European Commission

JRC TECHNICAL REPORTS

Revision of the material system analyses specifications

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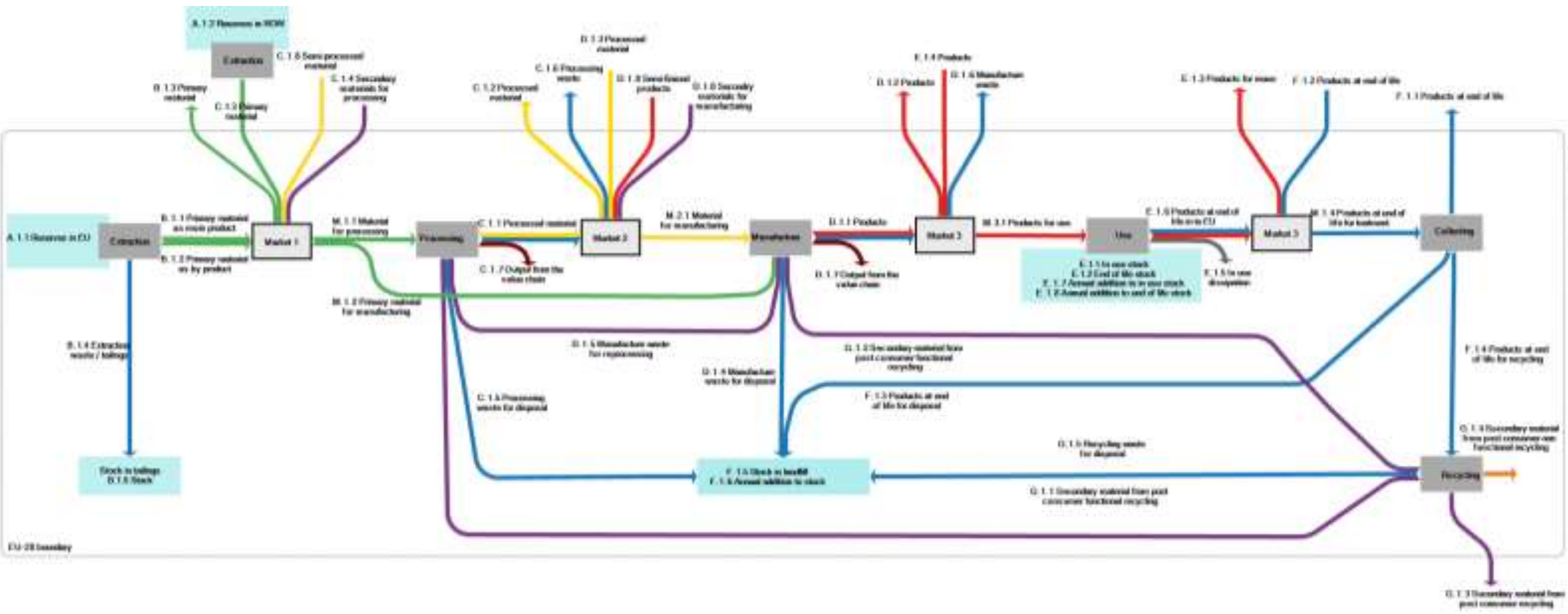
2020



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https://ec.europa.eu/jrc

JRC118827

EUR 30091 EN

PDF ISBN 978-92-76-10734-7 ISSN 1831-9424 doi:10.2760/374178

Luxembourg: Publications Office of the European Union, 2020

How to cite this report: Torres de Matos, Cristina, Wittmer, Dominic, Mathieux, Fabrice, Pennington, David, *Revision of the material system analyses specifications*, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-10734-7, doi:10.2760/374178, JRC118827

Acknowledgements

The authors acknowledge Beatriz Vidal-Legaz for the revison and contributions to section 5.3 MSA and Raw Materials Scoreboard.

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1 Introduction

Material System Analysis (MSA) is a methodology that investigates the stocks and flows of materials through the economy. It covers the materials along the overall supply chain, from extraction until end-of-life management e.g., through recovery or disposal. The MSA methodology and the results from the first set of studies conducted for the European Commission (EC) with an European Union (EU) scope were published in 2015 (Deloitte, 2015) by DG GROW in the context of the EU Raw Materials Initiative's (RMI) strategy (EC, 2008).

The EU Raw Materials Initiative's (RMI) strategy is a part of the Europe 2020's strategy for smart, sustainable, and inclusive growth (EC, 2008). This strategy shows that the EC is committed to "securing reliable and unhindered access to raw materials". The MSA studies represent a comprehensive data inventory of the material flows through the EU economy (industry and society). They consider the entire life cycle of a selected material which is crucial for a sustainable resource management, including the provision of evidence to inform discussions and decision making on the supply of raw materials. The MSA support the development of EU RM policies, and in the mid-term provide a basis for developing sound sustainable resource management strategies.

Beyond this primary application of the MSA, there exist various other applications that make use of the underlying data: The MSA contain key material specific data and information, and represent a solid pillar to support (1) the development of the list of Critical Raw Materials (EC, 2017), (2) the development of several RM scoreboard indicators (EC, 2018), (3) the monitoring of the circular economy (EC, 2018), (4) analyses of specific sectors, e.g. batteries (EC, 2018), and (5) provide fundamental inputs to social and environmental assessments including e.g. life cycle assessments, carbon footprints, etc.

The MSA are an important contribution to the development of the EC Raw Materials Information System (RMIS). The already produced MSA studies and their data sets are integrated into the RMIS[1] which is hosted at the Joint Research Centre (JRC) in Ispra. The RMIS 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[2] and a specific action of the Circular Economy Communication (EC, 2017) of the EC. The MSA is an important structured dataset for the RMIS and this also reinforces the need for regular updates of EU MSA.

It is important to highlight that the majority of other raw materials policy outputs (mentioned in the previous paragraphs) focus their data needs on only one or two stages of a material life cycle e.g the production (extraction, processing and manufacturing) and recycling. None of these other outputs take into consideration the EU consumption at the use stage. Due to its life cycle approach the MSA collects information on all life cycle stages, including EU flows and stocks at the use phase. This allows to collect important information to depict how EU consumption behaviours and in-use stocks can affect the availability and demand of raw materials. This information may be important to find strategies to change consumer behaviour towards a more sustainable consumption and increase material availability for other life-cycle stages.

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

[2] https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en/content/strategic-implementation-plan-sip-0

Moreover, MSA could be used to analyse the material systems in more detail, and to use them as a basis for material forecasts. In order to do so, it is necessary to develop understanding of dynamics of the EU flows and stocks (dynamisation).

Until this date two series of MSA studies have been published. The first one in 2015 covered MSA for 28 raw materials and the second in 2018 covered three raw materials. Currently, a new series of MSA studies is conducted that covers 14 raw materials, for publication in 2020.

Figure 1 gives an overview of the materials evaluated in the previous MSA studies and the current ones, which will be published in 2020.

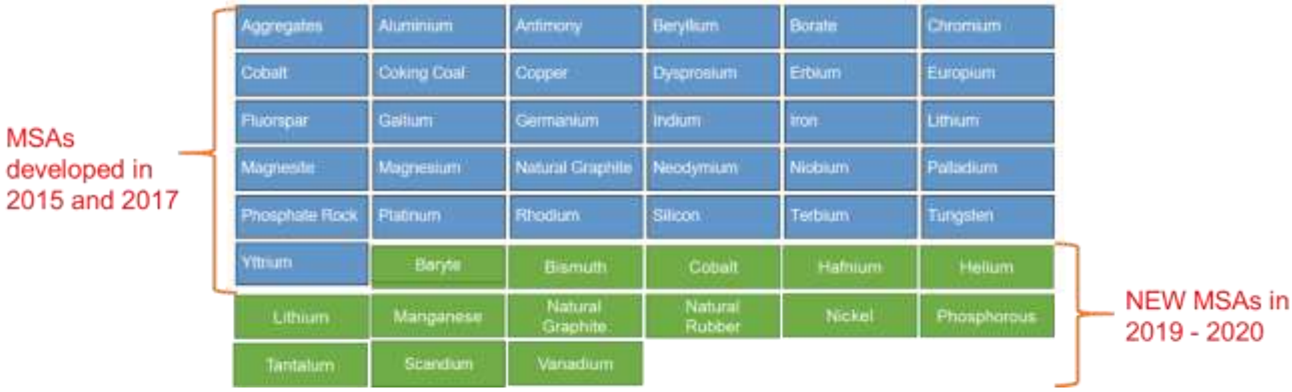


Figure 1. Materials covered in the 2015 and 2017 MSA studies (1st and 2nd studies) in blue and the materials covered in the MSA that will be published in 2020 in green (3rd study).

The use of MSA results has evolved since the methodology was originally developed. Practitioners identified several improvement opportunities during its application on numerous raw materials, and there is hence a need to adjust the methodology. This report summarises the methodological evolutions that are proposed to the MSA methodology, for its application to the 2020 series of MSA studies. It explains how and why the methodology has changed and evolved to better reflect reality; it should serve as an update to the study on the methodology published in 2015 (Deloitte, 2015). The report is structured as follows: Section 1 – Introduction (which includes: a summary description of the previous MSA studies and the ongoing ones; a summary of the original 2015 methodology), Section 2 - limitations and solutions to the MSA methodology, Section 3 - discusses the application of MSA for policy outputs, Section 4 - draws the main conclusions.

1.1 The MSA studies

1.1.1 First and second MSA studies

In 2012 the "Study on Data Needs for a Full Raw Materials Flow Analysis" (Risk & Policy Analysts Limited, 2012) was published by the European Commission in order to support identifying the information and data needs for complete raw materials flow analyses (MFA)[3]. On this basis, in 2015 the first MSA study was published for the EC and included

[3] MFA is a systematic assessment of the flows and stocks of materials within a system in space and time. It connects the sources, the pathways, and the intermediate and final sinks of a material. An MSA is an MFA applied on material systems within the geographical scope of the European Union, or an EU member state.

28 materials (Deloitte, 2015). The coverage of these first MSA studies for the EC were: 26 critical raw materials, lithium, and aggregates (Deloitte, 2015). The reference years considered at that time were 2012 and 2013.

In 2018, the second series of MSA studies was performed for the EC on three basic metals (Passarini, 2018): iron, copper, aluminium. The reference years were: 2013 for aluminium, 2014 for copper, and 2015 for iron. The scope was again for flows in, out, and within the EU.

1.1.2 Ongoing MSA studies

The focus of the previous MSA studies for the EC was on critical raw materials (CRMs); materials with a high risk of supply disruption and a high economic importance (Blengini, 2017). As the list of CRMs is under triannual revision ((EC, 2011), (EC, 2014), (EC, 2017)) new raw materials have entered the list over time. Additionally, some of the raw materials experienced rapid developments in the last years and have become particularly important for several strategic sectors in the EU. Updating and extending the MSA studies to new critical raw materials (identified in the 2017 EU CRM list) as well as other materials relevant for strategic value chains, such as batteries and other low carbon technologies is relevant and needed.

To address these needs, a 3rd series of MSA was launched for 2019 and 2020 by the EC[4]. The EC's DG JRC together with DG GROW is coordinating the development of 14 MSA, including five battery raw materials: (cobalt, lithium, manganese, nickel and natural graphite) and 9 critical raw materials, for which hitherto no MSA were developed in the previous studies (barytes, bismuth, hafnium, helium, natural rubber, phosphorus, scandium, tantalum and vanadium). External organisations support some MSA studies .

The studies that will be published in 2020 will update the MSA of cobalt, lithium and natural graphite. These raw materials are gaining increased attention due to their use in battery production, for which demand is expected to rise. Up-to-date knowledge of these material flows in the EU context is particularly necessary.

The 2020 studies run in parallel with the 2020 CRM assessment. The data and knowledge collected while developing the MSA will also be used in the CRM assessment; Chapter 4 displays which MSA flows are important for the CRM assessment.

1.2 MSA methodology

1.2.1 Description

The geographical focus of these MSA studies for the EC is the European Union. An MSA constitutes a map of processes, stocks and flows for a material in the EU economy throughout its overall life cycle, including: extraction, processing, manufacturing, use, collection and recycling. MSA account for the relevant stocks of a material stored in: 1) tailings; 2) landfills and 3) products in the use phase, 4) domestic reserves, and 5) foreign reserves (see blue boxes in Figure 2).

Figure 2 shows the MSA system, which visualises all the flows and stocks considered in a MSA.

Hitherto, the MSA methodology was applied to a selection of candidate materials of the EC criticality assessment. The MSA have been conducted by, or by order of, the European Commission.

[4] under the Administrative Arrangement SI2. 790994 between DG GROW and DG JRC

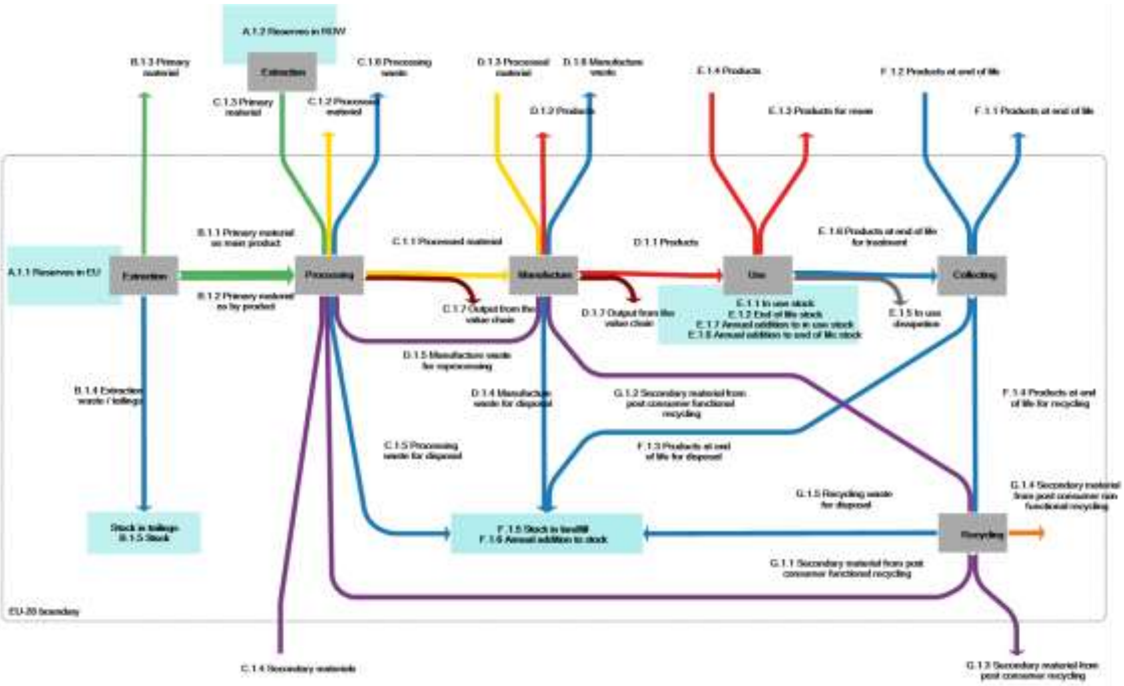


Figure 2. MSA system with all the processes (material life cycle stages), flows and stocks considered in a MSA. The system border is the geographical border of the EU.

The list of parameters (flows, stocks) considered in the MSA methodology, developed in 2015, is given in Table 1. The reference unit for all flows is "kg of material" e.g. Kg of Cobalt not of Cobalt ores, and must be coherent to ensure a complete mass balance.

Table 1. Parameters considered in the MSA methodology developed in 2015 (Deloitte, 2015)

Material Flow/Stock Parameter
A.1.1 Reserves in EU
A.1.2 Reserves in ROW (Rest of the World)
B.1.1 Production of primary material as main product in EU sent to processing in EU
B.1.2 Production of primary material as by product in EU sent to processing in EU
B.1.3 Exports from EU of primary material
B.1.4 Extraction waste disposed in situ/tailings in EU
B.1.5 Stock in tailings in EU
C.1.1 Production of processed material in EU sent to manufacture in EU
C.1.2 Exports from EU of processed material
C.1.3 Imports to EU of primary material
C.1.4 Imports to EU of secondary material
C.1.5 Processing waste in EU sent for disposal in EU
C.1.6 Exports from EU of processing waste
C.1.7 Output from the value chain
D.1.1 Production of manufactured products in EU sent to use in EU
D.1.2 Exports from EU of manufactured products
D.1.3 Imports to EU of processed material
D.1.4 Manufacture waste in EU sent for disposal in EU
D.1.5 Manufacture waste in EU sent for reprocessing in EU
D.1.6 Exports from EU of manufacture waste
D.1.7 Output from the value chain
E.1.1 Stock of manufactured products in use in EU
E.1.2 Stock of manufactured products at end-of-life that are kept by users in EU
E.1.3 Exports from EU of manufactured products for reuse
E.1.4 Imports to EU of manufactured products
E.1.5 In use dissipation in EU
E.1.6 Products at end-of-life in EU collected for treatment
E.1.7 Annual addition to in-use stock of manufactured products in EU
E.1.8 Annual addition to end-of life stock of manufactured products at end-of-life that are kept by users in EU
F.1.1 Exports from EU of manufactured products at end of life
F.1.2 Imports to EU of manufactured products at end of life
F.1.3 Manufactured products at end-of-life in EU sent for disposal in EU
F.1.4 Manufactured products at end-of-life in EU sent for recycling in EU
F.1.5 Stock in landfill in EU
F.1.6 Annual addition to stock in landfill in EU
G.1.1 Production of secondary material from post-consumer functional recycling in EU sent to processing in EU
G.1.2 Production of secondary material from post-consumer functional recycling in EU sent to manufacture in EU
G.1.3 Exports from EU of secondary material from post-consumer recycling
G.1.4 Production of secondary material from post-consumer non-functional recycling
G.1.5 Recycling waste in EU sent for disposal in EU

A detailed description of the MSA methodology and the scope of each flow is given in the final report of the 2015 MSA study (Deloitte, 2015).

1.2.2 MSA results

For each MSA, the results and background calculations are filed in excel spreadsheets, which give the value of each MSA flow and stock for the different life cycle stage. These excel files are not accessible to the public, but aggregated summary results are made public.

An MSA report describes the material life cycle. It presents both the share of material used in the EU manufacturing and the share of material in the EU use phase. Figure 3 presents an example of the distribution of end uses in the EU, both in the manufacturing stage and the use stage.

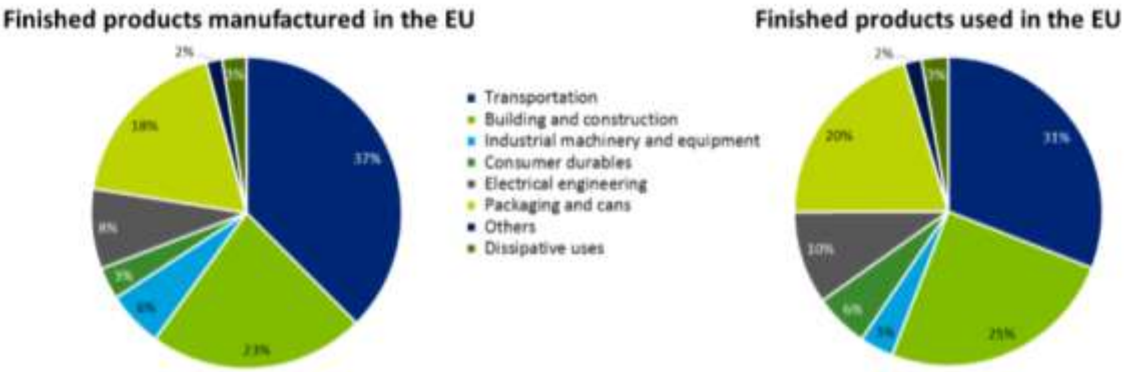


Figure 3. Shares of final uses, on the example of aluminium, in the EU per type of finished product (left) and type of end-use sector at the use stage (right). (Passarini, 2018)

Finally, a visual output of the MSA is the Sankey diagrams. These diagrams present the life cycle data obtained for each material. Two Sankey diagrams are derived from the MSA results: a detailed Sankey diagram and a simplified one. The detailed Sankey diagram applies the structure of the MSA system (cf. Figure 2), showing all the MSA flows and their values. Figure 4 shows an example of a detailed Sankey diagram for aluminium.

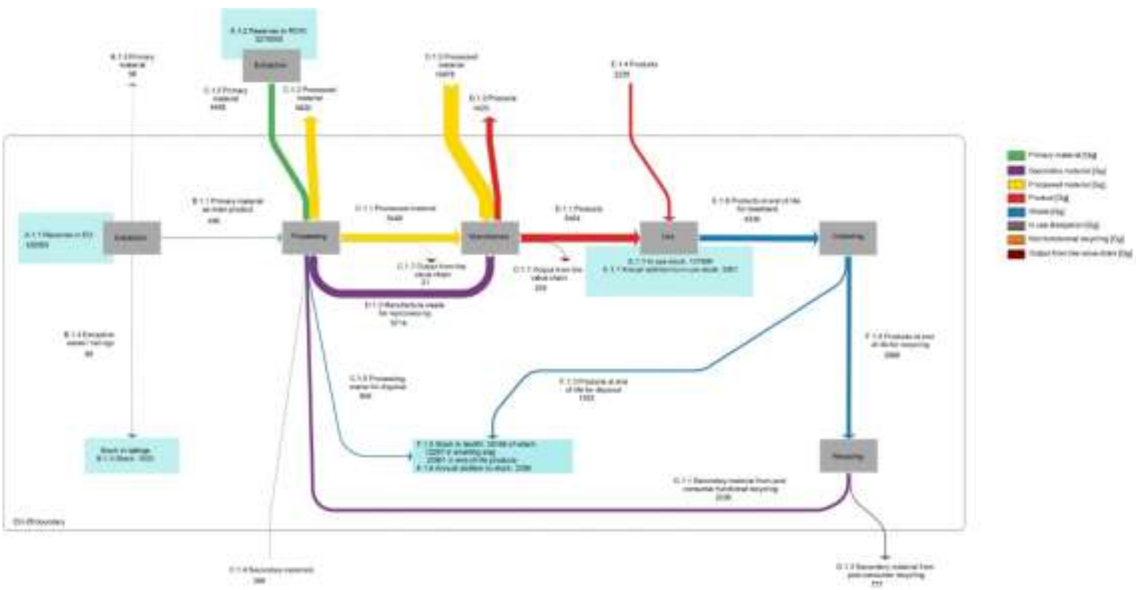


Figure 4. Detailed Sankey diagram for aluminium (2013). Values are in Gg aluminium (Passarini, 2018).

The simplified Sankey diagram aggregates the data in 7 categories: 1) imports, 2) exports, 3) functional recycling, 4) EU extraction, 5) addition to in use and end-of-life stocks, 6) addition to landfill and tailings and 7) losses and stockpiles. Figure 5 presents an example of a simplified Sankey diagram for aluminium.

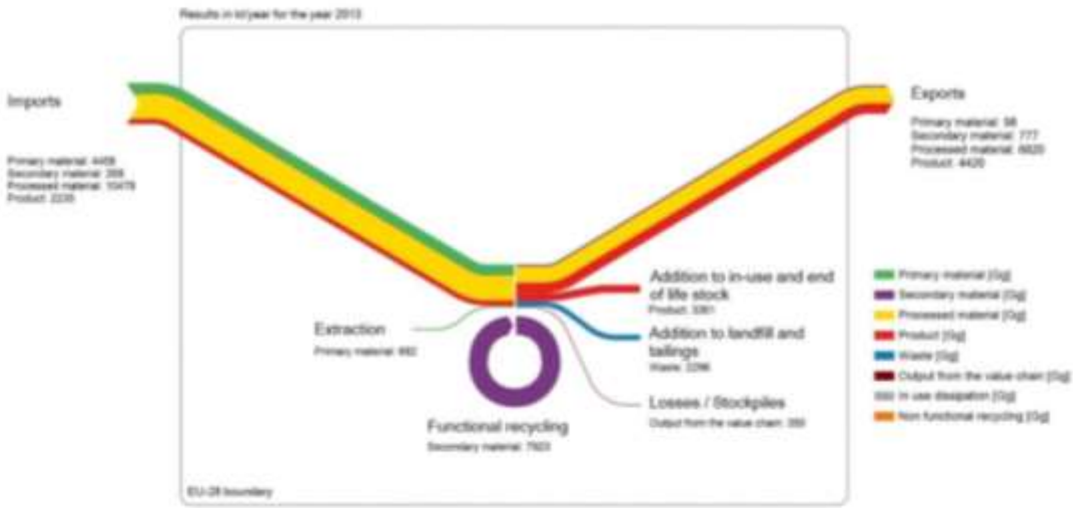


Figure 5 Simplified Sankey diagram for aluminium (Passarini, 2018)

Beyond this standardised way of presenting results, intermediate aggregation is possible. Depending on the focus of research, e.g.in scientific publications, the results can be presented differently.

2 Revision of the MSA methodology

This chapter presents the new improvements introduced to the MSA methodology for its application to the 2020 series of MSA studies and beyond. It explains the challenges while developing the MSA which contributed to these new proposals and the advantages these offer to the development of future MSA.

An example demonstrates the advantages in relation to the previous methodology for each group of proposed improvements.

This revision of the MSA methodology includes 3 types of improvements: 1) improvement on the MSA system; 2) changes in the scope of few flows; 3) changes in data specifications.

2.1 Improvement on the MSA system

2.1.1 Introduction of new stages "market stages"

In the methodology developed in 2015 exports of each commodity were reported separately to their imports. This is demonstrated in Figure 5, which shows that e.g. the exports of primary material B1.3 were reported leaving the extraction stage, while imports of primary material were reported directly entering processing stage (flow C.1.3); the same separation of trade flows is showed between C1.2 and D1.3.

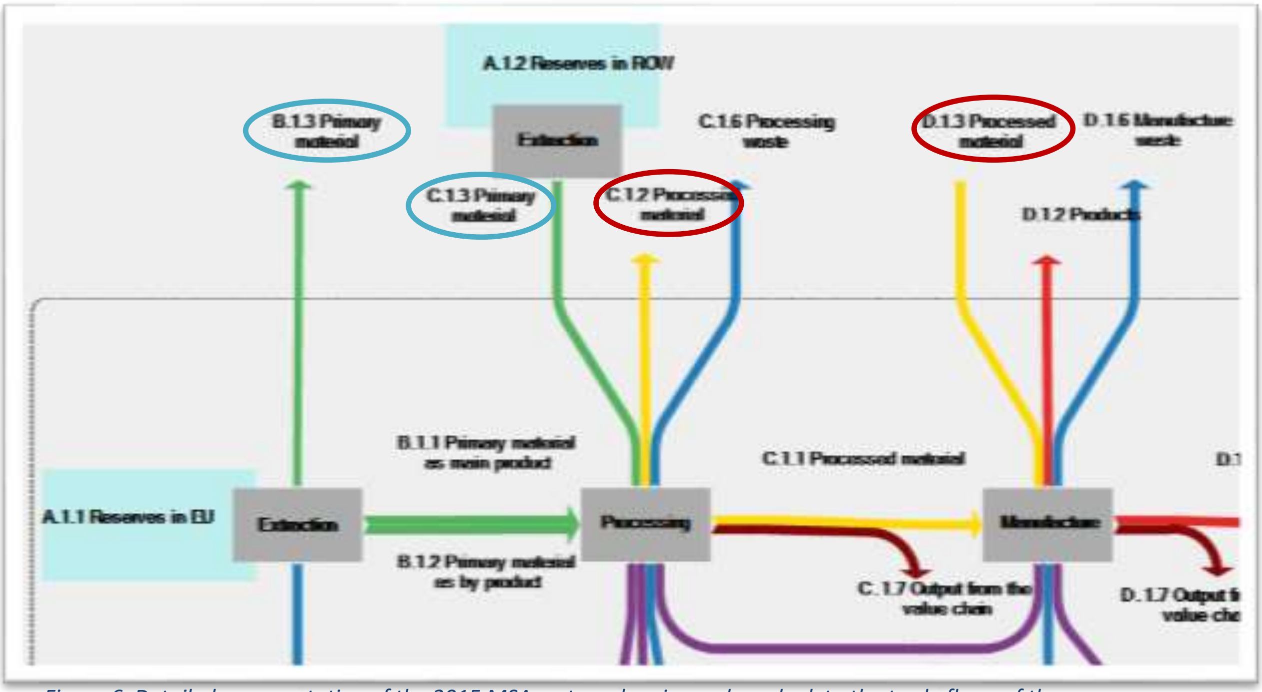


Figure 6. Detailed representation of the 2015 MSA system showing a closer look to the trade flows of the processes: extraction, processing and manufacture. Highlighted, in blue is the separation between the trade flows (exports and imports) of primary material and in red the trade flows of processed material.

This way of presenting the flows in the previous exercises created problems in the past due to the existence of re-exports. Re-exports are exports of a commodity that enter the

EU (import) and are then exported without any further processing. Therefore, dissociating exports and imports of the same commodity between 2 process stages created inconsistencies in the calculations of the output flows (e.g. B1.1 and C1.1), because they were determined by mass balance calculations.

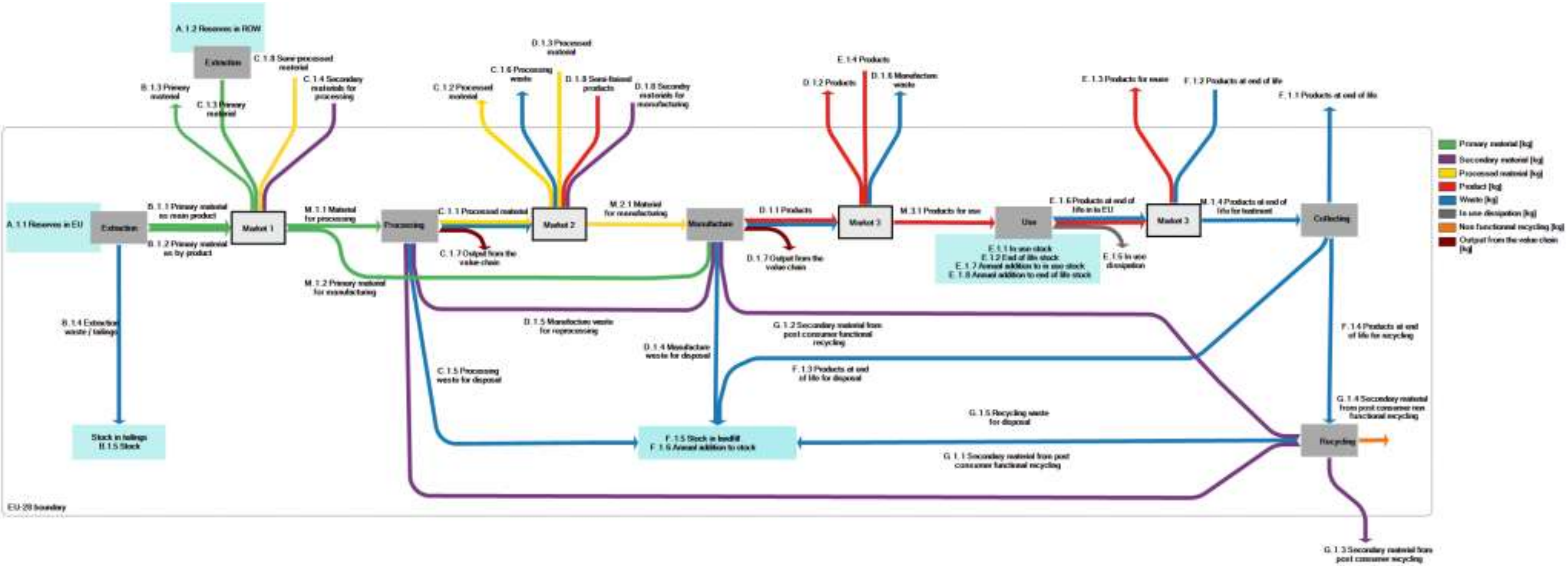
Example of encountered problem:

In 2015, the total amount of nickel content in nickel ores from EU production of (primary Nickel production) was 38.500.000 kg of Ni, while the reported exports of primary Nickel were 47.879.345 kg of Ni. This means that the flow B1.1 would be calculated as a negative flow of -14.216.891 kg of Ni. This situation can be explained by the existence of re-exports of primary Nickel imported to the EU (imports were 54.741.189 kg of Ni in 2015) without suffering any further processing.

The described problem of mass balances was due to the fact that the previous MSA system was not representative of the real physical flows and of the data collection, it showed aggregated information e.g. flow B1.1 was the result of EU extraction minus exports of primary material (B1.3) as well as Extraction waste/tailings (B1.4).

Solution:

In order to improve the MSA methodology and avoid the described issues, four "market stages" will be introduced between the following pairs of processes: 1) extraction and processing; 2) processing and manufacturing; 3) manufacturing and use and 4) use and collection stages. Figure 6 presents the proposed new structure incorporating the "market stages". This new system reflects better the real physical flows and where the data are measured in the system. It allows to display the EU production of primary material coming from extraction (Flows B1.1), which is currently reported by different databases e.g World Mining Data, BGS, USGS and Prodcom. At the same time, it allows to display directly, the apparent consumption of primary material in processing M1.1 and of processed material in manufacturing M2.1. Apparent consumption is given by Production + Imports – Exports.



These new changes are also in accordance with the recommendation of the MinFuture project, which are described in the report "A systems approach for the monitoring of the physical economy" (Evi Petavratzi, 2018).

Subsequent revisions of the MSA methodology may introduce yet more developments. For example, the system doesn't consider the possibility of stockpiling in the different stages. In the future, similarly to what is already implemented in the use stage, this may be considered by incorporating stocks. The current exercise does not include this to conserve comparability with previous exercises.

2.1.2 Introduction of new flows

One of the objectives of the MSA is to be able to represent the physical economy for numerous materials in a harmonised system. Some detailed information on material life cycle may be missing or hidden from the final system in order to achieve this overall harmonisation. However, while developing the MSA, practitioners felt the necessity to include extra flows that were not included in the 2015 methodology. The next paragraphs describe the new proposed flows to be integrated into the "universal" MSA system, as well as examples where their use is important.

C.1.8 Imports of semi-processed material send to processing in the EU

In the previous MSA methodology the imports entering the processing stage accounted only for primary material C1.3. However, for several materials, the EU imports also semi-processed material (which had undergone first processing steps extra-EU and then is further processed within the EU and later on used in the manufacturing stage). In the previous exercises this created inconsistencies that had to be solved through mass balances or by including semi-processed material in C1.3 in addition to the primary material. For example, this new proposed flow is necessary for cobalt to include Co mattes and other intermediates of cobalt metallurgy that are refined in the EU to produce Co metal, Co salts and other processed cobalt materials.

D.1.8 Imports of products requiring further manufacturing steps in the EU

Similarly to the previous flow, the EU manufacturing stage also receives imports of semi-finished products (which had undergone first manufacturing steps extra-EU and require further manufacturing steps in the EU). For example, steel may be considered as a semi-finished product produced during fabrication that still needs further manufacturing steps in the production of final products.

D.1.9 Imports of secondary raw material sent to manufacturing in the EU

The introduction of this flow allows the possibility of secondary material to be imported directly to the manufacturing stage, which could be important for instance for some steelmaking processes. This is the case for example the of imports of stainless steel was scrap that is used in the steelmaking process, which is important for several materials e.g. nickel.

2.1.3 Introduction of market output flows

Section 2.1.1 described the incorporation of "market stages" in the improved MSA system. After introducing these "market stages" new flows need to be added to describe the material flows exiting these market stages. Hence, the following five new flows were introduced:

M.1.1 – Material sent for processing in the EU: this corresponds to the amount of primary material that was produced in the EU extraction stage, in addition to imports of: primary, semi-processed and secondary material produced outside the EU minus the amount of primary material exported from the EU to the rest of the world and the amount of primary material that goes directly to the manufacturing process.

M.1.2 – Primary material sent for manufacturing: this corresponds to the amount of primary material that was produced in the EU and imported to the EU and subsequently was used directly in the manufacturing stage without passing through processing stages. The introduction of this flow is relevant for cases such a lithium, where certain forms of lithium coming from the extraction stage are directly used in the ceramic and glass industries.

M.2.1 – Processed material sent to manufacturing

Material processed in the EU plus imports of: processed, secondary material and semi-finished products from outside the EU and discounting the amount of processed material exported to outside the EU.

M.3.1 - Manufactured products sent to use in the EU: this corresponds to the amount of material within manufactured products produced in the EU and imported to the EU, discounting the amount of material that leaves the EU through manufactured products.

M4.1 - Products at end-of-life in EU collected for treatment: this corresponds to the material content in the products used in the EU and that are at their end-of-life, plus the amount of material in imported products at the end-of-life to be re-used in the EU minus the material exported within end-of-life products.

2.1.4 Introduction of more details in processing and manufacturing

Experiences from the previous MSA indicate that a division of processing and manufacturing stages in sub-processes is required, in particular for certain metals. For these materials the processing stage is divided into: a) smelting and b) refining while the manufacturing stage is divided into: a) fabrication and b) further manufacturing. Such detailed information is shown in the MSA spreadsheets, which allow for an improved resolution of the calculated aggregated results displayed in the Sankey diagram.

The MSA developed in 2015 and 2017 showed already detailed information for these processing and manufacturing stages in the spreadsheets. However, this detailed information was not always consistent for all materials. This extra information could be described in the MSA report or in future developments of the MSA Sankey diagrams with increased complexity of the information shown visually. This is now captured in the improved MSA methodology and will be consistently referred to in the MSA reports.

2.2 Changes in the scope of few flows

With the introduction of the "market stages" and the flows described in the former section, the scope of some previously existing flows needs to change in terms of the material that they represent. These are presented in Table 2.

Table 2. Comparison between the name and description of the flows developed in 2015 and the new proposed name and description

Flow Code	Flow name and description in 2015	New flow name and description
B1.1	**Production of primary material as main product in EU sent to processing in EU:** Annual quantity of the element in the production of primary material as main product in EU sent to processing in EU. Primary material refers to products at the gate of the mine, pit or quarry (ore or concentrate after a preliminary processing step in situ). This flow shows the EU production after subtracting exports of primary material.	**Production of primary material as main product in EU:** Annual quantity of the material in the production of primary material as main product in EU. In EU Primary material refers to products at the gate of the mine, pit or quarry (ore or concentrate after a preliminary processing step in situ). This flow represents the total EU production of primary material.
B1.2	**Production of primary material as by-product in EU sent to processing in EU:** Annual quantity of the element in the production of primary material as by-product in EU sent to processing in EU Primary material refers to products at the gate of the mine, pit or quarry (ore or concentrate after a preliminary processing step made in situ). This flow shows the EU production after subtracting exports of primary material as by-product.	**Production of primary material as by-product in EU:** Annual quantity of the material in the production of primary material as by-product in EU, in EU Primary material refers to products at the gate of the mine, pit or quarry (ore or concentrate after a preliminary processing step made in situ). This flow represents the total EU production of primary material as by-product.

C1.1	**Production of processed material in EU sent to manufacture in EU:** Annual quantity of the element in the production of processed material in EU sent to manufacture in EU. This flow shows the EU production after subtracting exports of processed material.	**Production of processed material in EU:** Annual quantity of the material in the production of processed material in EU.
D1.1	**Production of manufactured products in EU sent to use in EU:** Annual quantity of the element in the production of manufactured products in EU sent to use in EU. This flow shows the EU production after subtracting exports of manufactured products.	**Production of manufactured products in EU:** Annual quantity of the material in the production of manufactured products in EU.

Table 3 summarises the material flows and stocks parameters considered in the new version of the MSA methodology.

Table 3. Material Flow/Stock Parameters Red - Flow changed from 2015 Green - New Flow

Material Flow/Stock Parameter
A.1.1 Reserves in EU
A.1.2 Reserves in ROW
B.1.1 Production of primary material as main product in EU
B.1.2 Production of primary material as by product in EU
B.1.3 Exports from EU of primary material
B.1.4 Extraction waste disposed in situ/tailings in EU
B.1.5 Stock in tailings in EU
M.1.1 Material send to processing in the EU
M.1.2 Primary material send to manufacturing
C.1.1 Production of processed material in EU
C.1.2 Exports from EU of processed material
C.1.3 Imports to EU of primary material
C.1.4 Imports to EU of secondary material
C.1.5 Processing waste in EU sent for disposal in EU
C.1.6 Exports from EU of processing waste
C.1.7 Output from the value chain
C.1.8 Imports of semi-processed material send to processing in the EU
M.2.1 Processed material send to manufacturing
D.1.1 Production of manufactured products in EU
D.1.2 Exports from EU of manufactured products
D.1.3 Imports to EU of processed material send to manufacturing
D.1.4 Manufacture waste in EU sent for disposal in EU
D.1.5 Manufacture waste in EU sent for reprocessing in EU
D.1.6 Exports from EU of manufacture waste
D.1.7 Output from the value chain
D.1.8 Imports to EU of products requiring further manufacturing steps in the EU
D.1.9 Imports of secondary material send to manufacturing in the EU
M.3.1 Manufactured products send to use in the EU
E.1.1 Stock of manufactured products in use in EU
E.1.2 Stock of manufactured products at end-of-life that are kept by users in EU
E.1.3 Exports from EU of manufactured products for reuse
E.1.4 Imports to EU of manufactured products
E.1.5 In use dissipation in EU
E.1.6 Products at end-of-life collected for treatment in EU
E.1.7 Annual addition to in-use stock of manufactured products in EU
E.1.8 Annual addition to end-of-life stock of manufactured products at end-of-life that are kept by users in EU
M.4.1 Products at end-of-life in EU collected for treatment
F.1.1 Exports from EU of manufactured products at end of life
F.1.2 Imports to EU of manufactured products at end of life
F.1.3 Manufactured products at end-of-life in EU sent for disposal in EU
F.1.4 Manufactured products at end-of-life in EU sent for recycling in EU
F.1.5 Stock in landfill in EU
F.1.6 Annual addition to stock in landfill in EU
G.1.1 Production of secondary material from post-consumer functional recycling in EU sent to processing in EU
G.1.2 Production of secondary material from post-consumer functional recycling in EU sent to manufacture in EU
G.1.3 Exports from EU of secondary material from post-consumer recycling
G.1.4 Production of secondary material from post-consumer non-functional recycling
G.1.5 Recycling waste in EU sent for disposal in EU

2.3 Changes in the data specifications

Regarding data specifications, several improvements were introduced in the background documents used for data collection and calculations, these included: 1) a detailed description of each reference used in the MSA work; 2) data prioritisation; and 3) a characterisation of the type of use of the original data.

2.3.1 Detailed description of references used

Each data point used in the calculations of the MSA flows has to be referenced. In order to obtain more information on the data used for the calculations of each MSA flow the reference section of the MSA spreadsheet was improved by incorporating the following data characterisation fields:

1. Material: name of the material under study in the MSA;
2. Reference number: number used to identify the reference within the MSA file;
3. Author: names of the authors of the reference;
4. Year: year of publication of the reference;
5. Title: title of the reference;
6. Journal/Publisher: name of the journal or the publisher responsible for the publication of the reference;
7. URL: the web address were the publication or data source can be found;
8. Last updated/last accessed: corresponds to the date of the reference version accessed by the MSA practitioner or the date of the last access to the database by the MSA practitioner;
9. Temporal Coverage: time span over which the data set described in the reference was collected or generated;
10. Geographical Coverage: describes the geographical region(s) of focus of the data collected; E.g. EU-28; Global; EU-27
11. Type of source: classifies the reference in the following categories: (1) Official data, reviewed (EU, Member States, Other); (2) Official data, not reviewed (EU, Member States, Other); (3) Scientific publications, reviewed; (4) Commercial providers, reviewed; (5) Commercial providers, not-reviewed; (6) Experts and industry associations;
12. Material Coverage: is the names of the materials covered by the reference or dataset;
13. Life-cycle stages coverage: name of the life-cycle covered by the reference.

2.3.2 Characterisation of references by source type

As already mentioned in the previous section, the references used for data collection in the MSA studies will be classified according to 6 categories:

14. Official data, reviewed (EU, Member States, Other*);
15. Official data, not reviewed (EU, Member States, Other*);
16. Scientific publications, reviewed;
17. Commercial providers, reviewed;
18. Commercial providers, not-reviewed;
19. Experts and industry associations.

*Other: may include UN Comtrade or USGS.

The objective of this classification is to understand the origin of the references and to help infer the reliability of the data described in each reference. It is important to highlight that EU official statistics e.g. Eurostat data should be prioritised as source of data for the MSA flows.

In 2015 this information was not provided in such detail, as data were classified according to the source in 2 categories: 1. Data published or data given from expert (federation, company…) and 2. Estimation or Hypothesis.

2.3.3 Characterisation of the type of use of the original data

Each data point in the MSA calculation files will now be classified according to 4 categories:

a. Direct use from original source;
b. Consistent inter/ extrapolation of a data from the original source;
c. Coherent estimate from known facts/ multiple sources;
d. Hypothesis/ expert estimate.

These criteria describe how the original reference data were used to obtain each data point and it can give an awareness of data certainty. In this sense criteria "a. Direct use from original source" would typically represent a data point with lower uncertainty and criteria "d. Hypothesis/ expert estimate" would represent a point with higher uncertainty.

The 2015 and 2017 studies used a similar classification. On these studies a score in terms of data quality was associated to each criteria. This was removed for this update of the MSA methodology because without knowing the quality of the original data or assumption it is generally not possible to infer the quality of any other processing of that data.

Additional work will be needed in the future to calculate data uncertainty using scientific methods.

3 MSA and other policy outputs

As mentioned in section 1.3, the MSA data can be used to support different policy outputs and/or policy monitoring tools. The MSA data can support (1) the development of the list of Critical Raw Materials (CRMs) (EC, 2017), (2) the development of several Raw Materials Scoreboard indicators (EC, 2018), (3) the circular economy monitoring (EC, 2018), and (4) analyses for specific strategic sectors such as the strategic action plan on batteries (EC, 2018). Such data will be included in the Raw Materials Information System (RMIS).

The EC (JRC) report "Material Flow Analysis of Aluminium, Copper, and Iron in the EU-28" (Passarini, 2018) gave a detailed list of data overlaps between the MSA and CRMs assessment and the Raw Materials Scoreboard.

To support the strategic action plan on batteries, the 2020 MSA studies have a special focus on battery raw materials[5] with the development of 5 MSA dedicated to raw materials used in batteries: cobalt, lithium, manganese, natural graphite and nickel. Although, MSA studies have a multi-sectorial coverage (among which the battery sector), revised MSA studies for battery raw materials will certainly allow to improve the existing knowledge on battery raw materials, which is a requirement highlighted in the Commission staff working document Report on Raw Materials for Battery Applications (EC, 2018). In particular, the MSA will contribute to the pillar 1 of the strategic action plan "Securing the sustainable supply of raw materials", especially in relation to mapping the current and future primary and secondary raw materials availability for batteries.

The 2020 MSA studies are developed at the same time as the criticality assessment that will define the 2020 EU list of critical raw materials[6]. With this approach it is also possible to somewhat guarantee a harmonisation of the data used between the two exercises. The majority of the flows used in the criticality assessment are related to the extraction and the processing stages. However, since the CRM assessment needs the End-of-Life Recycling Input Rate (EoL-RIR) for calculating the supply risk (Blengini, 2017), the recycling flows G1.1 and G1.2 are also important.

In turn the EoL-RIR also an indicator used for the circular economy monitoring, making the results of the MSA of relevance also for this monitoring framework. It is important to highlight that the EOL-RIR has now to be calculated taking into account the introduction of the market stages. EOL-RIR equation has to take into account the exports of primary material, B1.3; as well as the imports of semi-processed material C1.8 and secondary material in the manufacturing stage D1.9. Please see the changes in the following equation(in red):

$$\mathrm{EOL} - \mathrm{RIR\,(current)} = \frac{G1.1 + G1.2}{B1.1 - B1.3 + B1.2 + C1.3 + C1.8 + D1.3 + C1.4 + D1.9 + G1.1 + G1.2}$$

A detailed overview of the MSA flows that are important for the CRM calculations, the circular economy monitoring and raw materials scoreboard is in the annexes

[5] battery raw materials are those raw materials considered of high importance for the key production lines of rechargeable batteries. The demand for these materials is expected to rise significantly for the coming decades due to the electrification of transport, power storage, unmanned vehicles etc.

[6] Therefore, this time the work of the MSA was divided in two stages: 1st focused on the flows important for the criticality assessment and 2nd the completion of the full MSA.

With the new improvements of the methodology it will be possible to use MSA flow such as B1.1 and C1.1 to directly calculate EU domestic production and B1.3, C1.2, C1.3, D1.3, M1.1 and M2.1 to calculate import reliance at extraction and processing stages, which are important indicators for the Raw Materials Scoreboard and the CRM assessment.

4 Conclusions

This report describes several improvements proposed to the EU MSA methodology developed in 2015. The main advance proposed is the introduction of "market stages" between the different life-cycle stages. These "market stages" allow for a more explicit representation of the physical reality and the measured data. They oblige to balance trade of a material in one single stage of the material life cycle. This decreases the risk of inconsistences in the mass balances. With this improvement, it will also be possible to directly obtain the EU production and consumption after each life-cycle stage e.g. extraction, processing and manufacturing.

The MSA is a comprehensive map of EU material flows and stocks throughout the EU economy. The results are published in the RMIS. The MSA results can be used to support different policy needs, in particular to support a sustainable resource management and security-of-supply. In addition, due to its characteristic to balance material flows, it is predestined to:

- make explicit inconsistencies of data along the supply chain, and thus allow to derive prioritisation for filling data gaps/weaknesses;
- use it as backbone for mapping analyses for environmental and societal analyses along the supply chain, by extending the system.

With the proposed improvements, the MSA will be able to better represent reality and increase its usefulness in the support of current and future EU policies and monitoring.

5 Annexes

5.1 MSA and the list of CRMs

Figure 7 highlights the MSA flows that are important to the criticality assessment.

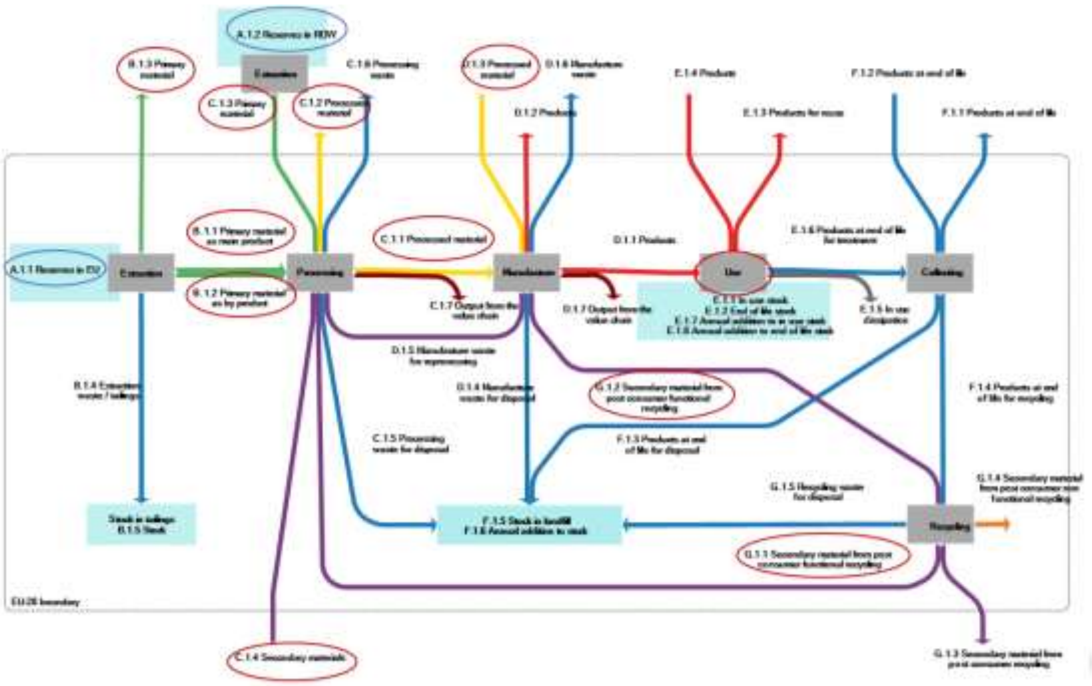


Figure 8. MSA study framework and material flows/stocks considered. Highlighted in blue flows that are needed to prepare the CRM factsheets and in red flows that are needed for both the factsheets and the CRM assessment.

The Table 3 shows the list of the flows necessary for the CRMs assessment and the corresponding CRM indicator.

One of the main results of the MSA studies is the division of the material consumption between different EU manufactured products, which directly relates to the CRM assessment's Economic Importance.

Additionally, the CRM assessment requires the disaggregation per country of flows C1.3 and D1.3. Therefore, the MSA data collection files now also include this information.

With the methodological improvements, information on EU sourcing can bedirectly obtained from the MSA flows information on EU sourcing (EU production of primary material and/or EU production of processed material) and apparent EU consumption of a material, which is in turn important to calculate import reliance.

Table 3. List of MSA flows used in the CRM assessment and the correspondent indicator.

MSA Flow	Use in the CRM assessment for calculating:
B.1.1 Production of primary material as main product in EU sent to processing in EU	Global production of primary material, EU Sourcing, Import reliance and EoL-RIR
B.1.2 Production of primary material as by product in EU sent to processing in EU	Global production of primary material, EU Sourcing, Import reliance and EoL-RIR
B.1.3 Exports from EU of primary material	Import reliance and EoL-RIR
C.1.1 Production of processed material in EU sent to manufacture in EU	Global production of processed material, EU Sourcing, Import reliance and EoL-RIR
C.1.2 Exports from EU of processed material	Import reliance and EoL-RIR
C.1.3 Imports to EU of primary material	EU Sourcing, Import reliance and EoL-RIR
C.1.4 Imports to EU of secondary material	EoL-RIR
D.1.3 Imports to EU of processed material	EU Sourcing, Import reliance and EoL-RIR
G.1.1 Production of secondary material from functional recycling in EU sent to processing in EU	EoL-RIR
G.1.2 Production of secondary material from functional recycling in EU sent to manufacture in EU	EoL-RIR
M.1.1 Material sent for processing in the EU	Import reliance
M.2.1 Processed material sent to manufacturing	Import reliance

5.2 MSA and the circular economy monitoring

One important output of the MSA are the flows that are used in the calculation of the End-of-Life Recycling Input Rate (EoL-RIR). This is an indicator of the circular economy monitoring framework and is given by the following equation (taking into account the MSA flows described in Figure 1):

$$\text{EOL} - \text{RIR (current)} = \frac{G1.1 + G1.2}{B1.1 + B1.2 + C1.3 + D1.3 + C1.4 + G1.1 + G1.2}$$

The EC(JRC) report "Towards Recycling Indicators based on EU flows and Raw Materials System Analysis data" (Talens Peiro L., 2018) gives a detailed description of the flows that are necessary for calculating this important indicator. This is represented in Figure 8 taken from the same report. Figure 8 shows also the interactions of EU processing and recycling flows with extra-EU countries in the definition of EoL-RIR.

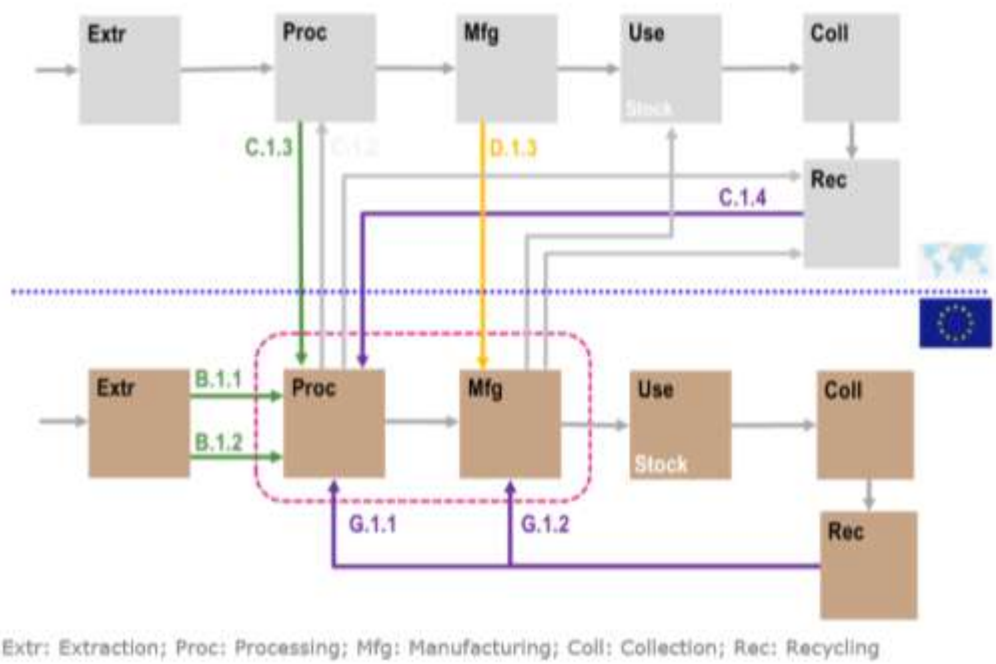


Figure 9. System boundaries and material flows included in the calculation of the EOL-RIR. (Talens Peiro L., 2018).

Table 4 shows other data links between the circular economy monitoring framework and the MSA studies.

With the changes in the MSA methodology the EOL-RIR equation has to take into account the exports of primary material, B1.3; as well as the imports of semi-processed material C1.8 and secondary material for manufacturing D1.9:

$$\text{EOL} - \text{RIR (current)} = \frac{G1.1 + G1.2}{B1.1 - B1.3 + B1.2 + C1.3 + C1.8 + D1.3 + C1.4 + D1.9 + G1.1 + G1.2}$$

Table 4. List of MSA flows that can be used in the calculations of the some of the circular economy monitoring framework indicators

MSA Flows	**Circular economy monitoring framework indicator**
B.1.1 Production of primary material as main product in EU sent to processing in EU	EU self-sufficiency for raw materials, EoL-RIR
B.1.2 Production of primary material as by product in EU sent to processing in EU	EU self-sufficiency for raw materials, EoL-RIR
B.1.3 Exports from EU of primary material	EU self-sufficiency for raw materials, EoL-RIR
C.1.1 Production of processed material in EU sent to manufacture in EU	EU self-sufficiency for raw materials, EoL-RIR
C.1.2 Exports from EU of processed material	EU self-sufficiency for raw materials, EoL-RIR
C.1.3 Imports to EU of primary material	EU self-sufficiency for raw materials, EoL-RIR
C.1.4 Imports to EU of secondary material	Trade in recyclable raw materials, EoL-RIR
D.1.3 Imports to EU of processed material	EU self-sufficiency for raw materials, EoL-RIR
G.1.1 Production of secondary material from functional recycling in EU sent to processing in EU	EoL-RIR
G.1.2 Production of secondary material from functional recycling in EU sent to manufacture in EU	EoL-RIR
G.1.3. Exports from EU of secondary material from post-consumer recycling	Trade in recyclable raw materials
M.1.1 Material sent for processing in the EU	EU self-sufficiency for raw materials
M.2.1 Processed material sent to manufacturing	EU self-sufficiency for raw materials

5.3 MSA and the Raw Materials Scoreboard

For the Raw Materials Scoreboard, considering its last edition in 2018 and with a view to the 2020 edition under development, the main indicators which show potential data overlaps with the MSA flows are:

3. Import reliance. This indicator presents data on import reliance over time by material category, based on Eurostat's economy-wide material flow accounts (EW-MFA); and import reliance for selected materials, based on the 2017 Study on the list of Critical Raw Materials. Import reliance is computed as the ratio between net imports (imports minus exports) divided by apparent domestic material consumption.

6. Domestic production. This indicator presents data on extraction of raw materials in the EU over time by material category, based on data from United Nations Environmental Programme International Resource Panel (IRP-UNEP)[7]. It also presents data on production over time of a selection of metals (aluminium, zinc, iron and steel and copper) at different production stages, based on World Mineral Statistics data provided by the British Geological Survey[8].

12. Mineral exploration. This indicator presents data on mineral exploration activities in the EU, based on data from S&P Global Market Intelligence. It also depicts mineral deposits, occurrences and showings in the EU-28, based on BGRM 2010 data from the ProMine project[9].

15. Material flows in the circular economy. This indicator shows material flows by material category through the EU-28 economy in 2014, in line with the COM(2018)29 final ''Monitoring Framework for the Circular Economy', developed by Mayer et al. (2019)[10].

16. Recycling's contribution to meeting materials demand. This indicator presents data on EOL-RIR as indication of the end-of-life recycling's contribution to the EU's demand for the candidate raw materials assessed in the 2017 EU criticality assessment[11]. EOL-RIR values come from the material flow data from Bio by Deloitte, 2015, 'Study on Data for a Raw Material System Analysis: Roadmap and Test of the Fully Operational MSA for Raw Materials'. For materials for which no material system analysis (MSA) studies are available, data are directly taken from COM(2017)490 final.

18. Trade in waste and scraps. This indicator presents data on exports and imports over time to and from non-EU countries and intra-EU trade of various waste and scraps flows, specifically 'iron and steel', 'copper, aluminium and nickel', 'precious metals' and 'paper and cardboard'. It also presents data on exports and imports in volume and value units for all waste and scrap categories listed before, except for precious metals. All data comes from Eurostat data (Comext). This indicator has been included among those for the circular economy monitoring framework.

[7] http://www. resourcepanel.org/reports/global-material-flows-and-resource-productivity-database-link.

[8] https://www.bgs.ac.uk/mineralsuk/statistics/ wms.cfc?method=searchWMS. Production at mining stage refers to domestic primary production, the production of processed and refined materials may also include imported and secondary raw materials.

[9] http://promine.gtk.fi/,

[10] https://onlinelibrary.wiley.com/doi/full/10.1111/jiec.12809

[11] COM(2017)490 final. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. 'On the list of critical raw materials 2017'

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KJ-NA-30091-EN-N

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doi:10.2760/374178

ISBN 978-92-76-10734-7