	2014	Gg	0

[1]Based on historic copper industry net-production shipments in Europe [3].

[2]Negligible loss [4]. To be computed from total in use stock.

[3]Average value based on [5-7].

Flow	Building and construction	Year	Unit	Value
	Imports of Cu in Building and construction to EU	2014	Gg	122
	Input of Cu in Building and construction use	2014	Gg	1,018
	EU Annual Growth of Cu consumption in Building and construction in EU	2014	%	0.6%[1]
	In use dissipation rate in Building and construction	2014	%/year	0.03%[2]
	Life span of Building and construction	2014	Year	40[3]
	Share of Building and construction at end of life kept by users	2014	%	0%
	Time during Building and construction at end of life are kept by users	2014	Year	0
	Share of Building and construction exported for reuse	2014	%	0%
E.1.1 Stock of manufactured products in use in EU	*Cu in stocks of Building and construction in EU*	2014	Gg	36,658
E.1.2 Stock of manufactured products at end-of-life that are kept by users in EU	*Cu in stocks of Building and construction at end of life kept by users in EU*	2014	Gg	0
E.1.3 Exports from EU of manufactured products for reuse	*Cu in exports for reuse of Building and construction*	2014	Gg	0
E.1.4 Imports to EU of manufactured products	*Cu in imports of Building and construction in EU*	2014	Gg	122
E.1.5 In use dissipation in EU	*In use dissipation of Cu in Building and construction*	2014	Gg	0
E.1.6 Products at end of life in EU collected for treatment	*Cu in Building and construction collected for treatment*	2014	Gg	817
E.1.7 Annual Addition to in-use stock of manufactured products in EU	*Cu in Annual addition on stocks of Building and construction in use in the EU*	2014	Gg	201
E.1.8 Annual addition to end-of life stock of manufactured products at end of life that are kept by users in EU	*Cu in Annual addition on stocks of Building and construction in the EU at end of life kept by users*	2014	Gg	0

[1]Based on historic copper industry net-production shipments in Europe [3].

[2]Losses due to atmospheric corrosion and pipe corrosion [4]. To be computed from total in use stock.

[3]Average value based on [5-7].

Flow	Industrial machinery and equipment	Year	Unit	Value
	Imports of Cu in Industrial machinery and equipment to EU	2014	Gg	591
	Input of Cu in Industrial machinery and equipment use	2014	Gg	589
	EU Annual Growth of Cu consumption in Industrial machinery and equipment in EU	2014	%	1.7%[1]
	In use dissipation rate in Industrial machinery and equipment	2014	%/year	0%[2]
	Life span of Industrial machinery and equipment	2014	Year	18[3]
	Share of Industrial machinery and equipment at end of life kept by users	2014	%	0%
	Time during Industrial machinery and equipment at end of life are kept by users	2014	Year	0
	Share of Industrial machinery and equipment exported for reuse	2014	%	0%
E.1.1 Stock of manufactured products in use in EU	*Cu in stocks of Industrial machinery and equipment in EU*	2014	Gg	9,229
E.1.2 Stock of manufactured products at end-of-life that are kept by users in EU	*Cu in stocks of Industrial machinery and equipment at end of life kept by users in EU*	2014	Gg	0
E.1.3 Exports from EU of manufactured products for reuse	*Cu in exports for reuse of Industrial machinery and equipment*	2014	Gg	0
E.1.4 Imports to EU of manufactured products	*Cu in imports of Industrial machinery and equipment in EU*	2014	Gg	591
E.1.5 In use dissipation in EU	*In use dissipation of Cu in Industrial machinery and equipment*	2014	Gg	0
E.1.6 Products at end of life in EU collected for treatment	*Cu in Industrial machinery and equipment collected for treatment*	2014	Gg	435
E.1.7 Annual Addition to in-use stock of manufactured products in EU	*Cu in Annual addition on stocks of Industrial machinery and equipment in use in the EU*	2014	Gg	154
E.1.8 Annual addition to end-of life stock of manufactured products at end of life that are kept by users in EU	*Cu in Annual addition on stocks of Industrial machinery and equipment in the EU at end of life kept by users*	2014	Gg	0

[1]Based on historic copper industry net-production shipments in Europe [3].

[2]Negligible loss [4]. To be computed from total in use stock.

[3]Average value based on [5-7].

Flow	Transportation equipment	Year	Unit	Value
	Imports of Cu in Transportation equipment to EU	2014	Gg	67
	Input of Cu in Transportation equipment use	2014	Gg	278
	EU Annual Growth of Cu consumption in Transportation equipment in EU	2014	%	1.4%[1]
	In use dissipation rate in Transportation equipment	2014	%/year	0.03%[2]
	Life span of Transportation equipment	2014	Year	16[3]
	Share of Transportation equipment at end of life kept by users	2014	%	0%
	Time during Transportation equipment at end of life are kept by users	2014	Year	0
	Share of Transportation equipment exported for reuse	2014	%	0%
E.1.1 Stock of manufactured products in use in EU	*Cu in stocks of Transportation equipment in EU*	2014	Gg	4,011
E.1.2 Stock of manufactured products at end-of-life that are kept by users in EU	*Cu in stocks of Transportation equipment at end of life kept by users in EU*	2014	Gg	0
E.1.3 Exports from EU of manufactured products for reuse	*Cu in exports for reuse of Transportation equipment*	2014	Gg	0
E.1.4 Imports to EU of manufactured products	*Cu in imports of Transportation equipment in EU*	2014	Gg	67
E.1.5 In use dissipation in EU	*In use dissipation of Cu in Transportation equipment*	2014	Gg	0
E.1.6 Products at end of life in EU collected for treatment	*Cu in Transportation equipment collected for treatment*	2014	Gg	222
E.1.7 Annual Addition to in-use stock of manufactured products in EU	*Cu in Annual addition on stocks of Transportation equipment in use in the EU*	2014	Gg	55
E.1.8 Annual addition to end-of life stock of manufactured products at end of life that are kept by users in EU	*Cu in Annual addition on stocks of Transportation equipment in the EU at end of life kept by users*	2014	Gg	0

[1]Based on historic copper industry net-production shipments in Europe [3].

[2]Losses from brake linings and railway [4]. To be computed from total in use stock.

[3]Average value based on [5-7].

Flow	Consumer and general goods	Year	Unit	Value
	Imports of Cu in Consumer and general goods to EU	2014	Gg	110
	Input of Cu in Consumer and general goods use	2014	Gg	239
	EU Annual Growth of Cu consumption in Consumer and general goods in EU	2014	%	-6.9%[1]
	In use dissipation rate in Consumer and general goods	2014	%/year	3%[2]
	Life span of Consumer and general goods	2014	Year	8[3]
	Share of Consumer and general goods at end of life kept by users	2014	%	0%
	Time during Consumer and general goods at end of life are kept by users	2014	Year	0
	Share of Consumer and general goods exported for reuse	2014	%	0%
E.1.1 Stock of manufactured products in use in EU	*Cu in stocks of Consumer and general goods in EU*	2014	Gg	2,118
E.1.2 Stock of manufactured products at end-of-life that are kept by users in EU	*Cu in stocks of Consumer and general goods at end of life kept by users in EU*	2014	Gg	0
E.1.3 Exports from EU of manufactured products for reuse	*Cu in exports for reuse of Consumer and general goods*	2014	Gg	0
E.1.4 Imports to EU of manufactured products	*Cu in imports of Consumer and general goods in EU*	2014	Gg	110
E.1.5 In use dissipation in EU	*In use dissipation of Cu in Consumer and general goods*	2014	Gg	36
E.1.6 Products at end of life in EU collected for treatment	*Cu in Consumer and general goods collected for treatment*	2014	Gg	360
E.1.7 Annual Addition to in-use stock of manufactured products in EU	*Cu in Annual addition on stocks of Consumer and general goods in use in the EU*	2014	Gg	-157
E.1.8 Annual addition to end-of life stock of manufactured products at end of life that are kept by users in EU	*Cu in Annual addition on stocks of Consumer and general goods in the EU at end of life kept by users*	2014	Gg	0

[1]Based on historic copper industry net-production shipments in Europe [3].

[2]3% of Cu use in Consumer and general goods is assumed to be dissipated during use [4]. To be computed from total in use stock.

[3]Average value based on [5-7].

Table S12 List of commodities containing copper. Based on [3, 5].

Classification	Code	Description	Cu content (%)	Copper cycle phase
SITC 1	28311	Ores and concentrates of copper	28,0%	Production
SITC 1	28312	Copper matte	98,0%	
SITC 1	68221	Bars, rods, angles, shapes, wire of copper	75,0%	Fabrication
SITC 1	68222	Plates, sheets, and strip of copper	79,0%	
SITC 1	68223	Copper foil	98,0%	
SITC 1	68224	Copper powders and flakes	99.9%	
SITC 1	68225	Tubes, pipes, and blanks, hollow bars of copper	98,0%	
SITC 1	68226	Tubes and pipe fittings of copper	98,0%	
SITC 1	69312	Wire, cables, ropes etc. not insulated of copper	99.9%	
SITC 3	6943	Nails, tacks, etc., made of copper	100.0%	Building and construction (parts of and finished products)
SITC 3	7414	Commercial refrigeration equipment, parts	3.6%	
SITC 3	7415	Air conditioning machines, parts	18.0%	
SITC 3	7752	Domestic refrigerators, freezers	4.0%	
SITC 3	69312	Stranded wire, ropes, cables, plaited bands, slings and the like, of copper	100.0%	
SITC 3	69352	Cloth (including endless bands), grill, netting and fencing, of copper wire	100.0%	
SITC 3	69734	Cooking or heating apparatus of a kind used for domestic purposes, non-electric	100.0%	
SITC 3	69742	Household articles and parts thereof, n.e.s., of copper	100.0%	
SITC 3	69752	Sanitary ware and parts thereof, n.e.s., of copper	100.0%	
SITC 3	69942	Copper springs	100.0%	
SITC 3	69971	Chain of copper and parts thereof	100.0%	
SITC 3	69973	Articles of copper, n.e.s.	100.0%	
SITC 3	764	Telecommunication equipment parts, n.e.s	10,0%	Electrical and electronic products (parts of and finished products)
SITC 3	7731	Insulated wire, etc., conductors	40,0%	
SITC 3	77317	Other electric conductors, for a voltage exceeding 1000V (to be deducted from S3-773)	-40,0%	
SITC 3	77318	Optical fibre cables (to be deducted from S3-773)	-40,0%	
SITC 3	716	Rotating electric plant (motors)	13.0%	Industrial machinery and equipment (parts of and finished products)
SITC 3	771	Electric power machinery	13.5%	
SITC 3	772	Electric switches, relays, circuits	7.0%	
SITC 3	774	Electro-medical and X-ray equipment	10.0%	
SITC 3	776	Transistors, valves, etc.	7.0%	
SITC 3	778	Electric machinery apparatus, n.e.s	10.0%	
SITC 3	7758	Electro-thermic appliances, n.e.s	6.0%	
SITC 3	781	Passenger motor vehicles excluding buses	1.5%	Transportation equipment (parts of and finished products)
SITC 3	782	Goods and special transport vehicles	1.0%	
SITC 3	783	Road motor vehicles, n.e.s	1.0%	
SITC 3	791	Railway vehicles and equipment	3.0%	
SITC 3	792	Aircraft and equipment	2.4%	
SITC 3	793	Ship, boat, float structures	1.0%	
SITC 3	751	Office machines	2.5%	Consumer and general goods (parts of and finished products)
SITC 3	752	Automatic data processing equipment	8.0%	
SITC 3	759	Parts for office machines	10.0%	
SITC 3	761	Television receivers, etc.	2.8%	
SITC 3	762	Radio-broadcast receivers	10.0%	
SITC 3	763	Sound recorder, phonograph	5.0%	
SITC 3	774	Electro-medical and X-ray equipment	10.0%	
SITC 3	7751	Household laundry equipment	3.0%	
SITC 3	7753	Dishwashing machines of the household type	1.5%	
SITC 3	7754	Electric shavers, clippers, parts	10.0%	
SITC 3	7757	Domestic electro-mechanical appliances	3.0%	

Table S13 Recovery rate and loss rate of the main copper processes. Based on [5, 8].

Process	Recovery rate	Loss rate
Extraction	90.0%	10.0%
Primary smelting	95.0%	5.0%
Secondary smelting	95.0%	5.0%
Primary refining	99.0%	1.0%
Secondary refining	97.0%	3.0%
Semi-finished products fabrication	99.5%	0.5%

Table S14 New scrap generation rates from end-use manufacturing. Based on [9].

End-use	New scrap generation rate
Electrical and electronic products	25%
Building and construction	25%
Industrial machinery and equipment	25%
Transportation equipment	25%
Consumer and general goods	25%

Table S15 Transfer coefficients for copper end-uses to the main waste categories. Based on [3, 6].

End-use application	C&D	IW	ELV	MSW	WEEE
Building and construction	0.91	-	-	0.00	0.09
Electrical and electronic products	0.6	0.2	-	0.00	0.2
Industrial machinery and equipment	-	0.9	-	0.00	0.1
Transportation equipment	-	-	1.0	-	-
Consumer and general goods	-	-	-	0.25	0.75

C&D: construction and demolition waste; IW: industrial waste; ELV: end-of-life vehicles; MSW: municipal solid waste; WEEE: waste electrical and electronic equipment.

Table S16 End-of-life collection (for recovery) rates and sorting efficiency of the main copper waste categories Based on [5].

End-use application	Collection rate	Sorting rate
Construction and demolition waste	78%	91%
Industrial waste	81%	87%
End-of-life vehicles	67%	61%
Municipal solid waste	52%	62%
Waste electrical and electronic equipment	50%	85%

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[3] Ciacci, L.; Vassura, I.; Passarini, F., 2017 Urban mines of copper: size and potential for recycling in the EU. Resources, 6, 6.

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[9] Soulier, M. et al., 2018. Dynamic analysis of European copper flows, Resources, Conservation and Recycling, 129, 143-152.

8.3 Iron

Figure S27 Complex Sankey diagram for iron (2015). Values are in Gg Fe.

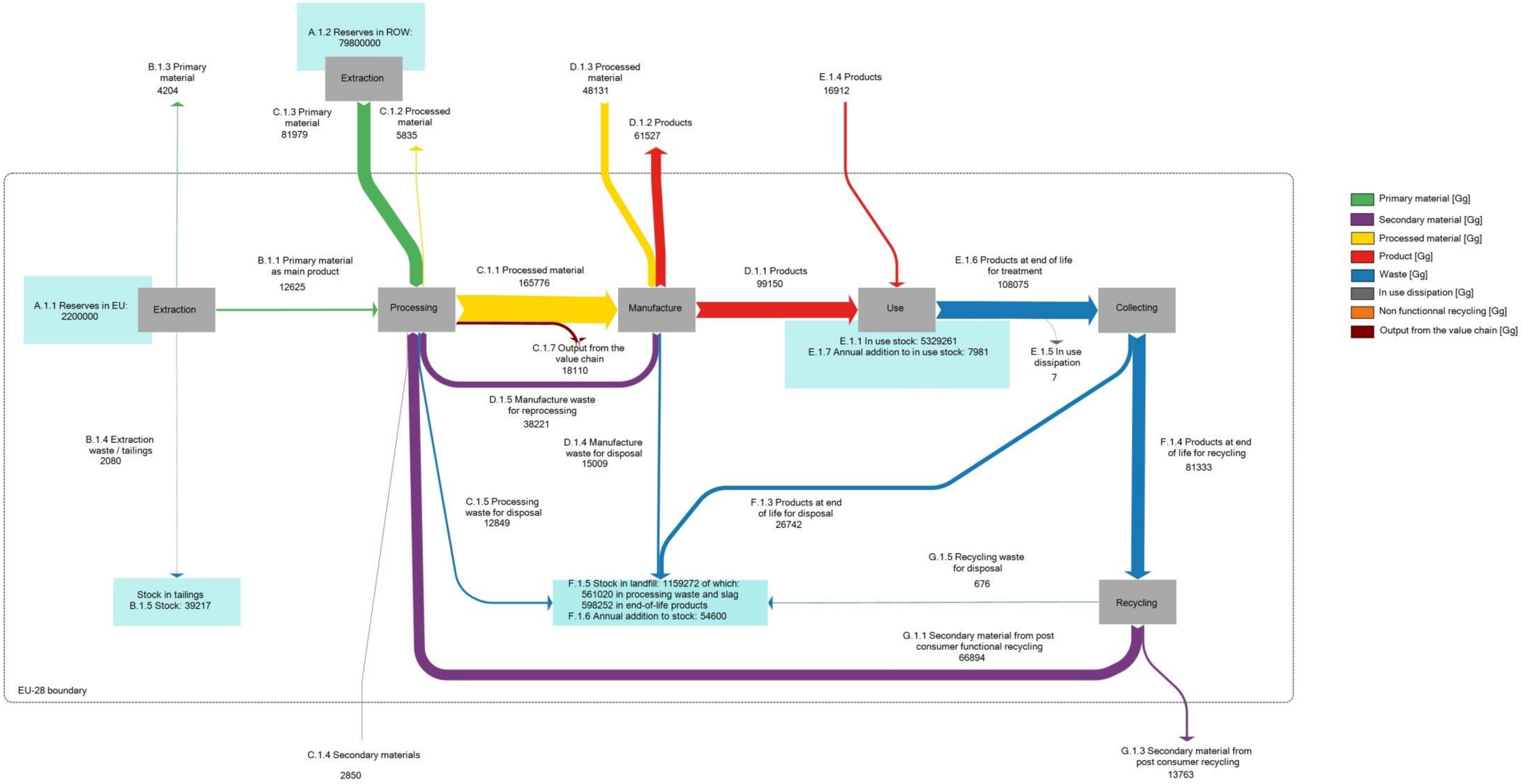

Figure S28 Disaggregation of iron flows within the processing and manufacture phases. Values are in Gg Fe.

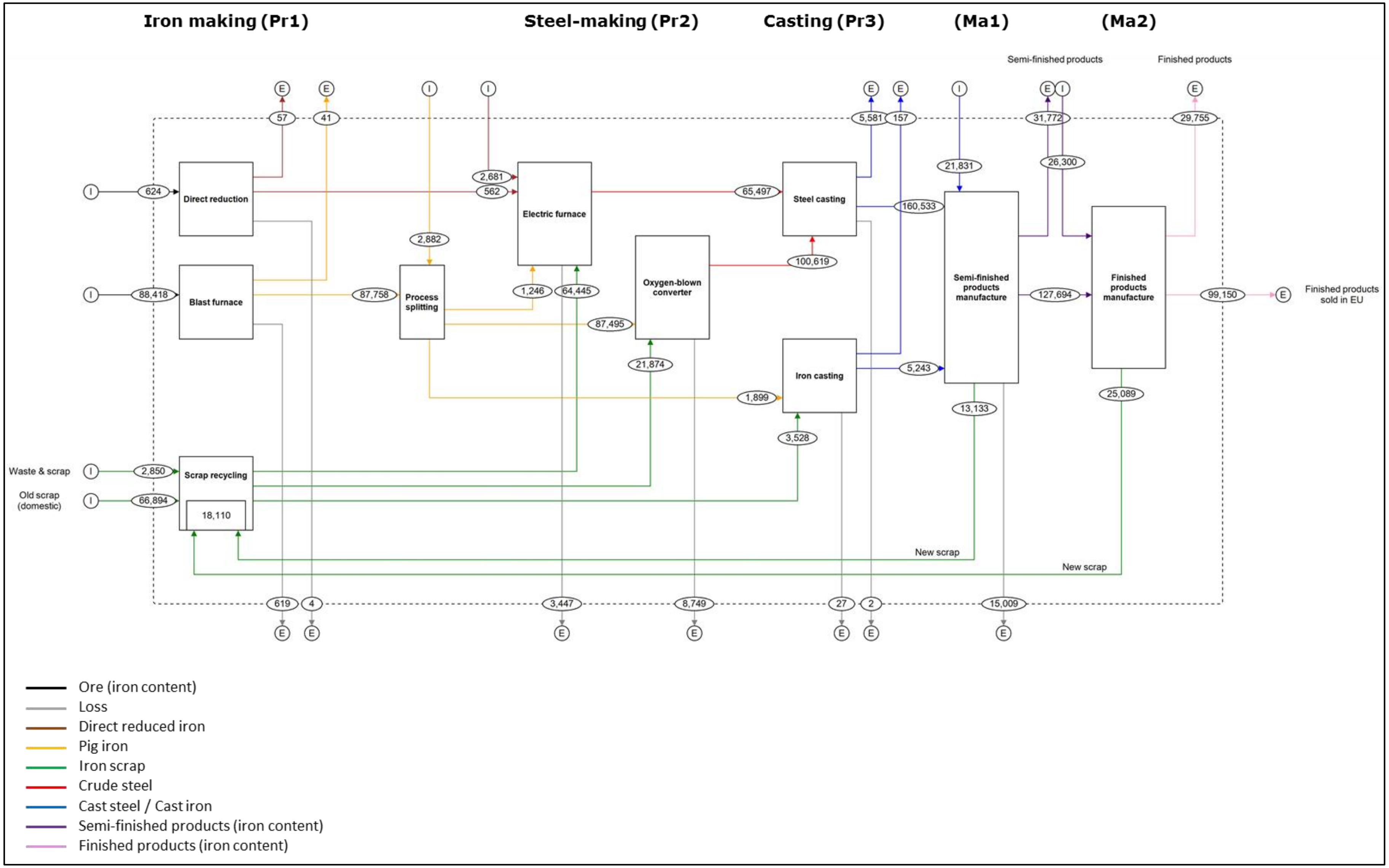
Iron making (Pr1)
Steel-making (Pr2)
Casting (Pr3)
(Ma1)
(Ma2)
Semi-finished products
Finished products
Direct reduction
Blast furnace
Process splitting
Electric furnace
Oxygen-blown converter
Steel casting
Iron casting
Semi-finished products manufacture
Finished products manufacture
Scrap recycling
18,110
Waste & scrap
Old scrap (domestic)
Finished products sold in EU
New scrap
New scrap
624
88,418
2,850
66,894
57
41
2,681
562
2,882
87,758
1,246
64,445
87,495
21,874
65,497
100,619
1,899
3,528
5,581
157
160,533
5,243
21,831
31,772
26,300
29,755
127,694
99,150
13,133
25,089
619
4
3,447
8,749
27
2
15,009
Ore (iron content)
Loss
Direct reduced iron
Pig iron
Iron scrap
Crude steel
Cast steel / Cast iron
Semi-finished products (iron content)
Finished products (iron content)

Table S17 Stock and flow model parameters and results for each main end-use application segment.

Flow	Transportation	Year	Unit	Value
	Imports of Fe in Transportation to EU	2015	Gg	6,442
	Input of Fe in Transportation use	2015	Gg	16,849
	EU Annual Growth of Fe consumption in Transportation in EU	2000	%	2.3%[1]
	In use dissipation rate in Transportation	2015	%/year	0,02%[2]
	Life span of Transportation	2015	Year	20[4]
	Share of Transportation at end of life kept by users	2015	%	0%
	Time during Transportation at end of life are kept by users	2015	Year	0
	Share of Transportation exported for reuse	2015	%	0%
E.1.1 Stock of manufactured products in use in EU	*Fe in stocks of Transportation in EU*	2015	Gg	274,259
E.1.2 Stock of manufactured products at end-of-life that are kept by users in EU	*Fe in stocks of Transportation at end of life kept by users in EU*	2015	Gg	0
E.1.3 Exports from EU of manufactured products for reuse	*Fe in exports for reuse of Transportation*	2015	Gg	0
E.1.4 Imports to EU of manufactured products	*Fe in imports of Transportation in EU*	2015	Gg	6,442
E.1.5 In use dissipation in EU	*In use dissipation of Fe in Transportation*	2015	Gg	3
E.1.6 Products at end of life in EU collected for treatment	*Fe in Transportation collected for treatment*	2015	Gg	10,731
E.1.7 Annual Addition to in-use stock of manufactured products in EU	*Fe in Annual addition on stocks of Transportation in use in the EU*	2015	Gg	6,114
E.1.8 Annual addition to end-of life stock of manufactured products at end of life that are kept by users in EU	*Fe in Annual addition on stocks of Transportation in the EU at end of life kept by users*	2015	Gg	0

[1]Own calculation based on 2000-2016 shipments in the EU. [1, 9]

[2]To be computed from total in use stock. [2]

[3]Average lifetime for transportation. [3]

Flow	Construction	Year	Unit	Value
	Imports of Fe in Construction to EU	2015	Gg	809
	Input of Fe in Construction use	2015	Gg	56,704
	EU Annual Growth of Fe consumption in Construction in EU	2000	%	-0.03%[1]
	In use dissipation rate in Construction	2015	%/year	0.01%[2]
	Life span of Construction	2015	Year	75[4]
	Share of Construction at end of life kept by users	2015	%	0%
	Time during Construction at end of life are kept by users	2015	Year	0
	Share of Construction exported for reuse	2015	%	0%
E.1.1 Stock of manufactured products in use in EU	*Fe in stocks of Construction in EU*	2015	Gg	4,296,375
E.1.2 Stock of manufactured products at end-of-life that are kept by users in EU	*Fe in stocks of Construction at end of life kept by users in EU*	2015	Gg	0
E.1.3 Exports from EU of manufactured products for reuse	*Fe in exports for reuse of Construction*	2015	Gg	0
E.1.4 Imports to EU of manufactured products	*Fe in imports of Construction in EU*	2015	Gg	809
E.1.5 In use dissipation in EU	*In use dissipation of Fe in Construction*	2015	Gg	4
E.1.6 Products at end of life in EU collected for treatment	*Fe in Construction collected for treatment*	2015	Gg	57,890
E.1.7 Annual Addition to in-use stock of manufactured products in EU	*Fe in Annual addition on stocks of Construction in use in the EU*	2015	Gg	-1,190
E.1.8 Annual addition to end-of life stock of manufactured products at end of life that are kept by users in EU	*Fe in Annual addition on stocks of Construction in the EU at end of life kept by users*	2015	Gg	0

[1]Own calculation based on 2000-2016 shipments in the EU. [1, 9]

[2]To be computed from total in use stock. [2]

[4]Average lifetime for construction. [3]

Flow	Mechanical engineering	Year	Unit	Value
	Imports of Fe in Mechanical engineering to EU	2015	Gg	6,646
	Input of Fe in Mechanical engineering use	2015	Gg	17,033
	EU Annual Growth of Fe consumption in Mechanical engineering in EU	2000	%	2.3%[1]
	In use dissipation rate in Mechanical engineering	2015	%/year	0%[2]
	Life span of Mechanical engineering	2015	Year	30
	Share of Mechanical engineering at end of life kept by users	2015	%	0%
	Time during Mechanical engineering at end of life are kept by users	2015	Year	0
	Share of Mechanical engineering exported for reuse	2015	%	0%
E.1.1 Stock of manufactured products in use in EU	*Fe in stocks of Mechanical engineering in EU*	2015	Gg	375,543
E.1.2 Stock of manufactured products at end-of-life that are kept by users in EU	*Fe in stocks of Mechanical engineering at end of life kept by users in EU*	2015	Gg	0
E.1.3 Exports from EU of manufactured products for reuse	*Fe in exports for reuse of Mechanical engineering*	2015	Gg	0
E.1.4 Imports to EU of manufactured products	*Fe in imports of Mechanical engineering in EU*	2015	Gg	6,646
E.1.5 In use dissipation in EU	*In use dissipation of Fe in Mechanical engineering*	2015	Gg	0
E.1.6 Products at end of life in EU collected for treatment	*Fe in Mechanical engineering collected for treatment*	2015	Gg	8,660
E.1.7 Annual Addition to in-use stock of manufactured products in EU	*Fe in Annual addition on stocks of Mechanical engineering in use in the EU*	2015	Gg	8,372
E.1.8 Annual addition to end-of life stock of manufactured products at end of life that are kept by users in EU	*Fe in Annual addition on stocks of Mechanical engineering in the EU at end of life kept by users*	2015	Gg	0

[1]Own calculation based on 2000-2016 shipments in the EU. [1, 9]

[2]To be computed from total in use stock. [2]

Flow	Domestic appliances	Year	Unit	Value
	Imports of Fe in Domestic appliances to EU	2015	Gg	1,872
	Input of Fe in Domestic appliances use	2015	Gg	3,844
	EU Annual Growth of Fe consumption in Domestic appliances in EU	2000	%	-2.0%[1]
	In use dissipation rate in Domestic appliances	2015	%/year	0%[2]
	Life span of Domestic appliances	2015	Year	15[5]
	Share of Domestic appliances at end of life kept by users	2015	%	0%
	Time during Domestic appliances at end of life are kept by users	2015	Year	0
	Share of Domestic appliances exported for reuse	2015	%	0%
E.1.1 Stock of manufactured products in use in EU	*Fe in stocks of Domestic appliances in EU*	2015	Gg	66,647
E.1.2 Stock of manufactured products at end-of-life that are kept by users in EU	*Fe in stocks of Domestic appliances at end of life kept by users in EU*	2015	Gg	0
E.1.3 Exports from EU of manufactured products for reuse	*Fe in exports for reuse of Domestic appliances*	2015	Gg	0
E.1.4 Imports to EU of manufactured products	*Fe in imports of Domestic appliances in EU*	2015	Gg	1,872
E.1.5 In use dissipation in EU	*In use dissipation of Fe in Domestic appliances*	2015	Gg	0
E.1.6 Products at end of life in EU collected for treatment	*Fe in Domestic appliances collected for treatment*	2015	Gg	5,200

Flow	Domestic appliances	Year	Unit	Value
E.1.7 Annual Addition to in-use stock of manufactured products in EU	*Fe in Annual addition on stocks of Domestic appliances in use in the EU*	2015	Gg	-1,355
E.1.8 Annual addition to end-of life stock of manufactured products at end of life that are kept by users in EU	*Fe in Annual addition on stocks of Domestic appliances in the EU at end of life kept by users*	2015	Gg	0

[1]Own calculation based on 2000-2016 shipments in the EU. [1, 9]

[2]To be computed from total in use stock. [2]

[5]Average lifetime for products. [3]

Flow	Metalware	Year	Unit	Value
	Imports of Fe in Metalware to EU	2015	Gg	133
	Input of Fe in Metalware use	2015	Gg	18,742
	EU Annual Growth of Fe consumption in Metalware in EU	2000	%	-0.9%[1]
	In use dissipation rate in Metalware	2015	%/year	0%[2]
	Life span of Metalware	2015	Year	15[5]
	Share of Metalware at end of life kept by users	2015	%	0%
	Time during Metalware at end of life are kept by users	2015	Year	0
	Share of Metalware exported for reuse	2015	%	0%
E.1.1 Stock of manufactured products in use in EU	*Fe in stocks of Metalware in EU*	2015	Gg	299,668
E.1.2 Stock of manufactured products at end-of-life that are kept by users in EU	*Fe in stocks of Metalware at end of life kept by users in EU*	2015	Gg	0
E.1.3 Exports from EU of manufactured products for reuse	*Fe in exports for reuse of Metalware*	2015	Gg	0
E.1.4 Imports to EU of manufactured products	*Fe in imports of Metalware in EU*	2015	Gg	133
E.1.5 In use dissipation in EU	*In use dissipation of Fe in Metalware*	2015	Gg	0
E.1.6 Products at end of life in EU collected for treatment	*Fe in Metalware collected for treatment*	2015	Gg	21,455
E.1.7 Annual Addition to in-use stock of manufactured products in EU	*Fe in Annual addition on stocks of Metalware in use in the EU*	2015	Gg	-2,713
E.1.8 Annual addition to end-of life stock of manufactured products at end of life that are kept by users in EU	*Fe in Annual addition on stocks of Metalware in the EU at end of life kept by users*	2015	Gg	0

[1]Own calculation based on 2000-2016 shipments in the EU. [1, 9]

[2]To be computed from total in use stock. [2]

[5]Average lifetime for products. [3]

Flow	Miscellaneous	Year	Unit	Value
	Imports of Fe in Miscellaneous to EU	2015	Gg	1,010
	Input of Fe in Miscellaneous use	2015	Gg	2,890
	EU Annual Growth of Fe consumption in Miscellaneous in EU	2000	%	-6.9%[1]
	In use dissipation rate in Miscellaneous	2015	%/year	0%[2]
	Life span of Miscellaneous	2015	Year	5[6]
	Share of Miscellaneous at end of life kept by users	2015	%	0%

Flow	Miscellaneous	Year	Unit	Value
	Time during Miscellaneous at end of life are kept by users	2015	Year	0
	Share of Miscellaneous exported for reuse	2015	%	0%
E.1.1 Stock of manufactured products in use in EU	*Fe in stocks of Miscellaneous in EU*	2015	Gg	16,768
E.1.2 Stock of manufactured products at end-of-life that are kept by users in EU	*Fe in stocks of Miscellaneous at end of life kept by users in EU*	2015	Gg	0
E.1.3 Exports from EU of manufactured products for reuse	*Fe in exports for reuse of Miscellaneous*	2015	Gg	0
E.1.4 Imports to EU of manufactured products	*Fe in imports of Miscellaneous in EU*	2015	Gg	1,010
E.1.5 In use dissipation in EU	*In use dissipation of Fe in Miscellaneous*	2015	Gg	0
E.1.6 Products at end of life in EU collected for treatment	*Fe in Miscellaneous collected for treatment*	2015	Gg	4,138
E.1.7 Annual Addition to in-use stock of manufactured products in EU	*Fe in Annual addition on stocks of Miscellaneous in use in the EU*	2015	Gg	-1,247
E.1.8 Annual addition to end-of life stock of manufactured products at end of life that are kept by users in EU	*Fe in Annual addition on stocks of Miscellaneous in the EU at end of life kept by users*	2015	Gg	0

[1]Own calculation based on 2000-2016 shipments in the EU. [1, 9]

[2]To be computed from total in use stock. [2]

[6]Based on [5].

Table S18 List of commodities containing iron. Based on [4, 6].

Code	Description	Fe content (%)	Iron cycle phase
S1-6723	Ingots of iron or steel	100%	Mill products and casting
S1-6725	Blooms, billets, slabs, etc. Of iron or steel	100%	
S1-6727	Iron or steel coils for re rolling	100%	
S1-6791	Iron castings in the rough state	94%	
S1-673	Iron and steel bars, rods, angles, shapes, sections	100%	Semi-finished products
S1-674	Universals, plates and sheets of iron or steel	100%	
S1-675	Hoop and strip of iron or steel	100%	
S1-676	Rails & rlwy track constr mat. Of iron or steel	100%	
S1-677	Iron and steel wire, excluding wire rod	100%	
S1-678	Tubes, pipes and fittings of iron or steel	100%	
S1-6911	Fin. structural parts & structures of iron steel	96%	
S1-69211	Tanks, etc. for storage or manuf. use of iron/steel	96%	
S1-69221	Casks, drums, etc. used for transport of iron/steel	96%	
S1-69231	Compressed gas cylinders of iron or steel	95%	
S1-69311	Wire, cables, ropes etc. not insulated, iron/steel	96%	
S1-6932	Wire of iron or steel, of types used for fencing	96%	
S1-69331	Gauze, netting, grill, fencing wire of iron steel	96%	
S1-69341	Expanded metal of iron or steel	96%	
S1-69411	Nails, tacks, staples, spikes, etc. of iron or steel	96%	
S1-69421	Nuts, bolts, screws, rivets, washers of iron/steel	96%	
S1-69711	Domestic stoves, etc. of iron or steel	95%	
S1-69721	Domestic utensils of iron or steel	95%	
S1-6979	Other household equipment of base metals	90%	
S1-6983	Chain and parts thereof of iron or steel	95%	
S1-6984	Anchors, grapnels and parts of iron or steel	95%	
S1-6985	Pins and needles of iron or steel	95%	
S1-69861	Springs & leaves for springs of iron or steel	95%	
S1-6988	Miscell. articles of base metal	90%	
S1-69891	Articles of iron or steel n.e.s	80%	
S1-7114	Aircraft incl. jet propulsion engines	12%	Transportation (parts of and finished products)
S1-7115	Internal combustion engines, not for aircraft	50%	
S1-7118	Engines, nes	50%	
S1-7291	Batteries and accumulators	20%	
S1-7294	Automotive electrical equipment	40%	
S1-7312	Electric railway locomotives, not self generat.	90%	
S1-7313	Railway locomotives, not steam or electric	90%	
S1-7314	Mechanically propelled railway and tramway cars	85%	
S1-7315	Rail & tram passenger cars not mech propelled	85%	
S1-7316	Rail.&tram. freight cars, not mechanically propd.	85%	
S1-7317	Parts of railway locomotives & rolling stock	90%	
S1-7321	Passenger motor cars, other than buses	65%	
S1-7322	Buses, including trolleybuses	80%	
S1-7323	Lorries and trucks, including ambulances, etc.	80%	
S1-7324	Special purpose lorries, trucks and vans	80%	
S1-7325	Road tractors for tractor trailer combinations	80%	

Code	Description	Fe content (%)	Iron cycle phase
S1-7327	Other chassis with engines mounted	80%	
S1-7328	Bodies & parts motor vehicles ex motorcycles	70%	
S1-73291	Motorcycles, auto cycles, etc.& side cars	45%	
S1-73311	Cycles, not motorized	50%	
S1-73312	Parts of vehicles of heading 733 11 & 733 4	50%	
S1-7333	Trailers & oth vehicles not motorized, & parts	50%	
S1-7334	Invalid carriages	50%	
S1-7341	Aircraft, heavier than air	13%	
S1-73492	Parts of aircraft, airships, etc.	13%	
S1-7351	Warships of all kinds	80%	
S1-7353	Ships and boats, other than warships	80%	
S1-7358	Ships, boats and other vessels for breaking up	80%	
S1-7359	Special purpose ships and boats	20%	
S1-7191	Heating and cooling equipment	70%	Construction (parts of and finished products)
S1-723	Equipment for distributing electricity	10%	
S1-8121	Central heating apparatus and parts	85%	
S1-8123	Sinks, wash basins, bidets, baths etc iron/steel	75%	
S1-695	Tools for use in the hand or in machines	85%	Mechanical engineering (parts of and finished products)
S1-7111	Steam generating boilers	95%	
S1-7112	Boiler house plant	95%	
S1-7113	Steam engines and steam turbines	65%	
S1-7116	Gas turbines, other than for aircraft	65%	
S1-7117	Nuclear reactors	65%	
S1-7121	Agricultural machinery for cultivating the soil	80%	
S1-7122	Agricultural machinery for harvesting, threshing	80%	
S1-7123	Milking machines, cream separators, dairy farm eq	70%	
S1-7125	Tractors, other than road tractors	70%	
S1-7129	Agricultural machinery and appliances, nes	80%	
S1-7141	Typewriters and cheque writing machines	50%	
S1-7142	Calculating & accounting machines etc	20%	
S1-7143	Statistical machines cards or tapes	20%	
S1-715	Metalworking machinery	65%	
S1-717	Textile and leather machinery	65%	
S1-718	Machines for special industries	75%	
S1-7192	Pumps and centrifuges	80%	
S1-7193	Mechanical handling equipment	10%	
S1-7196	Other non electrical machines	65%	
S1-7197	Ball, roller or needle roller bearings	90%	
S1-7198	Machinery and mechanical appliances, nes	75%	
S1-7199	Parts and accessories of machinery, nes	80%	
S1-7221	Electric power machinery	0%	
S1-7222	Apparatus for electrical circuits	55%	
S1-726	Elec. apparatus for medic.purp.,radiological ap.	50%	
S1-7293	Thermionic valves and tubes, transistors, etc.	10%	
S1-7295	Electrical measuring & controlling instruments	40%	
S1-7296	Electro mechanical hand tools	40%	
S1-7297	Electron and proton accelerators	50%	

Code	Description	Fe content (%)	Iron cycle phase
S1-7299	Electrical machinery and apparatus, nes	55%	
S1-81242	Lamps & lighting fittings & parts thereof	40%	
S1-861	Scientific, medical, optical, meas./contr. instrum.	55%	
S1-8951	Office and stationery supplies of base metals	80%	
S1-89999	Catapults and sim. aircraft launching gear, etc.	60%	
S1-95101	Armoured fighting vehicles	90%	
S1-95102	Artillery weapons, mach. guns and arms,n.e.s.	85%	
S1-95103	Parts of military ordnance	75%	
S1-95104	Sidearms and parts thereof	70%	
S1-95105	Revolvers and pistols	70%	
S1-95106	Projectiles and ammunition, n.e.s.	60%	
S1-7194	Domestic appliances, non electrical	65%	Domestic appliances (parts of and finished products)
S1-7195	Powered tools, nes	60%	
S1-724	Telecommunications apparatus	20%	
S1-72501	Domestic refrigerators, electrical	55%	
S1-72502	Domestic washing machines whether or not elec.	60%	
S1-72503	Electro mechanical domestic appliances nes	50%	
S1-72504	Electric shavers & hair clippers	50%	
S1-72505	Electric space heating equipment etc.	60%	
S1-7292	Electric lamps	20%	
S1-81243	Portable electric battery lamps	10%	
S1-696	Cutlery	85%	Metalware (parts of and finished products)
S1-6981	Locksmiths wares	80%	Miscellaneous (parts of and finished products)
S1-6982	Safes, strong rooms, strong room fittings etc.	80%	
S1-7149	Office machines, nes	20%	
S1-864	Watches and clocks	30%	
S1-8911	Phonographs, tape & other sound recorders etc.	10%	
S1-8914	Pianos and other string musical instruments	40%	
S1-8918	Musical instruments, nes	40%	
S1-8919	Parts and accessories of musical instruments	40%	
S1-894	Perambulators, toys, games and sporting goods	20%	
S1-9610	Coin other than gold ,not being legal tender	0%	

Table S19 Process efficiency rates (global averages).

Process	Efficiency rate (%)	Year of reference	Source
Direct reduction	99.3%	2008	[7]
Blast furnace	99.3%	2008	[7]
Electric furnace	95.0%	2008	[4]
Oxygen-blown converter	92.0%	2008	[4]
Open hearth furnace	87.1%	2008	[7]
Foundry casting	99.5%	2008	[7]
Semi-finished products (manufacture)	92.0%	2008	[4]
Finished products (manufacture)			
Transportation	73%	2008	[4]
Construction	83%	2008	[4]
Machinery	93%	2008	[4]
Products	77%	2008	[4]
End-of-life products (recovery)			
Transportation	82%	2008	[4]
Construction	82%	2008	[4]
Machinery	87%	2008	[4]
Products	58%	2008	[4]

Table S20 Mine production of iron in the EU. Values in kt Fe. [8].

Year	Mine production (kt Fe)
2011	17470
2012	17718
2013	18249
2014	18864
2015	16829

Table S20 Extra-EU trade of iron waste and scrap. Values in kt Fe. [1]**.**

Year	Import	Export
2012	3158	19543
2013	3191	16802
2014	3143	16953
2015	2850	13763
2016	2740	17771

References:

[1] European Steel Association (EUROFER), 2017. European steel in figures, 2017 edition covering 2012-2016. Available at: http://www.eurofer.org/News%26Events/PublicationsLinksList/201705-SteelFigures.pdf.

[2] Ciacci, L., Reck, B. K., Nassar, N. T. and T. E. Graedel, Lost by design. Environmental Science & Technology 2015 (49), 9443-9451, DOI: 10.1021/es505515z.

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[4] Pauliuk, S., Wang, T., and D. B. Müller, Steel all over the world: Estimating in-use stocks of iron for 200 countries. Resources, Conservation and Recycling 2013 (71), 22-30, DOI: 10.1016/j.resconrec.2012.11.008.

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[7] Cullen, J. M., Allwood, J. M. and M. D. Bambach, Mapping the Global Flow of Steel: From Steelmaking to End-Use Goods. Environmental Science & Technology 2012 (46), 13048-13055, DOI: 10.1021/es302433p.

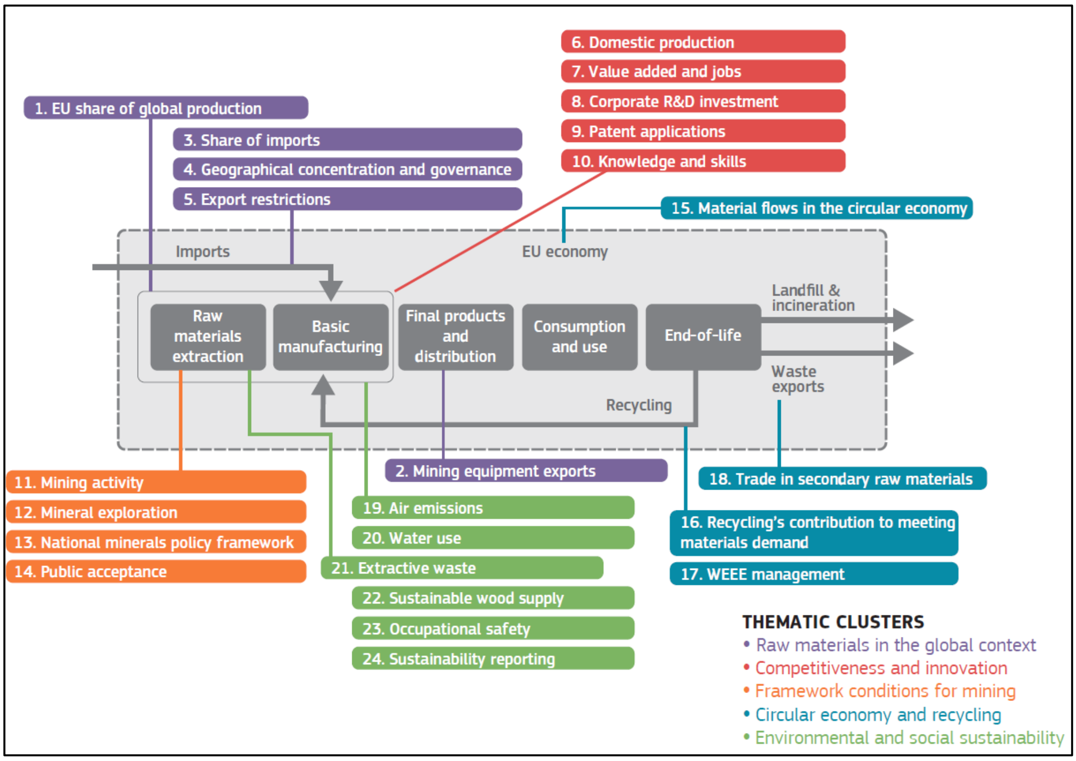
[8] Reichl, C.; Schatz, M.; Zsak, G., 2017. World Mining Data. Volume 32, Minerals Production, Vienna, Austria.

[9] European Steel Association (EUROFER), 2000. Annual report 2000. Available at: http://www.eurofer.org/News%26Events/PublicationsLinksList/2000-AnnualReportFinal.pdf.

8.4 Overview of the indicators included in the 2016 Scoreboard.

The Raw Materials Scoreboard[40] was launched in 2016 (Vidal-Legaz et al., 2016). It provides indicators for monitoring the raw materials sector in relation to competitiveness and growth (Figure S29). To enhance the Scoreboard for the 2018 release, a new study is being undertaken by the JRC to provide DG GROWTH with technical assistance, analysis and data for the improvement of selected indicators. The Scoreboard is part of the monitoring and evaluations scheme of the European Innovation Partnership on Raw Materials (EIP). The EIP on Raw Materials promotes both technological and non-technological innovation along the entire value chain of raw materials involving stakeholders from relevant upstream and downstream sectors. The EIP's Strategic Implementation Plan (SIP) sets out relevant actions necessary to achieve the EIP's objectives and targets, including research and development along the value chain, raw materials knowledge, best practices, revision of selected legislation, licensing steps, standardisation and policy dialogues. The actions cover all relevant raw materials and their value chains. Given the dependency of much of European industry on the international market, international co-operation forms an important and cross-cutting part of the EIP on Raw Materials.

Figure S29 The Raw Materials Scoreboard at a glance (Vidal-Legaz et al., 2016).



8.5 Details of the parameters considered in the CRM assessment

The EU CRM methodology was developed between April 2009 and June 2010 with the support of the European Commission's (EC) Ad-Hoc Working Group on Defining Critical Raw Materials (AHWG-CRM) within the RMI in close cooperation with EU Member States (MS) and stakeholders (EC, 2010). The EC criticality methodology has already been used twice; to create a list of 14 CRMs for the EU in 2011 (EC, 2011) and an updated list of 20

[40] http://bookshop.europa.eu/en/raw-materials-scoreboard-pbET0215541/

CRMs in 2014 (EC, 2014). A next update of the CRM list (every three years according to the RMI) is foreseen in 2017 using a slightly revised methodology (Blengini et al., 2017) briefly described below. The CRM assessment consists of an investigation of a material's economic importance (EI) and supply risk (SR). For this, a variety of parameters are considered including, e.g., information on the global and EU supplier mix, import reliance (considering material imports, exports, and domestic production figures), substitution, and end-use shares[41].

Economic Importance (EI). The parameter on Economic Importance (EI) aims at providing insight on the importance of a material for the EU economy in terms of end-use applications and the Value Added (VA) of corresponding EU manufacturing sectors at the NACE Rev.2 (2-digit level). The EI formula of the revised criticality methodology is as follows:

$$\boldsymbol{EI} = \sum\nolimits_{s} (\boldsymbol{A_s} * \boldsymbol{Q_s}) * \boldsymbol{SI_{EI}}$$

Where:

EI = economic importance

As = the share of end use of a raw material in a NACE Rev. 2 2-digit level sector;

Qs = the sector's VA at the NACE Rev. 2 (2-digit level);

SI_{EI} = the substitution index of a RM related to economic importance

S denotes sector

EI specific Substitution Index (*SI_{EI}*) for a given candidate material is calculated using the Substitute Cost-Performance (SCP) parameters assigned to each substitute material multiplied by the sub-share of each substitute in a given application, and in turn to the share of the end-use application.

$$\boldsymbol{SI_{EI}} = \sum_{\boldsymbol{i,a}} (\boldsymbol{SCP_i} * \boldsymbol{Sub\text{-}share_{i,a}} * \boldsymbol{Share_a})$$

Where:

i denotes an individual substitute material

a denotes an individual application of the candidate material

SCP = Substitute Cost Performance parameter;

Share = the share of the raw materials in an end-use application;

Sub-share = the sub-share of each substitute within each application;

Supply Risk (SR). The parameter on SR reflects the risk of a disruption in the EU supply of the material. It is based on the concentration of primary supply from raw materials producing countries, considering their governance performance and trade aspects. Depending on the EU import reliance (IR), proportionally the two sets of the producing countries are taken into account - the global suppliers and the countries from which the EU is sourcing the raw materials. SR is measured at the 'bottleneck' stage of the material (extraction or processing) which presents the highest supply risks for the EU. Substitution and recycling are considered as risk reducing measures.

[41] Details of the parameters considered in the EI and SR calculations are also given in the CRM Guidelines and Background reports.

The revised methodology uses the following SR formula:

$$SR = \left[\left(HHI_{WGI,t}\right)_{GS} \cdot \frac{IR}{2} + \left(HHI_{WGI,t}\right)_{EUsourcing} \left(1 - \frac{IR}{2}\right)\right] \cdot (1 - EoL_{RIR}) \cdot SI_{SR}$$

Where:

SR = Supply Risk

GS = Global Supply, i.e. global suppliers countries mix

$EU_{sourcing}$ *= actual sourcing of the supply to the EU, i.e. EU domestic production plus other countries importing to the EU*

HHI = Herfindahl-Hirschman Index (used as a proxy for country concentration)

WGI = scaled World Governance Index (used as a proxy for country governance)

t = trade parameter adjusting WGI

IR = Import Reliance

EOL_{RIR} *= End-of-Life Recycling Input Rate*

SI_{SR} *= Substitution Index related to supply risk*

Import Reliance (IR) of a candidate material (see the chapter 3.2) is calculated as follows:

$$Import\ Reliance\ (IR) = \frac{Import - Export}{Domestic\ production + Import - Export}$$

HHI_{WGI} for Global Supplier country concentration and EU28 actual sourcing country concentration is adjusted by a trade parameter and calculated as follows:

$$(HHI_{WGI,t})_{GS\ or\ EUsourcing} = \sum_c (S_c)^2 WGI_c * t_c$$

where:

S_c *= the share of country c in the global supply (or EU sourcing) of the raw material;*

WGI_c *= the rescaled score in the World Governance Indicators of country c;*

Export restrictions types (source: OECD's Inventory of Restrictions on Exports of Raw Materials)

Variable *t* is constructed as follows:

$$t_c = (ET\text{-}TA_c \text{ or } EQ_c \text{ or } EP_c \text{ or } EU_c)$$

where:

t_c *= the trade-related variable of a country c for a candidate raw material (RM);*

$ET\text{-}TA_c$ *= parameter reflecting an export tax imposed (%) by a country c, eventually mitigated by trade agreement (TA) in force;*

EQ_c *= parameter reflecting an export physical quota imposed by a country c (physical units, e.g. tones);*

EP_c = parameter reflecting an export prohibition introduced by a country c for a candidate RM;

EU_c = EU countries parameter c for a candidate RM equals to 0.8.

End-of-Life Recycling Input Rate (EOL_{RIR}) is understood as 'the ratio of recycling from old scrap to European demand of a candidate raw material (equal to primary and secondary material inputs)' and can be based on the flows of the MSA study:

$$EOL-RIR=\frac{G.1.1+G.1.2}{B.1.1+B.1.2+C.1.3+D.1.3+C.1.4+G.1.1+G.1.2}$$

SI_{SR} - specific Substitution Index (SI_{SR}) of a candidate material is calculated as a geometric average of the three parameters (SP, SCr and SCo) assigned to each substitute material, multiplied by the sub-share of each substitute in a given application, and to the share of the end-use:

$$SI_{SR} = \sum_{i,a}[(SP_i * SCr_i * SCo_i)^{1/3} * Sub\text{-}share_{i,a} * Share_a]$$

Where:

i denotes an individual substitute material;

a denotes an individual application of the candidate material;

SP = Substitute Production reflects global production of the substitute and the material as an indicator of whether sufficient amounts of substitute material are available;

SCr = Substitute Criticality takes into account whether the substitute was critical in the previous EU list;

SCo = Substitute Co-production takes into account whether the substitute is primary product or mined as co-/by-product;

Share = the share of the candidate materials in an end-use application;

Sub-share = the sub-share of each substitute within each application;

8.6 Details of the parameters considered in the RMIS trade module

The trade module in RMIS 2.0 is currently being developed and aims to capture various indicators of country's trade performance, dynamics and structure which are crucial in determining a country's market position and competitiveness in various segments of the value chain. These indicators are relevant to a wide spectrum of industrial stakeholders and can strengthen the systemic understanding of raw material supply chains. The process of economic globalization has led to increasingly diversified production networks and import and export flows of commodities. Industrial societies increasingly rely on production and imports of raw materials to satisfy their material needs for production and increase the revenues generated from exports of semi-finished and final goods. Against this backdrop, responding to the challenges of increasing fragmentation and increasingly complex trade exchanges worldwide are already high on the EU trade political agenda (EC, 2015).

8.7 Data overlaps of the MSA study with other raw material-related outputs

Table S21 Data overlaps of the MSA study with other policy-related outputs by DG GROWTH[42,43].

MSA Study (RMIS Overarching Structure)		CRM Assessment		Trade Module (RMIS)		RM Scoreboard	
Material Flow/Stock Parameter	Life-Cycle Stage	Indicator	Details	Indicator	Details	Indicator	Details
A.1.1 Reserves in EU	Exploration	-	-	-	-	12 (?)	-
A.1.2 Reserves in ROW	Exploration	-	-	-	-	-	-
B.1.1 Production of primary material as main product in EU sent to processing in EU	Extraction	SR	$(HHI_{WGI,t})_{EU}$ IR (Domestic Production) EOL-RIR	-	-	6 16	Domestic Production (6) Recycling (16)
B.1.2 Production of primary material as by product in EU sent to processing in EU	Extraction	SR	$(HHI_{WGI,t})_{EU}$ IR (Domestic Production) EOL-RIR	-	-	3 6 16	Import depencence (Domestic Production) (3) Domestic Production (6) Recycling (16)
B.1.3 Exports from EU of primary material	Extraction	SR	IR (Exports)	?	-	-	-
B.1.4 Extraction waste disposed in situ/tailings in EU	Extraction	-	-	-	-	-	-
B.1.5 Stock in tailings in EU	Extraction	-	-	-	-		-
B.2.1 Country concentration	Extraction	SR	$(HHI_{WGI,t})_{GS}$ $(HHI_{WGI,t})_{GS}$	-	-	4	Geographical concentration & governance (4)
B.2.2 Governance risk supply	Extraction	SR	$(HHI_{WGI,t})_{GS}$ $(HHI_{WGI,t})_{GS}$	-	-	4	Geographical concentration & governance (4)
B.2.3 Production of primary material as main product in ROW	Extraction	SR	$(HHI_{WGI,t})_{GS}$		-	4	Geographical concentration & governance (4)
B.2.4 Production of primary material as by product in ROW	Extraction	SR	$(HHI_{WGI,t})_{GS}$	-	-	4	Geographical concentration & governance (4)
B.2.5 Industry structure in EU	Extraction	-	-	-	-	11	Mining activity in EU (11)
C.1.1 Production of processed material in EU sent to manufacture in EU	Processing	-	-	-	-	-	-

[42] Overlaps also exist with the Minventory study for stocks in the EU (MSA parameters A1.1 and B1.5) and possibility A1.2 (Reserves in ROW). However, because the Minventory study to date only includes metadata on these parameters it was not further included in this table.

[43] Data overlaps also exist with the EC circular economy monitoring framework, namely the end-of-life recycling input rate which is based on the MSA studies.

MSA Study (RMIS Overarching Structure) Material Flow/Stock Parameter	Life-Cycle Stage	CRM Assessment Indicator	CRM Assessment Details	Trade Module (RMIS) Indicator	Trade Module (RMIS) Details	RM Scoreboard Indicator	RM Scoreboard Details
C.1.2 Exports from EU of processed material	Processing	SR	IR (Exports)	?	-	-	-
C.1.3 Imports to EU of primary material	Processing	SR	EOL-RIR IR (Imports)	?	-	3 16	Import dependence (Exports) (3) Recycling (16)
C.1.4 Imports to EU of secondary material	Processing	SR	EOL-RIR IR (Imports)	?	-	3 16	Import dependence (Exports) (3) Recycling (16)
C.1.5 Processing waste in EU sent for disposal in EU	Processing	-	-		-	-	-
C.1.6 Exports from EU of processing waste	Processing	-	IR (Exports)	?	-	3 18 (?)	Import dependence (Exports) (3) Trade in secondary RM (18)
C.1.7 Output from the value chain	Processing	-	-	-	-	-	-
D.1.1 Production of manufactured products in EU sent to use in EU	Manufacture	SR	$(HHI_{WGI,t})_{EU}$ (EU Consumption)	-	-	-	-
D.1.2 Exports from EU of manufactured products	Manufacture	-	-	?	-	-	-
D.1.3 Imports to EU of processed material	Manufacture	SR	EOL-RIR	?	-	16	Recycling (16)
D.1.4 Manufacture waste in EU sent for disposal in EU	Manufacture	-	-	-	-	-	-
D.1.5 Manufacture waste in EU sent for reprocessing in EU	Manufacture	-	-	-	-	-	-
D.1.6 Exports from EU of manufacture waste	Manufacture	-	-	?	-	18 (?)	Trade in secondary RM (18)
D.1.7 Output from the value chain	Manufacture	-	-	-	-	-	-
D.2.1 Main uses	Manufacture	EI	As = Share of end use in a NACE Rev. 2 2-digit level sector	-	-	-	-
D.2.2 Substitutes	Manufacture	SR, EI	SI_{SR} = Substitution Index (supply risk) SI_{EI} = Substitution Index (economic importance)	-	-	-	-
D.2.3 Economic importance	Manufacture	EI	-	-	-	-	-
E.1.1 Stock of manufactured products in use in EU	Use	-	-	-	-	-	-
E.1.2 Stock of manufactured products at end of life that are kept by users in EU	Use	-	-	-	-	-	-
E.1.3 Exports from EU of manufactured	Use	-	-	?	-	-	-

MSA Study (RMIS Overarching Structure) Material Flow/Stock Parameter	Life-Cycle Stage	CRM Assessment Indicator	CRM Assessment Details	Trade Module (RMIS) Indicator	Trade Module (RMIS) Details	RM Scoreboard Indicator	RM Scoreboard Details
products for reuse							
E.1.4 Imports to EU of manufactured products	Use	SR	$(HHI_{WGI,t})_{EU}$ (EU Consumption)	?	-	-	-
E.1.5 In use dissipation in EU	Use	-	-	-	-	-	-
E.1.6 Products at end of life in EU collected for treatment	Use	-	-	-	-	-	-
E.1.7 Annual addition to in-use stock of manufactured products in EU	Use	-	-	-	-	-	-
E.1.8 Annual addition to end-of life stock of manufactured products at end of life that are kept by users in EU	Use	-	-	-	-	-	-
F.1.1 Exports from EU of manufactured products at end of life	Collection	-	-	?	-	-	-
F.1.2 Imports to EU of manufactured products at end of life	Collection	-	-	?	-	-	-
F.1.3 Manufactured products at end of life in EU sent for disposal in EU	Collection	-	-	-	-	-	-
F.1.4 Manufactured products at end of life in EU sent for recycling in EU	Collection	-	-	-	-	-	-
F.1.5 Stock in landfill in EU	Collection	-	-	-	-	-	-
F.1.6 Annual addition to stock in landfill in EU	Collection	-	-	-	-	-	-
G.1.1 Production of secondary material from post consumer functional recycling in EU sent to processing in EU	Recycling	SR	EOL-RIR	-	-	16	Recycling (16)
G.1.2 Production of secondary material from post consumer functional recycling in EU sent to manufacture in EU	Recycling	SR	EOL-RIR	-	-	16	Recycling (16)
G.1.3 Exports from EU of secondary material from post consumer recycling	Recycling	-	-	?	-	-	-
G.1.4 Production of secondary material from post consumer non-functional recycling	Recycling	-	-	-	-	-	-
G.1.5 Recycling waste in EU sent for disposal in EU	Recycling	-	-	-	-	-	-

8.8 List of MSA studies available and needs, e.g., due to the new CRM list

Table S22 Data needs for MSA data sets in the future.

CRM Candidate Materials	Existing MSAs		Data Needs	
	2015 MSA Study (Year 2012)	Current Study[1]	CRM 2017 List	Additional Materials of Possible Importance[2]
Aggregates	X			
Aluminium		X		
Antimony	X		X	
Baryte			X (MSA non existing)	
Bauxite				
Bentonite				
Beryllium	X		X	
Bismuth			X (MSA non existing)	
Borate	X		X	
Cerium				
Chromium	X			
Cobalt	X		X	
Coking coal	X			
Copper		X		
Diatomite				
Dysprosium	X			
Erbium	X			
Europium	X			
Feldspar				
Fluorspar	X		X	
Gadolinium			(MSA non existing)	X (REE)
Gallium	X		X	
Germanium	X		X	
Gold				
Gypsum				
Hafnium			X (MSA non existing)	
Helium			X (MSA non existing)	
Holmium				X (REE)
Indium	X		X (MSA non existing)	
Iridium				
Iron		X		
Kaolin clay				
Lanthanum				X (REE)
Lead				
Limestone				
Lithium	X			
Lutetium				
Magnesite	X			
Magnesium	X		X	
Manganese			X (MSA non existing)	
Molybdenum				X (Alloying element)
Natural cork				
Natural graphite	X		X	

CRM Candidate Materials	Existing MSAs		Data Needs	
	2015 MSA Study (Year 2012)	Current Study[1]	CRM 2017 List	Additional Materials of Possible Importance[2]
Natural Rubber			X (MSA non existing)	
Natural Teck wood				
Neodymium	X			X (REE)
Nickel				X (Major metal)
Niobium	X		X	X (Alloying element)
Palladium	X			
Perlite				
Phosphate rock	X		X	
Phosphorus			X	
Platinum	X			
Potash				
Praseodymium			(MSA non existing)	X (REE)
Rhenium				
Rhodium	X			
Ruthenium				
Samarium			(MSA non existing)	X (REE)
Sapele wood				
Scandium			X (MSA non existing)	
Selenium				
Silica sand				
Silicon metal	X		X	
Silver				
Sulphur				
Talc				
Tantalum			X (MSA non existing)	
Tellurium				
Terbium	X			X (REE)
Thulium			(MSA non existing)	X (REE)
Tin				
Titanium				X (alloying element)
Tungsten	X		X	
Vanadium			X (MSA non existing)	
Ytterbium			(MSA non existing)	X (REE)
Yttrium	X			X (REE)
Zinc				X (major metal)

[1]New MSA presented in this report.
[2]Materials suggested to be included in new MSA studies (not covered in the CRM 2017 list).

List of abbreviations

CE	Circular Economy
CRM	Critical Raw Materials
DMC	Domestic Material Consumption
DMI	Direct Material Input
EC	European Commission
EIP-RM	European Innovation Partnership on Raw Materials
EOL-RIR	End-of-life recycling input rate
EOL-RR	End-of-life recycling rate
ESTAT	Eurostat
EW-MFA	Economy-Wide Material Flow Accounts
Gt	Giga tonne
MFA	Material Flow Analysis
MSA	EU Raw Material System Analysis
MSW	Municipal Solid Waste
NSA	Net Addition to Stocks
RMIS	EU Raw Materials Information System
SRM	Secondary Raw Materials

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