Material System Analysis of five battery-related raw materials: Cobalt, Lithium, Manganese, Natural Graphite, Nickel

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- Cristina Torres de Matos (Joint Research Centre - European Commission) coordinated the work and prepared the report;

- Luca Ciacci (University of Bologna) led the MSA for manganese, natural graphite and nickel;

- María Fernanda Godoy León and Jo Dewulf (Ghent University) led the MSA for cobalt;

- Maren Lundhaug and Daniel B. Müller (Norwegian University of Science and Technology) led the MSA for lithium;

- Konstantinos Georgitzikis and Dominic Wittmer (Joint Research Centre - European Commission) reviewed the MSAs and the report;

- Fabrice Mathieux (Joint Research Centre - European Commission) helped coordinating the work and reviewed the report.

Abstract

The transition to a climate-neutrality is expected to boost the demand for batteries in the coming years. If the EU wants to be competitive in the global market of battery manufacturing it has to ensure a sustainable, secure supply of raw materials needed for the batteries value chain. Therefore, reliable systemic information on recent availability of these raw materials within the EU economy is crucial to identify hotspots and define ways to secure their sustainable supply. Material System Analysis (MSA) can provide crucial information for the recent past on sustainable resource management, including the provision of evidence to inform policy decision-making on the sustainable and competitive supply of e.g. battery raw materials.

This report focuses on the MSA studies of five selected materials used in batteries: cobalt, lithium, manganese, natural graphite, and nickel. It summarises the results related to material stocks and flows for each material. The MSA studies, were performed for five consecutive reference years, i.e. from 2012 to 2016. This report however presents only the MSA results for 2016. Priority has been given to official and publicly available data sources. Because of their importance for the future battery value chain in Europe, the five MSA have been harmonised considering the latest available datasets publicly available on batteries stocks and flows (update from the ProSum database).

The five battery-related materials analysed show a very strong reliance on imports along the value chain. In particular the material systems are all highly dependent on imports of primary and/or semi-processed materials. The EU self-sufficiency was analysed separately for each stage. For the extraction stage, natural graphite had the lowest value of EU self-sufficiency in 2016 (less than 1% of the amount used in manufacturing was extracted in the EU), while nickel had the highest (37% of nickel in its primary forms was extracted in the EU). For the EU manufacturing stage, 75% of the products containing cobalt and lithium consumed in the use stage were produced in the EU, in 2016. On the other hand, the EU manufacturing of manganese, natural graphite and nickel products was self-sufficient to satisfy the EU consumption and supplying the external market.

For all these materials the functional recycling of old scrap is still low and under development in the EU. Cobalt has the highest end-of-life recycling input rate (EOL-RIR) with 22%, while for lithium, this rate is close to 0%. This indicates that the EU is currently able to only slightly decrease its dependency on primary material using secondary materials recycled domestically.

For the period covered by the MSA (2012-2016), results confirm that battery manufacturing has not been a dominant application. Based on the strong promotion of clean technologies, the demand for these raw materials is expected to multiply. As a consequence, imports of these materials will intensify, as domestic processing and manufacturing increases. The situation is however less clear for the net balance of the final products (containing these materials). In the coming years, the expansion in EU capacity to produce significant amounts of batteries and related final products will determine industry's competitiveness on the world battery market.

1 Introduction

The transition to a climate-neutral economy is expected to boost the demand for batteries in the coming years. The European Commission identified the battery value chain as strategic element to achieve European Union (EU) goals in terms of climate neutrality and competitiveness of the EU industry (European Commission, 2019). In a recent report, the European Commission quantified the expected 2030 and 2050 EU's fast growing needs of several battery-related raw materials for electric vehicle batteries and energy storage, considering 2019 climate-neutral scenarios (European Commission, 2020a). The recent tightening of the EU greenhouse emissions targets (Van der Leyen, 2020) is likely to accelerate further the transition to climate-neutral systems and hence the need for batteries. In 2019, the battery manufacturing in the EU was only 3% of the global production. For the EU to be competitive in the global market of battery manufacturing, it has to ensure the supply of raw materials (RM) used in the batteries. Therefore, information on the current and future availability of these raw materials within the EU economy is crucial to define ways to secure their sustainable supply.

In order to develop the raw materials knowledge base planned in the Raw Materials Initiative (European Commission, 2008), the European Commission launched in 2012 the Study on Data Needs for a Full Raw Materials Flow Analysis and that produced the Material System Analysis (MSA) methodology (Bio by Deloitte, 2015). MSA is a methodology that investigates the stocks and flows of materials through the EU economy[1]. It analyses the materials along the overall supply chain, from extraction until end-of-life management e.g., through recovery or disposal.

MSA can provide crucial information on sustainable resource management, including the provision of evidence to inform policy decision-making on the sustainable and competitive supply of e.g. battery raw materials. In this way, MSA represents a solid pillar to support several policy actions on RM:

(1) the development of the list of Critical Raw Materials (European Commission, 2020b),
(2) the development of several indicators of the Raw Materials Scoreboard (European Commission, 2018a),
(3) the monitoring of the circular economy (European Commission, 2018b),
(4) the analysis of specific sectors such as in the context of the strategic action plan on batteries (European Commission, 2018c), and
(5) the provision of fundamental inputs to social and environmental assessments including e.g. life cycle assessments, carbon footprints, etc.

The first series of 28 MSA studies was published in 2015 (Bio by Deloitte, 2015) covering 28 materials and the second series in 2018 covering three materials (Passarini et al., 2018). The focus of the previous MSA studies for the EC was on candidates for the list of critical raw materials (CRMs); i.e. materials with a high risk of supply disruption and a high economic importance (Blengini et al., 2017). As the list of CRMs is under revision every 3 years (European Commission, 2011; 2014; 2017; 2020) new candidates were considered while new raw materials have entered the list over time, and others have left it. Additionally, some of the raw materials experienced rapid developments in their usage over last years and have become particularly important for strategic sectors in the EU. For example, the storage of energy is an emerging technology with high relevance to the EU industrial base, including dual use applications (Blagoeva et al., 2019). Therefore, batteries are considered a strategic sector for the EU.

This report focuses on five selected materials that are key components for today and future batteries: cobalt, lithium, manganese, natural graphite, and nickel. All of them, except nickel, were mentioned in the Strategic Action Plan on Batteries (European Commission, 2018c) as priority raw materials under the pillar "secure access to raw materials".

The current study updates the MSA of cobalt, lithium and natural graphite that were performed for the first time in 2015 (Bio by Deloitte, 2015), whereat for manganese and nickel the study performs the analyses for the first time. Up-to-date MSA provides valuable knowledge of these material flows in the EU context.

[1] Material Flow Analysis (MFA) or Substance Flow Analysis (SFA) are core methods of Industrial Ecology. The MSA is a specific type of static MFA where the system border is the overall EU.

1.1 MSA methodology

The MSA methodology was developed and published for the European Commission (EC) with an EU scope in 2015 (Bio by Deloitte, 2015) and has been revised in 2020 (Torres de Matos et al., 2020). The MSA applies the basic principles of Material Flow Analysis (MFA) on the EU, namely the systems approach and the mass balance (on system and process level).

MSA maps and quantifies raw or advanced materials along their overall life cycle in the European Union, including: extraction, processing, manufacturing, use, collection, recycling, reuse and disposal. Additionally, it accounts for the relevant material stocks in:

1) tailings;
2) landfills;
3) products in the use phase,
4) domestic reserves, and
5) foreign reserves (see blue boxes in Figure 1)

Figure 1 shows the MSA system, with detail of the flows and stocks considered. They are listed in Annex 1.

In comparison with the MSAs performed in 2015 the current MSA methodology allowed to increase the resolution of the MSA system as described in Torres de Matos et al., 2020 and presented in Figure 1. Additionally, for the case of cobalt new data on trade of semi-processed material was analysed considering the following trade codes: 81052000, 75011000, 75030090 (see Table A3 in Annexes). For lithium the data is presented in tonnes of Li while in 2015 it was presented in Lithium Carbonate Equivalent (LCE) and new information was collected using the available statistics. Additionally, in the current exercise the project team privileged public available data and official statistics, while in the 2015 some flows were estimated based on stakeholders communications.

1.2 Approach followed by the project team

The MSA studies of each individual material were performed according with the following distribution (see Table 1). The JRC coordinated the work done and assembled the current report. Because of their interrelations, in particular for batteries, the work for each raw material was regularly aligned with the four others.

Table 1. Distribution of the MSA studies between the experts involved in the work

Raw Material	**Author**
Cobalt	María Fernanda Godoy León and Jo Dewulf Ghent University
Lithium	Maren Lundhaug and Daniel Beat Müller Norwegian University of Science and Technology
Manganese	Luca Ciacci, University of Bologna
Natural Graphite	Luca Ciacci, University of Bologna
Nickel	Luca Ciacci, University of Bologna

The MSA studies, were performed by experts for five consecutive reference years, from 2012 to 2016, taking the EU (without the UK) as the system boundary. Priority has been given to official and publicly available data sources. This report summarises for each material the flows and stocks of the year 2016.

The detailed calculations and the results for the full period covered (2012-2016) are stored in MSA excel files retained by the European Commission.

The first draft of the complete MSA studies was presented in a workshop were several raw material experts were allowed to comment and discuss the MSA results, as described in section 1.2.1.

After the workshop a harmonisation of the battery flows was performed for all battery raw materials as described in section 1.2.2.

1.2.1 Validation workshop

From 10 to 12 September 2019 an expert workshop was organised by the SCRREEN project together with DG GROW and the JRC to support the 2020 EU criticality assessment and material system analysis. The main goals were to: 1) validate the data and data sources used in both studies; 2) exchange data, information and knowledge on the target raw materials.

A dedicated section on battery raw materials was organised in the second day of the workshop for the following materials: cobalt, lithium, natural graphite, manganese and nickel. The draft MSA excel files and reports were distributed to the participants before the workshop and the related/draft results were presented in the workshop, followed by discussion. The comments received during and after the workshop were addressed, resulting in the revised version of the calculations and reports. A list of the experts attending the workshop is provided in Annexes.

1.2.2 Harmonisation of the battery flows

During the development of the MSA studies presented in this report the project team faced several challenges related to data availability, which are summarised in the following chapters. In particular it was difficult to define the flows of each raw material for the manufacturing, use and collection of batteries. EU statistical data on trade and production of batteries was not available and several assumptions had to be taken.

For harmonisation of the partially joint battery flows, a common approach was followed for all the battery materials using a dataset updated from the Horizon 2020 ProSUM project and made available in RMIS in November 2019 (RMIS/ProSUM, 2019). This dataset provided for each material the amount in batteries that: 1) is “placed on the market” (POM) in the use phase each year i.e. input to the use phase; 2) is stored in the use phase (physical stock in use, including “hibernating”), and 3) leave the stock in use each year as waste. The inputs / stocks / outputs structure of the dataset makes it particularly adapted to the MSA context.

The ProSUM data was then used to calculate the flows for the battery in the use phase. Table 2 shows the correspondence between ProSUM data and MSA flows.

Table 2. Correspondence between ProSUM data and MSA flows

ProSUM data	MSA flows
Place on the Market	M.3.1 Manufactured products send to use in the EU
Stock	E.1.1 Stock of manufactured products in use in EU and E.1.2 Stock of manufactured products at end-of-life that are kept by users in EU
Waste	E.1.6 Products at end-of-life collected for treatment in EU and E.1.3 Exports from EU of manufactured products for reuse
Stock Change	E.1.7 Annual addition to in-use stock of manufactured products in EU and E.1.8 Annual addition to end-of-life stock of manufactured products at end-of-life that are kept by users in EU

Additionally, the same assumptions and data sources were used to calculate the flows of manufacturing, collection and recycling. All the battery flows were calculated for the following product categories: portable batteries, mobility batteries; e-bikes and industrial batteries.

The RMIS/ProSum dataset used integrates a variety of data sources, which were updated and combined to get a comprehensive picture on the overall battery flows entering the European market. Industrial data originating from the market research firm Avicenne on the volumes of rechargeable batteries were combined with information sourced from Eurostat and European Alternative Fuels Observatory (EAFO). These are linked with statistics from several national authorities as well as with the ProSUM data for batteries contained in electronic equipment. The extensive data structure takes into account average battery lifetimes to calculate trends of the battery stocks and related waste generation. In combination with expert interviews, the chosen approach allows for a detailed differentiation between electrochemical systems and battery applications of portable, industrial, and automotive batteries. Calculation of the stocks and flows of critical raw materials (CRMs) and other metals are made by using composition data for 20 elements, including of course cobalt, lithium, manganese, graphite and nickel.

Following this alignment, final versions of the calculations and reports were produced, which are summarised in this report.

The five following chapters report the main findings of the MSA of cobalt, lithium, manganese, natural graphite and nickel, using a consistent structure. Chapter 7 draws conclusions on these MSA.

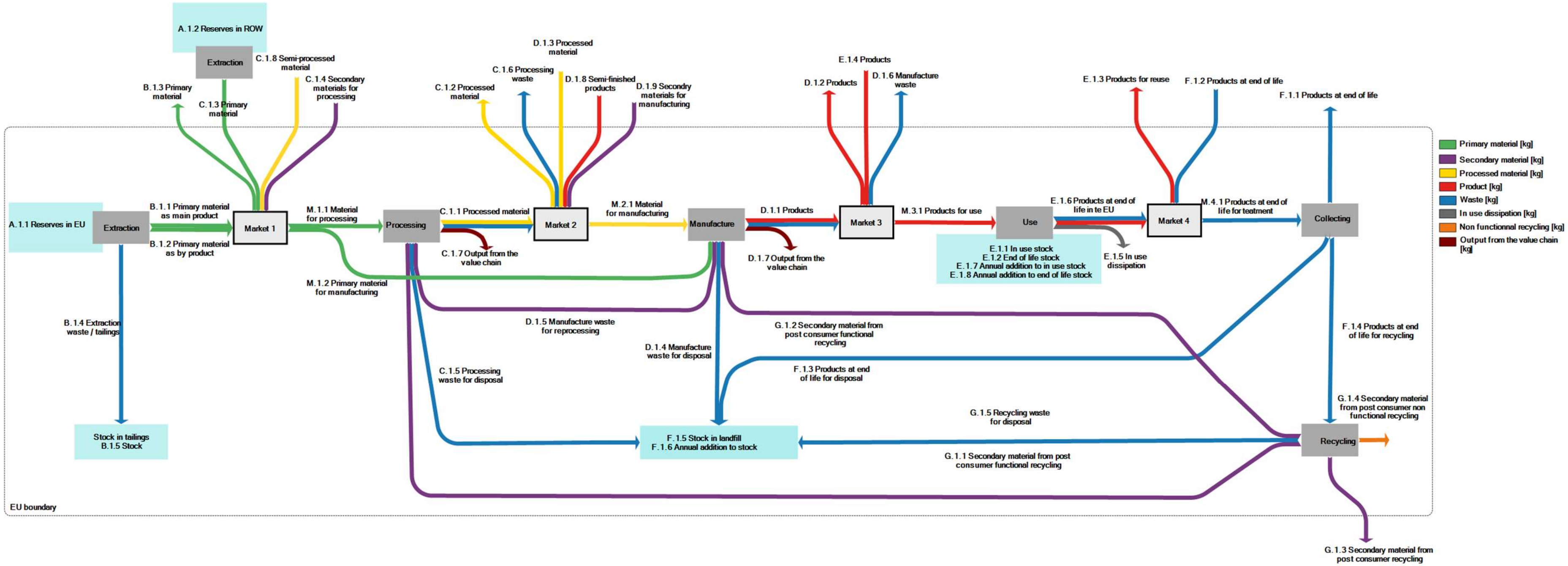

Figure 1: MSA system with all the processes (material life cycle stages), flows and stocks considered in a MSA. The system border is the geographical border of the EU (without the UK).

2 Material system analysis of Cobalt

2.1 Value chain

Cobalt (Co) is a transition metal not abundant in the Earth's crust. Cobalt is mainly obtained as a by-product of nickel and copper, and it is usually concentrated at the extraction site before being traded. According to the Cobalt Institute (CI), about 50% of cobalt production originates from nickel ores, 44% from copper ores and 6% from primary cobalt production. Common ores of cobalt are cobaltite, erythrite, carrollite, and skutterudite ((European Commission, 2017); (Cobalt Institute, 2019a)).

The concentrated ores of cobalt are refined through various processes into a variety of forms: intermediate cobalt products (e.g. cobalt-containing mattes, crude cobalt hydroxide), products of refined cobalt metal (e.g. cathodes, briquettes, ingots, granules, and powder) and refined cobalt chemicals (e.g. cobalt chloride, cobalt oxide, cobalt hydroxide, cobalt salts).

The present analysis includes all cobalt forms used in the EU economy. Cobalt is used for the production of chemical compounds employed in: i) rechargeable batteries for electric vehicles, e-bikes, laptops, phones, medical devices, cordless tools; ii) pharmaceutical applications; iii) biogas refining; iv) pigments, paint driers, trace metal additives for agricultural and medical use; and iv) catalysts for petroleum refining, polyester precursors, and hydroformylation and gas to liquids (GTL) process. Regarding metallurgical applications, cobalt is used in: i) superalloys for aeronautic applications; ii) wear/corrosion resistant alloys; iii) prosthetics, medical, and dental alloys; iv) high speed steels; v) hard metals for metal tooling (e.g. diamond tools, drills and cutting tools, grinding tools, hot rolls, rotary cutters, can tooling, metal forming tools); and vi) magnets. Specific cobalt substances are used for particular end-uses in order to provide very specific performance and end-user product characteristics.

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

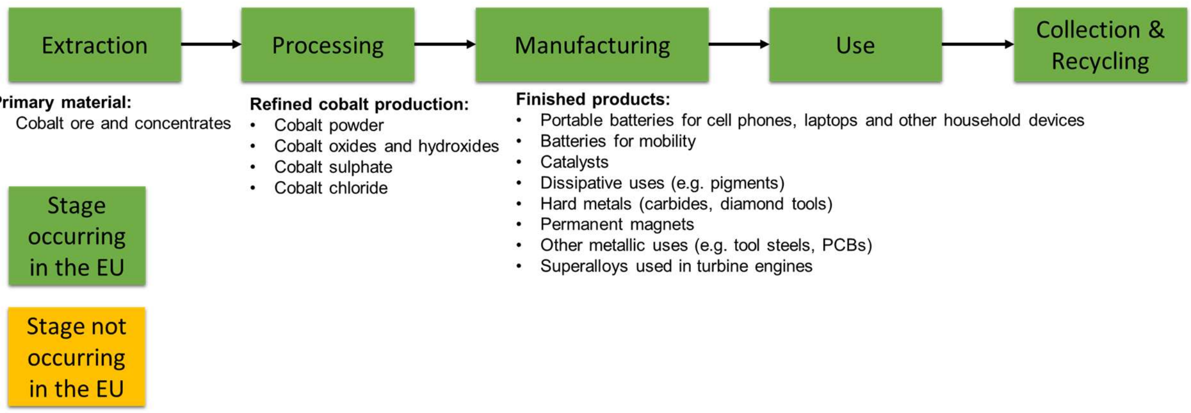

Figure 2. Value chain of cobalt, steps in green occur in the EU, steps in orange occur only outside of the EU

2.2 Description of the main flows and stocks

Flows and stocks are accounted in mass of cobalt (kt Co) and are representative of the year 2016. 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.

World resources of cobalt are estimated around 25,000 kt of cobalt, with around 7,000 kt of cobalt reserves worldwide (Shedd, 2017). Additional over 120,000 kt could exist in manganese nodules and crusts on the floor of the Atlantic, Indian, and Pacific Oceans. In the EU the reserves are estimated as 35.1 kt of cobalt (Minerals4EU, 2014).

The world annual production of mined cobalt was around 126 kt Co in 2016, and the main producer country is the Democratic Republic of Congo, accounting for 55% of the global production in 2016. China, Canada and New Caledonia account for 8%, 6% and 5% respectively of the world mine production (WMD, 2019).

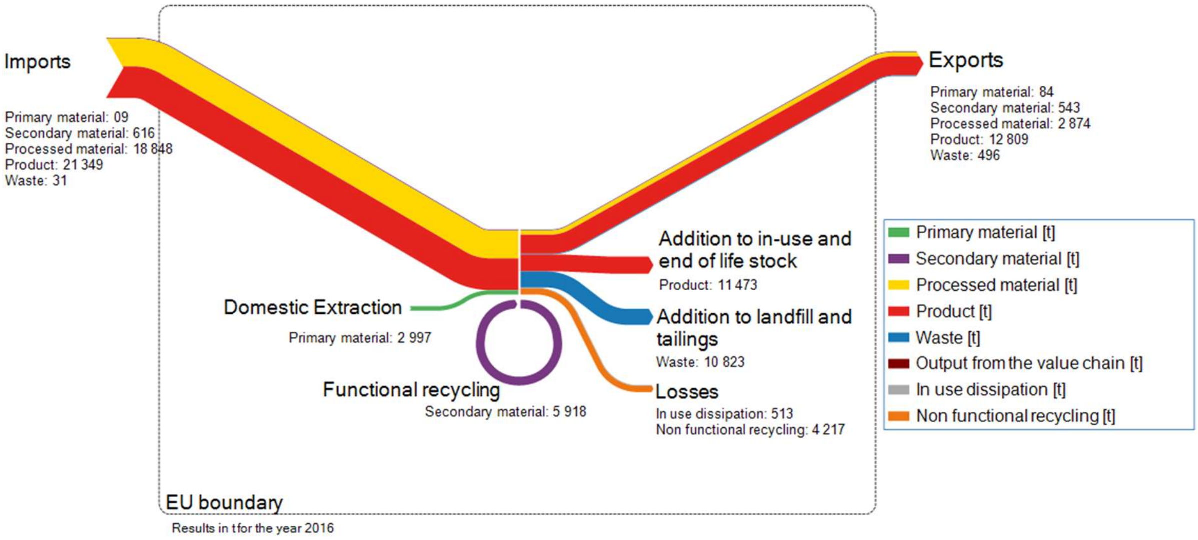

Figure 3. Simplified Sankey diagram of the flows of cobalt in the EU (without the UK), the imports of processed material include 10.3 kt of semi-processed material and 8.5 kt of processed material.

3 kt Co in cobalt concentrates were extracted from domestic mines (in Finland) in 2016. At the same time, mining activities disposed of 0.7 kt Co in tailings.

The EU imported 0.009 kt of cobalt in concentrates, 0.6 kt of Co secondary material, and 10.3 kt of Co in intermediates (semi-processed materials, mainly crude cobalt hydroxide and Co-containing mattes) mainly from the Democratic Republic of the Congo. These imports together with the Co domestically extracted and recovered from new and old scrap supplied the processing industry, which produced a total of 14 kt of refined cobalt in Finland, Belgium and France. With the refined cobalt produced in the EU and imported (imports of refined cobalt were around 8.5 kt Co in 2016, in addition to the 10.3 kt of semi-processed material), the European industry manufactured various finished products containing around 24 kt of cobalt, which consisted mainly of superalloys (8.5 kt of Co), various products for dissipative uses (7 kt of Co) (e.g. tyre adhesives, paint dryers, ceramics and pigments), hard metals (3.3 kt of Co) and catalysts (2.8 kt) (see Figure 4 – left). Batteries represented only 3% of the EU manufacturing demand (0.6 kt), mainly for the production of e-mobility batteries. After considering imports of finished products (around 21 kt of Co content) and exports (around 13 kt of Co content, see Figure 3), the EU total consumption of products containing cobalt amounted to about 33 kt in 2016 (see Figure 4 – right). In the use phase 9% of cobalt was embedded in portable batteries and smaller shares in mobility and industrial batteries (3 and 1% respectively).

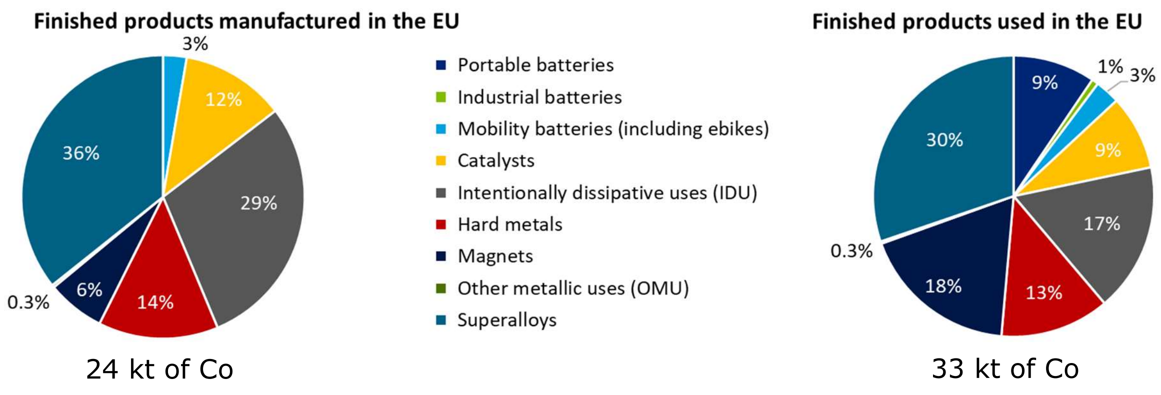

Figure 4: Shares of finished products containing cobalt manufactured in the EU (left) and shares of finished products containing cobalt used in the EU (right), by application.

The quantity annually entering the in-use stock was estimated at around 11.5 kt of cobalt (see Figure 3). This accounts for the annual addition to the in-use stock and to the 'hoarded' or 'hibernating' stock[2]. About 0.7 kt of cobalt left the stock as exports of products for reuse, 0.5 kt Co were dissipated in use (presented in Figure 3 as losses), and around 20 kt Co were available in end-of-life products available for treatment.

[2] Stocks of products at its end-of-life still kept by the users.

Batteries for electric vehicles and superalloys are recycled in significant proportion at their end of life. However, batteries for consumer electronics, hard metals for metal tooling, and catalysts are collected and recycled in lower proportion at their end-of-life, because collection is less efficient. Pigments and other dissipative applications (e.g. chemicals for pharmaceuticals) are not recyclable. Magnets and metallic applications such as semi-conductors and printed circuit boards are not-functionally recycled[3]. As a result, a total amount of around 6.4 kt Co (considering also the amount exported) was functionally recycled in 2016 in the EU (see Figure 3). Non-functional recycling, considered as losses in Figure 3, accounted for around 4 kt of cobalt, mainly in the production of steel (European Commission, 2017). The remainder of the cobalt-bearing scrap (about 11 kt Co) was disposed of and considered as addition to landfill in Figure 3.

2.3 Indicators

Table 3 summarises recycling and EU self-sufficiency indicators.

Nearly 60% of Co was collected. The ratio of recycling from old scrap to EU demand for cobalt in the manufacturing stage (end-of-life recycling input rate (EOL-RIR)) resulted in 22%, while the ratio of functional recycling of old scrap and cobalt collected resulted in 32% (end-of-life recycling rate (EOL-RR)). Cobalt losses in waste, downcycling and net-export of recycled cobalt prevent the existence of more close-loop material flows in the EU, despite respectable end-of-life recycling rates in some of the applications (e.g. superalloys). Other applications such as magnets and other alloys containing cobalt are predominantly recycled into stainless steel and the cobalt content is not recovered (European Commission, 2017). As mentioned before, there are applications from which cobalt is dissipated during use (0.5 kt of Co), for example pigments, glass, and paints (Harper et al., 2012).

Regarding self-sufficiency the EU relies on imports for all the stages, in particular for the extraction stage. In 2016 only 18% of cobalt was extracted in the EU. For the processing and manufacturing stages the EU self-sufficiency is lower than 72%, which means that the EU requires additionally nearly 30% of imports to fulfil the EU demand in these two stages.

For the five years analysed there was no substantial change for recycling indicators and for the EU self-sufficiency in the extraction stage. A decrease of almost 10% was observed for the self-sufficiency in the processing and manufacturing stages, which can be explained by the recent increase in demand of cobalt for all the applications.

Table 3: Different indicators *that describe cobalt situation in the EU.*[4]

Indicator	Formula	2012	2013	2014	2015	2016
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	17%	18%	21%	21%	22%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	33%	33%	30%	30%	32%
Collection Rate	F1.4/(M4.1)	55%	55%	60%	60%	60%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	14%	20%	16%	21%	18%
Self-sufficiency Processing	C1.1/M2.1	83%	80%	72%	62%	72%
Self-sufficiency Manufacturing	D1.1/M3.1	80%	79%	72%	72%	72%

2.4 Data sources, assumptions and reliability of results

A number of data sources were consulted for the development of the MSA of cobalt. The main data sources are the Eurostat Comext database (Eurostat 2019a), Eurostat PRODCOM database (Eurostat 2019b), Cobalt Institute (Cobalt Institute, 2019a and 2019b), the British Geological Survey (Petavratzi et al., 2019), the United States Geological Survey, the French Geological Survey (BRGM) and the Geological Survey of Finland. Data were

[3] Cobalt that is recycled to other products than the ones considered in Figure 3, where it will not have the same function. This means that this recycling will not decrease the demand for primary Co in manufacturing.

[4] These recycling rates were calculated considering that 100% of the collected superalloys are recycled. However, these values can vary. According to the National Research Council (1983), around 80% of the collected superalloys are recycled (20% is disposed). In addition, according to Reck and Graedel (2012), around 80% is functionally recycled. Considering these numbers: EOL-RIR=19%, EOL-RR=between 22 and 25%.

also obtained from private markets review reports by private companies, from scientific papers and public reports (e.g. Harper et al., 2012; Asari and Sakai, 2013; Nomura and Suga; 2013; Baldé et al., 2017; RMIS/ProSUM, 2019; thinkstep AG, 2017).

The trade statistics for cobalt intermediate commodities was incomplete since no data was reported for some key countries such as Finland. However, using alternative sources e.g. UN Comtrade database and Finnish customs database (ULJAS, 2019) it was possible to estimate a trade balance for semi-processed cobalt at about 10 kt, in order to close the mass balance between the extraction phase and the processing phase.

From the manufacturing step to the recycling step, the flows and stocks of cobalt are calculated based on trade statistics of finished products, average lifespan of products, and collection and recycling practices. This means that the results for the steps of use, collection and recycling have high uncertainty. For the recycling phase in particular, the amount of cobalt that is functionally or non-functionally recycled is highly influenced by the market price.

A list of commodities containing cobalt is provided in the annexes (Table A2 in Annexes).

3 Material system analysis of Lithium

3.1 Value chain

Lithium comes from three main sources, brines, hard rock and clay. Brine and hard rock are currently the most mined from the three (Brown et al., 2016; Gunn, 2013). Due to lithium's high reactivity it can only be found in nature in the form of compounds such as silicates, which are found in igneous rocks and mineral clay, and chlorides which are found in brines (Gunn, 2013).

Lithium has a variety of end uses, with the two currently largest end uses being li-ion batteries and glass and ceramics, accounting in 2016 for approximately 70% of the global use of lithium. For the EU, approximately 90% of the lithium are used for these two purposes, see Figure 7. The majority of end uses of lithium are dissipative, meaning that it is not possible to recycle (Ciacci et al., 2015). Currently, recycling is only considered feasible from li-ion batteries. But here, lithium is currently facing both technical and economic challenges due to its high reactivity and relatively low price of virgin material. The value chain of lithium is presented below.

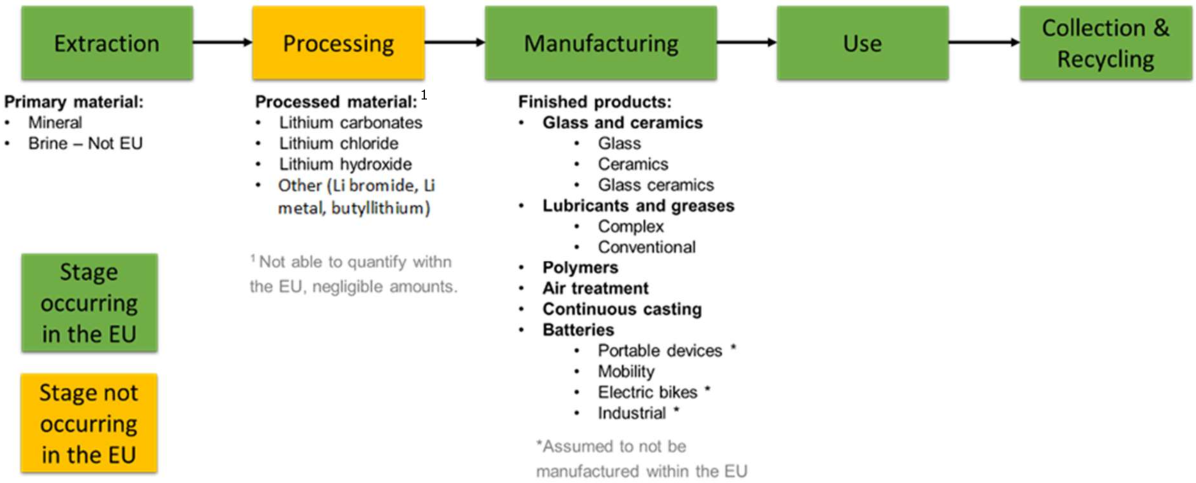

Figure 5. Value chain of lithium, steps in green occur in the EU, steps in orange occur only outside of the EU.

3.2 Description of the main flows and stocks

The flows and stocks of lithium are accounted in mass of elemental lithium (kt Li) and are representative of the year 2016.

Global lithium reserves are estimated to be over 13 million tonnes in 2018. The largest reserves, approximately 70% lies within the lithium triangle (Chile, Bolivia and Argentina) in the form of brines. The estimated total resources are between 45 and 62 million tonnes (Christmann et al., 2015; Jaskula, 2018). The largest producers are Chile followed closely by Australia, both producing around 1.3 million tonnes of lithium in 2016. The lithium triangle accounted for over 50% of the total world production.

The refining route of lithium is complex and highly globalised. Lithium resources are mainly found in South America (brine) and Australia (mineral), but the majority of refining occurs in Asia (International Energy Agency, 2019; Rohstoffagentur in der BGR, 2017). World production in 2016 was estimated to be 38 kt of lithium, however the actual global refining capacity is of 58 kt Li (Jaskula, 2018). The EU was the world's second largest lithium consumer with 21% in 2016, only surpassed by China consuming 40% (Jaskula, 2018). In 2016 approximately 4 kt of lithium was placed on the EU market.

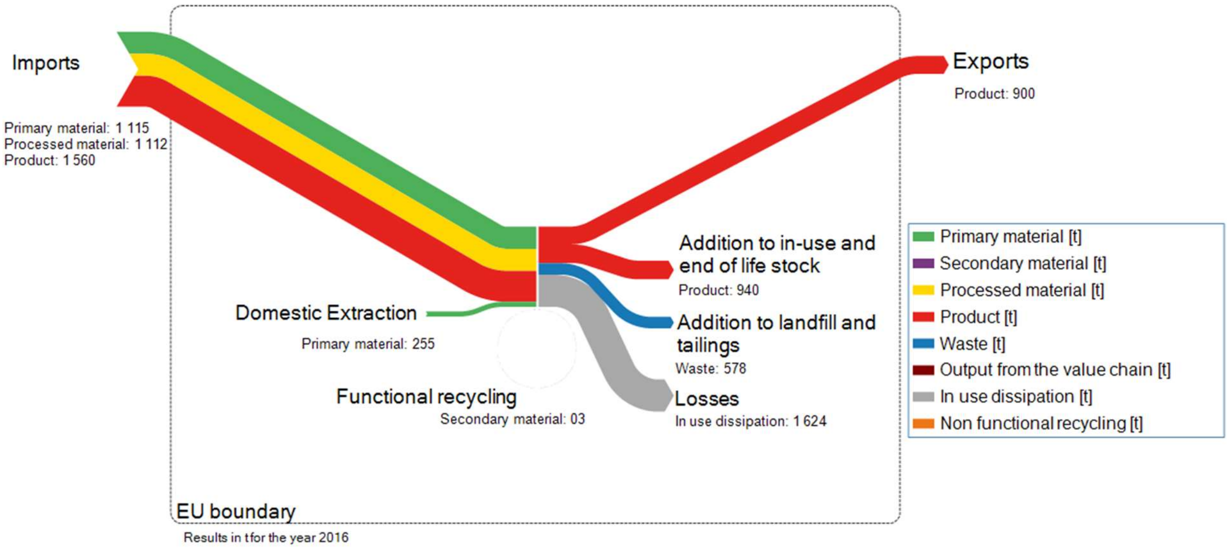

Figure 6. Simplified Sankey diagram of the flows of lithium in the EU (without the UK).

Portugal is the only country in the EU currently mining lithium, accounting for 0.5% of the world production (WMD, 2019). Lithium resources are also found in Czechia, Austria, Spain, France, Germany, Finland and Ireland in the form of different lithium bearing minerals. A recent study estimated a total of over 8 million tonnes of Li_2O available from identified hard rock deposits, in the EU (Gourcerol et al., 2019).

The domestic EU supply of 0.3 kt Li (see Figure 6) from Portugal is directly used in glass and ceramics manufacturing, filling 17% of the in-use demand in this sector. All the lithium required for other applications and the remaining demand of the EU glass and ceramics sector are imported. As reported in Figure 6, in 2016, the EU imported 93% of its total demand of lithium. These imports were 1.1 kt Li of lithium in its primary forms used directly in the manufacturing of glass and ceramics. Manufacturing was also supplemented with 1.1 kt Li imported either as lithium compounds or as intermediate goods used in manufacturing. While approximately 1.6 kt Li was imported as lithium embedded in final products, see Figure 6.

The amount of lithium refined within the EU is negligible. There is currently only one lithium-refining facility within the EU, Albermale in Germany, that produces specialty lithium chemicals and metal from imported lithium carbonate (ALBERMARLE, 2019; Jaskula, 2018). However, it is not possible to estimate these numbers due to lack of information.

The EU manufacturing of lithium containing goods was approximately 2.4 kt of lithium. Manufacturing of lithium within the EU are divided into the following categories see Figure 7: (1) Glass and ceramics (glass, ceramics and glass ceramics, total 1.3 kt Li), (2) Lubricants and greases (complex and conventional, total 0.6 kt Li), (3) Polymers (0.03 kt Li), (4) Continuous casting (0.1 kt Li), (5) Aluminium alloys production (0.05 kt Li), (6) Batteries (Mobility batteries (0.3 kt Li)). After considering the trade of finished products the EU total consumption of products containing lithium amounted to about 3.2 kt in 2016.

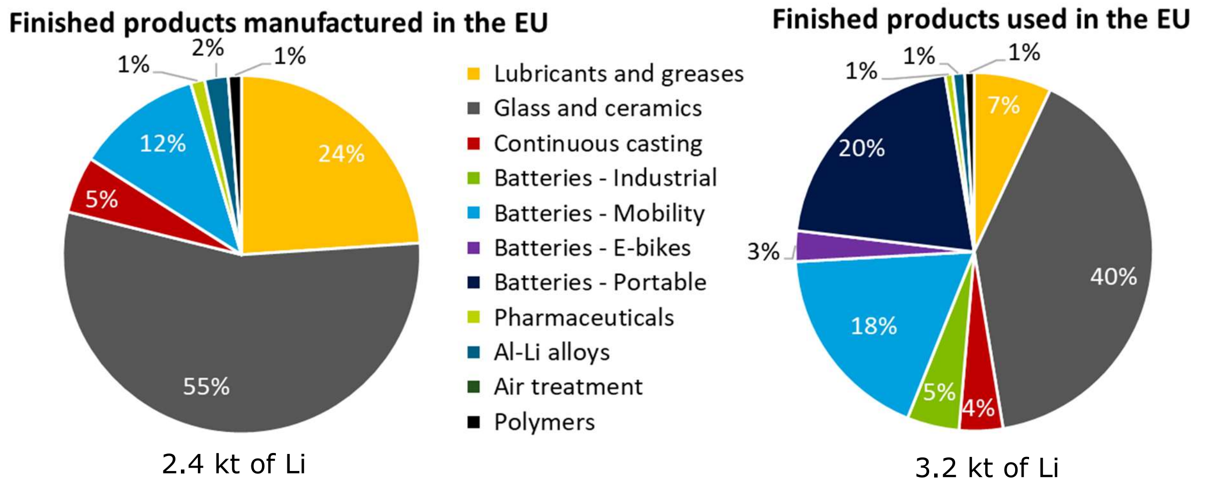

Figure 7. Shares of finished products containing lithium manufactured in the EU (left) and shares of finished products containing lithium used in the EU (right), by application

The quantity annually entering the in-use stock was estimated at around 1 kt of lithium (see Figure 6). This accounts for the annual addition to the in-use stock and to the 'hoarded' or 'hibernating' stock[5]. In total in 2016 19.5 kt Li were stored in in-use stocks. However, only 6.6 kt of lithium embedded in the stocked batteries can be potentially recovered through recycling. The remaining is mainly glass and ceramics in which the lithium cannot be recovered through a recycling process (Wietelmann and Steinbild, 2014). 1.6 kt of the lithium put into use are classified as dissipative and is considered as losses in Figure 6, while 0.6 kt Li are disposed of in landfill and tailings.

It is possible to recycle the lithium from lithium-ion batteries, but this is currently facing several technical and economic challenges[6]. Current collection rates, small quantities contained in products and the low price of primary materials also provide little economic incentive to recycle lithium (Wietelmann and Steinbild, 2014). This prevents the existence of a close loop of lithium material flows in the EU.

Of the total amount of lithium old scrap collected (i.e., 0.5 kt Li), about 0.3 kt of lithium were collected for recycling and only 0.003 kt Li were actually recycled, Figure 6.

3.3 Indicators

Table 4 summarises recycling and EU self-sufficiency indicators.

Nearly 53% of Li in end-of-life products were collected, but, for reasons described above, the amount of recycled lithium is negligible. The ratio of functional recycling of old scrap and lithium collected resulted in 0.4% (end-of-life recycling rate (EOL-RR)), and the input of this to the EU demand for lithium in the manufacturing stage (end-of-life recycling input rate (EOL-RIR)) resulted in 0.1%.

Regarding EU self-sufficiency the EU relies on lithium imports. In 2016 only 17% of lithium was extracted in the EU. The overall domestic extraction and imports supplied the EU manufacturing, which required additionally nearly 25% of imports of processed materials to complete the demand for lithium products.

For the five years analysed there was no substantial change for recycling indicators. The EU self-sufficiency in the extraction stage appears to be increasing, due to the increase in extraction capacity in Portugal and lower imports. At the same time, the manufacturing stage self-sufficiency decreased by almost 10%, due to the increase in demand of lithium in particular for battery products.

[5] Stocks of products at its end-of-life still kept by the users.

[6] As for instance pyrometallurgical recycling techniques are not suitable due to the high reactivity of lithium (Chagnes and Światowska, 2013.; Talens Peiró et al., 2013)

Table 4: Different indicators that describe the lithium situation in the EU.

Indicator	Formula	2012	2013	2014	2015	2016
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	0.1%	0.1%	0.1%	0.1%	0.1%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	0.4%	0.4%	0.4%	0.4%	0.4%
Collection Rate	F1.4/(M4.1)	48%	48%	49%	51%	53%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	9%	8%	7%	7%	17%
Self-sufficiency Processing	C1.1/M2.1	-	-	-	-	-
Self-sufficiency Manufacturing	D1.1/M3.1	83%	81%	84%	78%	75%

3.4 Data sources, assumptions and reliability of results

There are large data limitations with regards to lithium, this applies to both trade and production data across the entire value chain. For some flows it was not possible to differentiate Europe from EU (manufacturing and use of (1) pharmaceuticals and (2) Al-li alloys), it was assumed that the European situation is similar to the EU. In addition, as lithium is in most cases used as a chemical compound in small amounts in either products or processes, assumptions needed to be made regarding the lithium content in these products.

Priority have been given to official sources such as Eurostat (Eurostat 2019a, 2019b), UN Comtrade, the British Geological Survey, United States Geological Survey and World Mining Data. In addition the reports from the French Geological Survey (BRGM) (Labbé et al., 2012) Federal Institute for Geosciences and Natural Resources (BGR) (Rohstoffagentur in der BGR, 2017) and Deutsche Bank (Hocking, 2016) were used. Dataset on batteries RMIS/ProSUM, 2019. In some instances where it was not possible to gather statistics for all the years, a growth rate on earlier reported years was used.

Due to complexity in the value chain, lack of trade and production codes and confidentiality aspects, several assumptions along the value chain were made. Leading to uncertainties in the results of the MSA.

A list of commodities containing lithium is provided in the annexes (Table A3 in Annexes).

4 Material system analysis of Manganese

4.1 Value chain

Manganese is produced commercially from blends of ores in which this element exists commonly as an oxide. Manganese extracted from minerals is mainly processed to ferro-manganese and ferro-silico-manganese. Ferro-manganese and ferro-silico-manganese are the main intermediate forms used in the steel industry, which constitutes the main driver for manganese demand in EU. In steelmaking, manganese is used as alloying element and/or as a deoxidiser due to its high capability to fix sulphur, oxygen, and phosphorus. Beyond steelmaking, manganese is also used in the production of aluminium alloys, pigments, and batteries. In particular, for the latter use, synthetic manganese dioxide is the main raw material to produce electrolytic manganese, which is used in zinc-carbon batteries as well as in rechargeable alkaline cells.

Manganese intermediate products (e.g., steel and electrolytic manganese) may be incorporated into finished products. The main end-uses of manganese include transportation, building and construction, engineering, domestic appliances, metalware, other miscellaneous metallurgy applications, and batteries.

Figure 8 depicts the value chain of manganese, its intermediates and end-uses covered in this study.

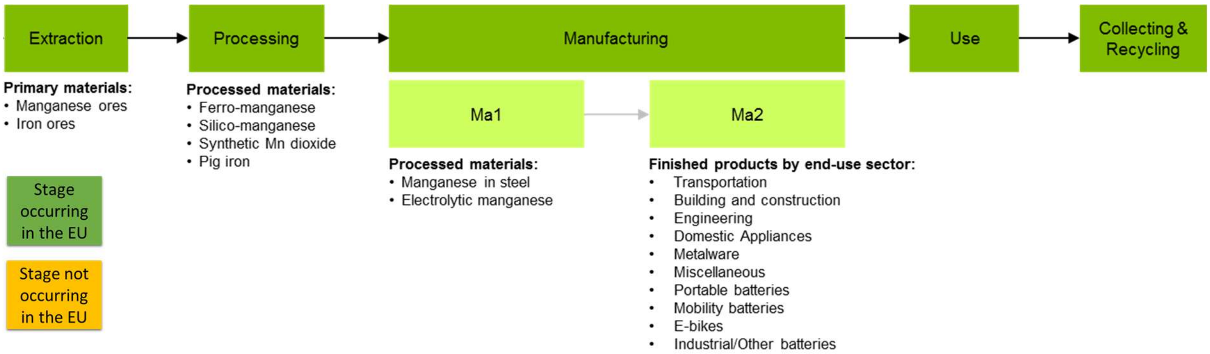

Figure 8. Value chain of manganese, steps in green occur in the EU, steps in orange occur only outside of the EU. Ma1/Ma2: consecutive manufacturing processes along the supply chain.

4.2 Description of the main flows and stocks

Flows and stocks are accounted in mass of manganese (kt Mn) metallic equivalent and are representative of the year 2016.

Global manganese reserves are estimated at about 760,000 kt Mn, with South Africa, Ukraine, Brazil and Australia accounting for more than three quarters of the global manganese reserves. In 2016, the world production of ferro-manganese and ferro-silico-manganese was near 14,000 kt Mn[7] and the top producer country was China, followed by India.

In the EU, manganese reserves are reported only for Romania, however they do exist in other countries. These reserves are estimated at about 18,000 kt Mn, smaller reserves are not reported. In 2016, about 296 kt Mn were extracted in the EU, see Figure 9 (including also extraction waste of around 70 kt Mn), i.e. in Bulgaria (65% of total manganese extraction in EU), in Hungary (26%) and in Romania (9%) (Minerals4EU, 2014, Minerals Intelligence Network for Europe, 2019; Corathers, 2015; WMD 2019).

[7] https://www.manganese.org/wp-content/uploads/2019/05/IMnI_Statistics_2020.pdf

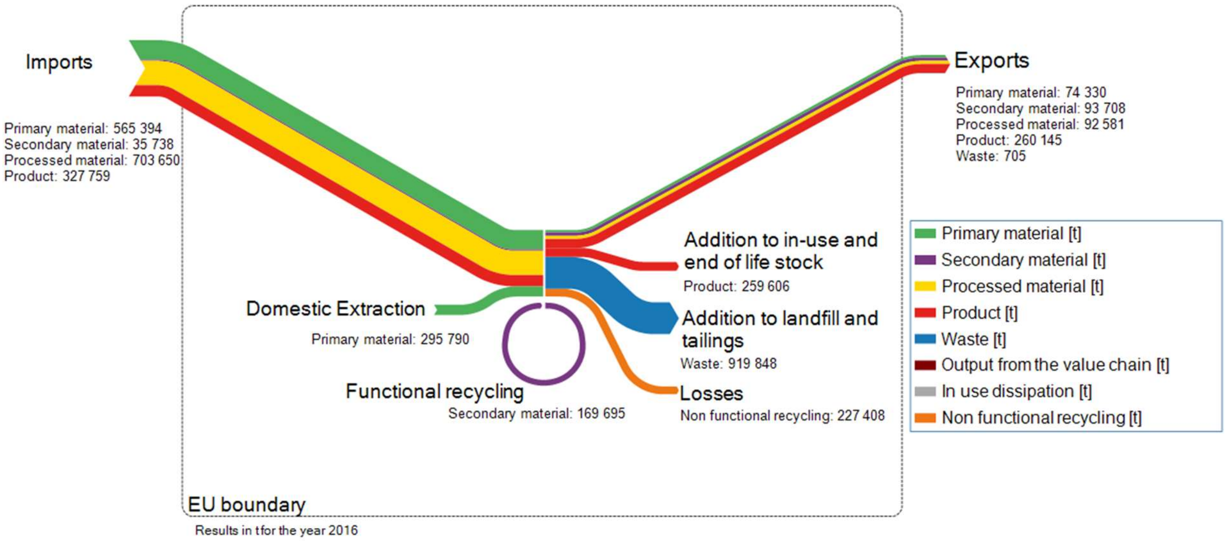

Figure 9. Simplified Sankey diagram for manganese for the year 2016 in the EU (without the UK), the imports of products include also 191 kt Mn of intermediate products, supplied to the manufacturing stage.

The domestic input to EU manganese smelting was supplemented with imports of manganese ores and concentrates (565 kt Mn, see Figure 9).

A total of 697 kt Mn of processed material were produced in the EU: 220 kt Mn in ferro-manganese, 159 kt Mn in silico-manganese, 20 kt Mn in synthetic manganese (II) oxide, and 298 kt Mn were processed into pig iron in iron smelting in the EU. Beyond ferro-manganese and ferro-silico-manganese, manganese naturally present in bearing ores was also accounted for in this study.

As input to the EU manufacturing stage the Mn smelting output was supplemented with: 611 kt Mn processed material net-imported (imports accounted 704 kt of processed material while the exports were 93 kt, see Figure 9), 191 kt Mn in intermediate products and 36 kt Mn in secondary materials imported from outside the EU. Additionally, about 170 kt Mn were supplemented from post-consumer functional recycling. Manufacturing stage starts with the production of intermediate products: steel (1,236 kt Mn) and electrolytic semi-finished products (23 kt Mn), while 665 kt Mn were lost due to deoxidation in steelmaking (data not shown). These intermediate products were then incorporated into finished products that cover the main end-uses of Mn manufactured in the EU: transportation (201 kt Mn), building and construction (421 kt Mn), engineering (163 kt Mn), domestic appliances (19 kt Mn), metalware (134 Mn), other miscellaneous metallurgical uses (19 kt Mn), portable batteries (19 kt Mn), mobility batteries (2 kt Mn), e-bikes (0.1 kt), industrial and other batteries (0.4 kt Mn). Manganese new scrap generated from products manufacturing (i.e., 411 kt Mn in 2016) was internally recycled.

Figure 10 shows the distribution by end-use sector of manganese-containing finished products manufactured (pie-chart on the left hand side) and used (pie chart of the right hand side) in EU.

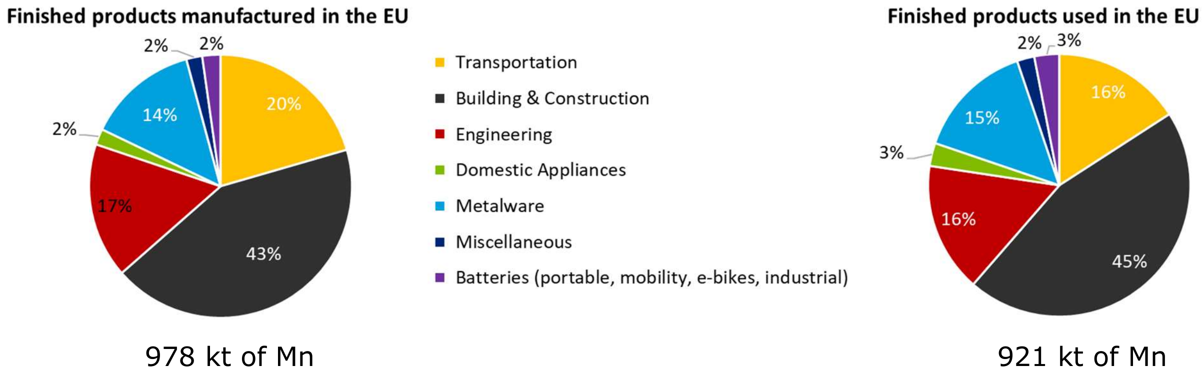

Figure 10: Shares of finished products containing manganese manufactured in the EU (left) and shares of finished products containing manganese used in the EU (right), by application.

The quantity annually entering the in-use stock was estimated at about 260 kt Mn in 2016, see Figure 9. The total stock of products in-use is quantified at about 34,820 kt Mn.

From the total amount leaving the use phase (661 kt of Mn in 2016), 5 kt of Mn were exported in products for reuse, 493 kt Mn were collected and sorted for recycling, while about 162 kt Mn were lost due to inefficiency after the collecting. The export of 94 kt Mn waste and scrap as well as the 227 kt Mn entering non-functional recycling (see Figure 9) and about 2 kt Mn of recycling waste reduced the amount of secondary manganese input to domestic processing at 170 kt Mn in 2016.

4.3 Indicators

Table 5 summarises recycling and EU self-sufficiency indicators.

The collection rate at end-of-life was 75%, and the end-of-life recycling rate (EoL-RR) was 40%. The ratio of recycling from old scrap to European demand for manganese (i.e., end-of-life recycling input rate, EOL-RIR) resulted in 9%. The differences between collection, EOL-RR and EOL-RIR were due to the fact that the amount recycled was very low when compared with the total input to manufacturing. In fact, a high volume of manganese was: i) lost as manufacturing waste (665 kt Mn due to to deoxidation) and stored in the stocks in use (260 kt Mn), which are not yet available for recycling.

Regarding self-sufficiency the EU relies on imports for extraction and processing stages and is self-sufficient for manufacturing, exporting more that the amount imported. In 2016 only 31% of manganese was extracted and 45% was refined in the EU, the rest was imported (imports include also secondary materials). The amount of manganese consumed in the use phase (M3.1) is lower than what is manufactured in the EU (D1.1), resulting in a self-sufficiency higher than 100%. These results demonstrate that the EU manufacturing capabilities are sufficient to cover the demand for all the main application sectors except for the batteries sector, where EU manufacturing is limited.

For the five years analysed there was no substantial change for all the analysed indicators.

Table 5. Different indicators that describe manganese situation in the EU.

Indicator	Formula	2012	2013	2014	2015	2016
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	8%	8%	9%	8%	9%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	41%	36%	40%	35%	40%
Collection Rate	F1.4/(M4.1)	75%	75%	75%	75%	75%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	31%	23%	28%	29%	31%
Self-sufficiency Processing	C1.1/M2.1	45%	43%	44%	44%	45%
Self-sufficiency Manufacturing[8]	D1.1/M3.1	120%	120%	117%	115%	113%

4.4 Data sources, assumptions and reliability of results

The main sources of production and trade data are the World Mining Data database (WMD, 2019), the United Nations Commodity Trade Statistics Database (United Nations, 2019), the United States Geological Survey (Corathers, 2015, 2019), the Minerals Intelligence Network for Europe (Minerals4EU, 2014), the International Manganese Institute (International Manganese Institute, 2013; Risk & Policy Analysts Ltd., 2015), the World Steel Association (World Steel Association, 2017), Eurostat (Eurostat, 2019a, 2019b, 2019c), the Kirk-Othmer Encyclopedia (Matricardi and Downing, 2012), the Ullmann's Encyclopedia of Industrial Chemistry (Reidies, 2000; Wellbeloved et al., 2000), (RMIS/ProSUM, 2019), (Recharge, 2017), and (Trinomics, 2018).

[8] Manufacturing of Mn includes final products and semi-finished products. The self-sufficiency manufacturing indicator was calculated accordingly.

Additional information including a list of commodities containing manganese (Table A4 in Annexes), process efficiency, collection and separation efficiency of manganese at end-of-life was gathered from peer-reviewed papers in literature (Biswal, et al., 2015; Ciacci et al., 2015; Jeong et al., 2009; Nuss et al., 2014; Olivetti et al., 2011; Passarini et al., 2018; Pauliuk et al., 2013).

5 Material system analysis of Natural Graphite

5.1 Value chain

Three different types of natural graphite ores are mined in the world, which require different processing: crystalline (or flake) graphite, microcrystalline (or amorphous) graphite and vein (or lump) graphite. First processing (mineral processing) generally involves mechanical separation and flotation, which is done in proximity of the mine. Further processing is required for higher quality products such as anode materials, expanded graphite and nuclear applications includes milling, spheroidisation and purification by chemical and/or thermal treatment.

The main uses of natural graphite as finished products comprise refractory materials, anode materials for Li-ion cells and other (primary) batteries, friction materials, lubricants, and other miscellaneous applications such as sealing applications, pencils, fire retardants, steel recarburising, brushes for electric motors etc. Figure 11 depicts the value chain of natural graphite, its intermediates and end-uses covered in this study.

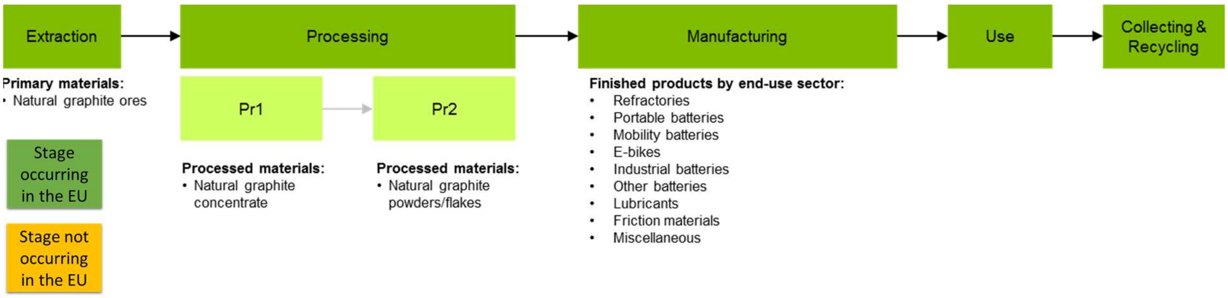

Figure 11. Value chain of natural graphite, steps in green occur in the EU, steps in orange occur only outside of the EU.

5.2 Description of the main flows and stocks

Natural graphite flows and stock are accounted in mass of carbon (kt C) and are representative of the year 2016.

Global natural graphite reserves are estimated at about 81,000 kt C, with China accounting for 75% and Russia and Ukraine for 9% of total reserves. In 2016, the world production of natural graphite was more than 1,100 kt and the top producer country was China (69% of global natural graphite production), followed by India (11%) (Robinson et al., 2017).

In the EU, natural graphite reserves are estimated at about 156 kt C. There are no imports of run-of-mine[9] natural graphite ores into the EU since the first processing steps of mechanical separation and flotation only take place near by the mines. Three active mines exist in the EU, namely in Kaisersberg (Austria), Kropfmühl (Germany) and Woxna (Sweden), for a EU total production of about 0.7 kt in 2016 (there are no exports of natural graphite ores) (WMD, 2019).

[9] Ore in its natural and unprocessed state;

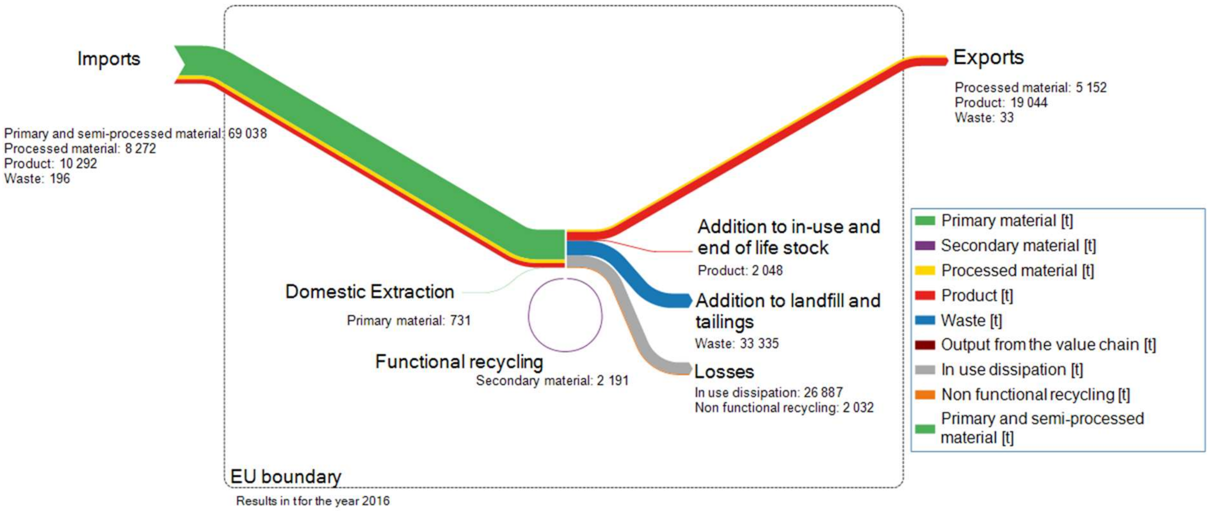

Figure 12. Simplified Sankey diagram for natural graphite for the year 2016 in the EU (without the UK), imports of primary material include material semi-processed at the mining site.

The EU industry is highly dependent on imports of semi-processed natural graphite (i.e. in the form of flakes, amorphous, and vein graphite), importing 69 kt in 2016 (see Figure 12). The EU industry also accounted with 3 kt of processed natural graphite net imports. Up to 17% of the input material can be lost during the entire processing and manufacturing of natural graphite (depending on the product). Part of the manufacturing waste generated is directly reprocessed on site or sent to the processing state (about 0.2 Kt C in 2016), however most of the natural graphite contained in the generated waste is sent for disposal. This occurs even with the existing bans, in countries like Germany, on landfilling wastes with well-defined calorific values.

In 2016 the EU manufacturing industries produced 62 kt of C contained in various finished products including refractories (33 kt C), Li-ions batteries (2 kt C), other batteries (3 kt C), lubricants (4 kt C), friction materials (5 kt C) and other miscellaneous applications (15 kt C). About 53 kt C contained in those products were sold in the EU market, with the rest being net-exported (8.7 kt C). Figure 13 shows the distribution by end-use sector of natural graphite-containing finished products manufactured (pie-chart on the left hand side) and used (pie chart of the right hand side) in EU.

Figure 13: Shares of finished products containing natural graphite manufactured in the EU (left) and shares of finished products containing cobalt used in the EU (right), by application.

The quantity annually entering the in-use stock was estimated at about 2 kt C in 2016, Figure 12. The total stock of products in-use is quantified at about 87 kt C. As reported in Figure 12 about 27 kt C were lost due to dissipative uses.

From the total amount leaving the use phase (24 kt C): 0.3 kt C were exported in products for reuse and 20 kt C were lost due to inefficiency at end-of-life, while 4 kt C were collected for recycling, of which only 2 kt C were sorted and recovered for functional recycling.

Most of the natural graphite contained in the end-of-life products ends up in landfill, either as hazardous waste (due to contamination during use) or in standard landfills. The stock accumulated in landfill over the last 20 years is estimated at about 594 kt C (calculation based on waste generated from processing to recycling step, extraction tailings excluded).

Functional recycling only exists for refractory materials, which is applied on small scale only. Moreover, natural graphite is oxidized to CO_2 during the pyrometallurgical recycling of batteries and accumulators. As there is no appropriate parameter in the MSA to describe such process (i.e. output from the value chain from recycling as CO_2 emissions), the project team chose to consider this flow as non-functional recycling.

5.3 Indicators

Table 6 summarises recycling and EU self-sufficiency indicators.

The collection rate of end-of-life graphite was 17%, and the end-of-life recycling rate (EoL-RR) 10%. The ratio of recycling from old scrap to the EU demand for natural graphite (end-of-life recycling input rate (EOL-RIR)) resulted in 3%.

Regarding self-sufficiency, the extraction stage is highly dependent on imports, in 2016 only 1% of natural graphite was extracted in the EU, while the rest was imported (imports include also semi-processed material). The overall domestic extraction and imports supplied the processing and manufacturing stages, which show little to no dependency of imports. The amount of nickel consumed in the use phase (M3.1) is lower than what is manufactured in the EU (D1.1), resulting in a self-sufficiency higher than 100%.

For the five years analysed there was no substantial change for any of the indicators analysed.

Table 6. Different indicators that describe natural graphite situation in the EU.

Indicator	Formula	2012	2013	2014	2015	2016
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	3%	2%	2%	3%	3%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	8%	8%	8%	8%	8%
Collection Rate	F1.4/(M4.1)	17%	17%	16%	18%	17%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	10%	0.8%	0.9%	1%	0.9%
Self-sufficiency Processing	C1.1/M2.1	92%	86%	88%	95%	95%
Self-sufficiency Manufacturing	D1.1/M3.1	111%	110%	109%	111%	116%

5.4 Data sources, assumptions and reliability of results

The main sources of production and trade data are Eurostat (Eurostat, 2019a, 2019b, 2019c), the World Mining Data database (WMD, 2019), the United Nations Commodity Trade Statistics Database (United Nations, 2019), the United States Geological Survey (Olson, 2015, 2019), Confederation of the European Bicycle Industry (Confederation of the European Bicycle Industry, 2019), the Kirk-Othmer Encyclopedia (Kalyoncu and Taylor, 2002), Accurec (Accurec, 2019), RMIS (RMIS/ProSUM, 2019), Recharge (Recharge, 2017).

Additional information including a list of commodities containing natural graphite (Table A4 in the annexes), process efficiency, collection and separation efficiency of natural graphite at end-of-life was gathered from peer-reviewed papers and industry reports in literature (Baldé et al., 2015; BIO by Deloitte, 2015; Clark, 2016; Trinomics, 2018; Tsakalidis and Thiel, 2018).

6 Material system analysis of Nickel

6.1 Value chain

The main primary sources of nickel are sulphide ores and laterite ores. Flash smelting is generally the main pyrometallurgical production route for sulphide ores, while acid pressure leaching is commonly preferred for hydrometallurgical processing of laterite ores. Nickel ore is generally smelted and refined to produce nickel metal comprising electrolytic nickel, powders and briquettes (nickel Class I) or for an intermediate material (nickel pig iron and ferro-nickel) for the steel industry (nickel Class II) or nickel chemicals.

Nickel Class I, nickel Class II, and nickel chemicals are inputs to the fabrication stage to produce intermediate products ("first-uses") like stainless steel products, alloy steel, nickel/copper alloys, other nickel metallurgy applications and miscellaneous intermediate products. These products are incorporated into finished products. The main end-uses of nickel include building and construction, transportation, engineering, electro and electronics, other applications in metal goods, portable batteries, mobility batteries, e-bikes, and industrial batteries.

Figure 14 below depicts the value chain of nickel, its intermediates and end-uses covered in this study. The Figure shows the value chain steps that take place within and outside the EU.

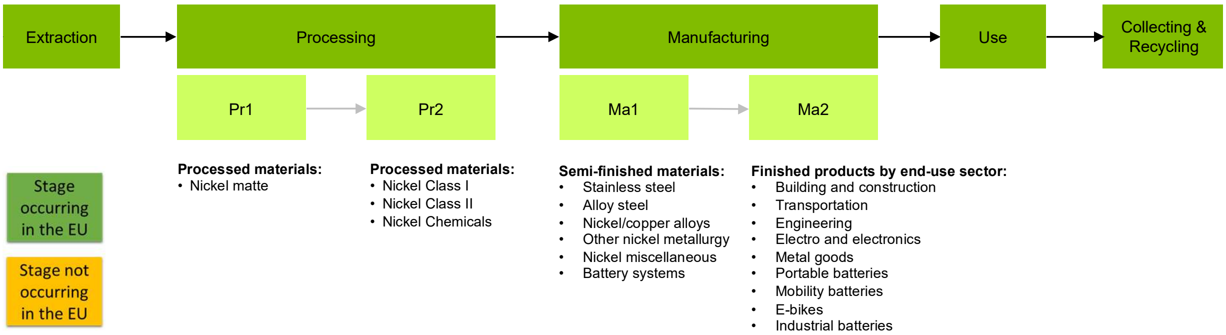

Figure 14. Value chain of nickel, steps in green occur in the EU, steps in orange occur only outside of the EU.

6.2 Description of the main flows and stocks

Flows and stocks are accounted in mass of nickel (kt Ni) metallic equivalent and are representative of the year 2016.

Global nickel reserves are estimated at about 75,000 kt Ni, with Australia, Indonesia, South Africa, Russia and Canada accounting for more than half of the global nickel reserves. In 2016, the world refinery production was more than 1,800 kt Ni and the top producer country was China (23% of global refined nickel production) (Nickel Institute, 2019a; McRae, 2019).

In the EU, nickel reserves are estimated at about 479 kt of Ni (Minerals4EU, 2014). In 2016, around 44 kt Ni were produced from domestic mines, mainly in Greece (45% of total nickel production in EU) and Finland (40%), followed by Spain (14%), and Poland (2%) (WMD, 2019), whereas 11 kt Ni were disposed of in tailings (domestic extraction in Figure 16 includes the amount in tailings).

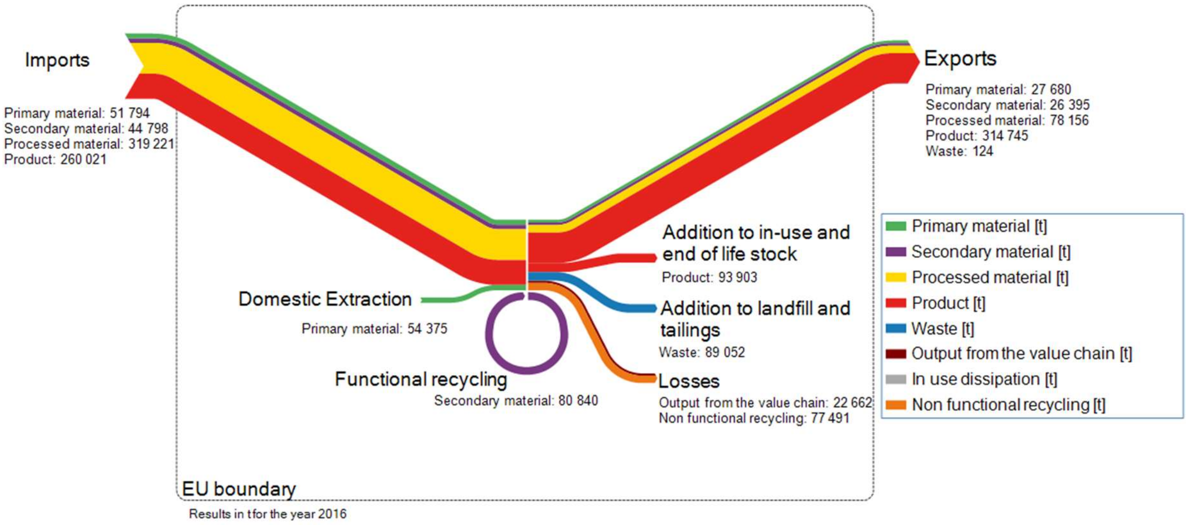

Figure 15. Simplified Sankey diagram for nickel for the year 2016 in the EU (without the UK), imports of processed material include semi-processed forms 49 kt. Imports of products include also imports of intermediate products 158 kt Ni.

Input to nickel processing (i.e., smelting and refining) was supplemented with imports of 52 kt Ni in nickel ores and concentrates and 49 kt Ni in semi-processed forms. On the other hand the EU exported 28 kt Ni in primary forms (see Figure 15). The EU produced 70 kt Ni of refined nickel (of which 23 kt Ni were, however, stockpiled at intermediate production facilities), 8 kt Ni in processing waste were sent to disposal (contributing to the amount in landfill) and 78 kt Ni in nickel mattes (15 kt Ni) and in refined nickel (63 kt Ni) were exported.

The EU manufacturing was supplemented with: imports of processed materials (270 kt Ni, Figure 15 shows imports of both processed and semi-processed material), imports of intermediate products (158 kt Ni, in Figure 15 included in the total amount of products imported), 45 kt Ni of secondary materials and 81 kt Ni of domestic post-consumer functional recycling, see Figure 15. Overall, the EU produced 413 kt Ni in finished products. The main end-use segments of nickel products manufactured in the EU included: products for building and construction (43 kt Ni), transportation (76 kt Ni), engineering (160 kt Ni), electro and electronics (43 kt Ni), other applications in metal goods (88 kt Ni), portable batteries (0.5 kt Ni), mobility batteries (3 kt Ni), industrial batteries (0.4 kt Ni), and e-bikes (<0.1 kt Ni). Nickel “new scrap” generated from finished products manufacturing was internally recycled to stainless steel production.

Exports of 315 kt Ni in finished products from EU and imports of 102 kt Ni in finished products to EU resulted in about 350 kt of total nickel input to domestic use in 2016. Figure 16 shows the distribution by end-use sector of nickel-containing finished products manufactured (pie-chart on the left hand side) and used (pie chart of the right hand side) in EU.

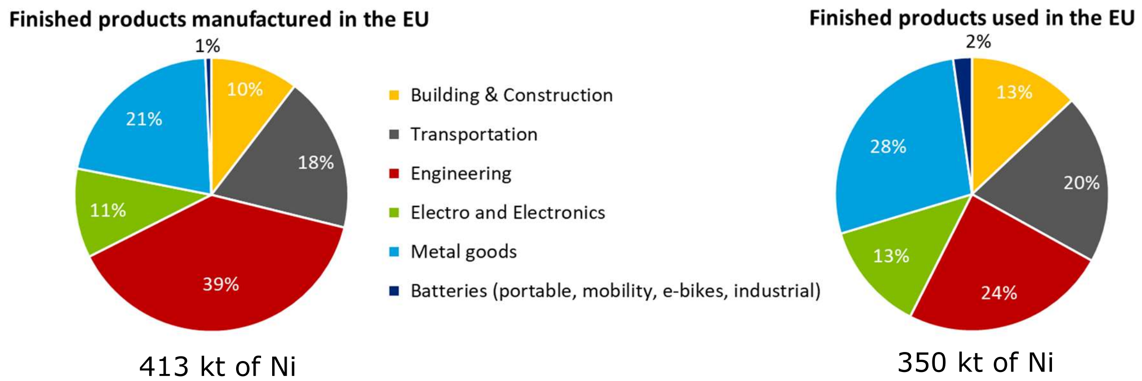

Figure 16: Shares of finished products containing nickel manufactured in the EU (left) and shares of finished products containing cobalt used in the EU (right), by application.

The quantity annually entering the in-use stock was estimated at about 94 kt of Ni accumulated in the stock in EU in 2016. The total stock of products in-use in 2016 was estimated to be about 6,805 kt Ni.

From the total amount leaving the use phase more than 186 kt Ni were collected and sorted for recycling, while about 69 kt Ni were lost in waste streams. Exports of products for reuse and products at end of life (both <1 kt Ni) were negligible. Functional recycling allowed to recover 81 kt Ni to the internal EU market while 26 kt Ni recovered was exported, 77 kt Ni was loss in non-functional recycling and about 1 kt Ni waste was sent for disposal (see Figure 15).

6.3 Indicators

Table 7 summarises recycling and EU self-sufficiency indicators.

The collection rate for Nickel was 73% and the end-of-life recycling rate (EoL-RR) was 42% in 2016. The ratio of recycling from old scrap to the EU demand for nickel (end-of-life recycling input rate (EOL-RIR)) resulted in 16%. A considerable fraction of secondary nickel collected for recycling at end-of-life is actually exported from the EU.

Regarding self-sufficiency, the EU is import dependent for both the extraction and processing stages. In 2016 less than 37% of nickel was extracted and 18% was processed within the EU the rest was imported (imports include also secondary raw materials). The overall domestic production and imports in the extraction and processing stages supplied the EU manufacturing. The EU manufacturing capability is sufficient to cover the EU demand for nickel products. The amount of nickel consumed in the use phase (M3.1) is lower than what is manufactured in the EU (D1.1), resulting in a self-sufficiency higher than 100%.

For the analysed period there was no substantial change for all the indicators.

Table 7. Different indicators that describe nickel situation in the EU.

Indicator	Formula	2012	2013	2014	2015	2016
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	11%	13%	12%	13%	16%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	54%	45%	40%	36%	42%
Collection Rate	F1.4/(M4.1)	72%	72%	73%	73%	73%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	40%	62%	62%	62%	37%
Self-sufficiency Processing	C1.1/M2.1	18%	16%	13%	14%	18%
Self-sufficiency Manufacturing[10]	D1.1/M3.1	199%	189%	169%	164%	160%

6.4 Data sources, assumptions and reliability of results

The main sources of production and trade data are Eurostat (2019a, 2019b), the United Nations Commodity Trade Statistics Database (United Nations, 2019), the World Mining Data database (WMD, 2019), the United States Geological Survey (McRae, 2015, 2019), the Minerals Intelligence Network for Europe (Minerals Intelligence Network for Europe, 2019), the Nickel Institute (Nickel Institute, 2019a, 2019b), the International Stainless Steel Forum (International Stainless Steel Forum, 2018), RMIS/Prosum data (RMIS/ProSUM, 2019), Recharge (2017), Trinomics (2018), and survey with M. Mistry and P. Chhabra from the Nickel Institute (Mistry and Chhabra, 2019).

[10] Manufacturing of Ni includes final products and semi-finished products. The self-sufficiency manufacturing indicator was calculated accordingly.

Additional information including a list of commodities containing nickel (Table A5 in the Annexes), process efficiency, collection and separation efficiency of nickel at end-of-life was gathered from peer-reviewed papers in literature (Ciacci et al., 2015; Crundwell, 2011; Graedel et al., 2015; Norgate et al., 2007; Passarini et al., 2018; Pauliuk et al., 2013; Reck et al., 2008).

7 Conclusions

This section presents the conclusions for each MSA study and compares also the main results achieved across the targeted raw materials. All data refers to 2016.

The MSA of **cobalt** reveals that the EU is dependent on imports of cobalt, in particular on intermediate cobalt forms (e.g. cobalt-containing mattes, crude cobalt hydroxide) and refined cobalt. The domestic extraction of cobalt represented only 12% of the total input to the EU manufacturing. The EU consumption of finished products containing cobalt was about half satisfied by the EU manufacturing (24 kt) and half met by imports (21 kt). At end-of-life cobalt was recovered mainly from superalloys, batteries and catalysts achieving an EOL-RR of 32% and an EOL-RIR of 22%. 26% of the cobalt input to the EU was lost (in tailings, landfill or dissipated in use) and 26% was accumulated in use stocks.

The MSA of **lithium** shows that the EU is dependent on imports of lithium, in almost equal amounts of primary and processed material. The domestic extraction of lithium represented only 9% of the total input to the EU manufacturing. The EU consumption of finished products containing lithium was 60% covered by the EU manufacturing (2.4 kt) and the rest satisfied with imports (1.6 kt). The recycling of lithium was extremely low (EOL-RR was 0.4% and EOL-RIR was 0.1%,) which is explained by technical challenges, low lithium prices and the dissipative nature of lithium in the majority of the applications. 54% of the lithium input to the EU was lost or disposed of in tailings, landfill or dissipated in use, and 23% was accumulated in use stocks.

The MSA of **manganese** also reveals a dependency on imports, in particular on refined manganese. The domestic extraction represented only 15% of the total input to the EU manufacturing. The EU consumption of finished products containing manganese was mainly satisfied by the EU manufacturing (978 kt Mn manufactured in EU). At end-of-life the recycling of manganese was also low when compared with the total input to manufacturing (EOL-RIR was 9%). 49% of the manganese input was lost or disposed of in tailings and landfill and 14% was accumulated in use stocks.

The MSA of **natural graphite** depicts a high EU dependency on imports of semi-processed material (natural graphite flakes, amorphous and vein). The domestic extraction represented less than 1% of the total input to the EU manufacturing. The demand for natural graphite contained in products for final use in the EU was mainly satisfied by the EU manufacturing (62 kt of natural graphite in EU). The end of life recycling of natural graphite is also low (EOL-RIR was 3%). Due to the dissipative nature of applications such as: refractories (20% of natural graphite dissipated in use), friction materials (100% dissipation), lubricants (100%) and miscellaneous (100%) and the fact that the recycling was low (EOL-RR only 10%) the majority of natural graphite (62%) was lost.

The MSA of **nickel** reveals a high EU dependency on imports of processed material. The domestic extraction represented less than 9% of the total input to the EU manufacturing. The EU consumption of finished products containing nickel was mainly satisfied by the EU manufacturing (413 kt of nickel were manufactured in the EU). At end-of-life nickel functional recycling achieved 16% of the manufacturing demand. 13% of the nickel input to the EU was lost in tailings and landfilled and 16% was accumulated in use stock and stockpiled at intermediate production facilities.

Key performances indicators derived from the MSAs for the five battery-related raw materials are presented in Figure 17. The five battery materials analysed show a very strong dependence on imports along the value chain (see Figure 17): they are all highly dependent on imports of primary or semi-processed material.

The EU is efficient in collecting products containing the target materials (collection rate higher than 53%, except for natural graphite, see Figure 17), in particular batteries. For these materials the functional recycling of old scrap is still subject to improvement in the EU. For cobalt, manganese and nickel the MSA showed recycling rates between 32 and 42%. When these values are compared with the total input to manufacturing the maximum EOL-RIR was obtained for cobalt with 22%. This indicates that the EU is not yet able to decrease its dependency of primary material using secondary materials domestically recycled. Due to the dissipative nature of the applications for natural graphite and lithium, their recycling shows very low values when compared with the other materials. Regarding self-sufficiency, while for cobalt and lithium the self-sufficiency of the EU manufacturing is not higher than 75%, the EU manufacturing of manganese, natural graphite and nickel products is self-sufficient and thus can satisfy the EU consumption in the use phase.

Additionally, the stocks in use will become another potential source of raw material in the future, and these embed considerable amounts of cobalt, manganese and nickel.

For the period covered by the MSA (2012-2016), the results show that the battery sector is not yet a dominant application for any of the five battery-related materials analysed. As the transportation sector gradually turns electric and energy storage is increasingly important for the wide deployment of renewable power generation, the demand for these raw materials is expected to dramatically grow in the battery applications. This will also change the role of the use share of these materials in battery applications. As a consequence, foreign trade will intensify, as the EU needs to import larger volumes of raw and refined battery materials for the domestic processing and manufacturing, given the announced battery manufacturing projects across the EU. The situation is however, less clear for the net balance of the final products, its direction will depend in the capacity for the EU industry to increase its competitiveness on this sector in comparison with the foreign market and to develop and produce significant amounts of batteries and related final products.

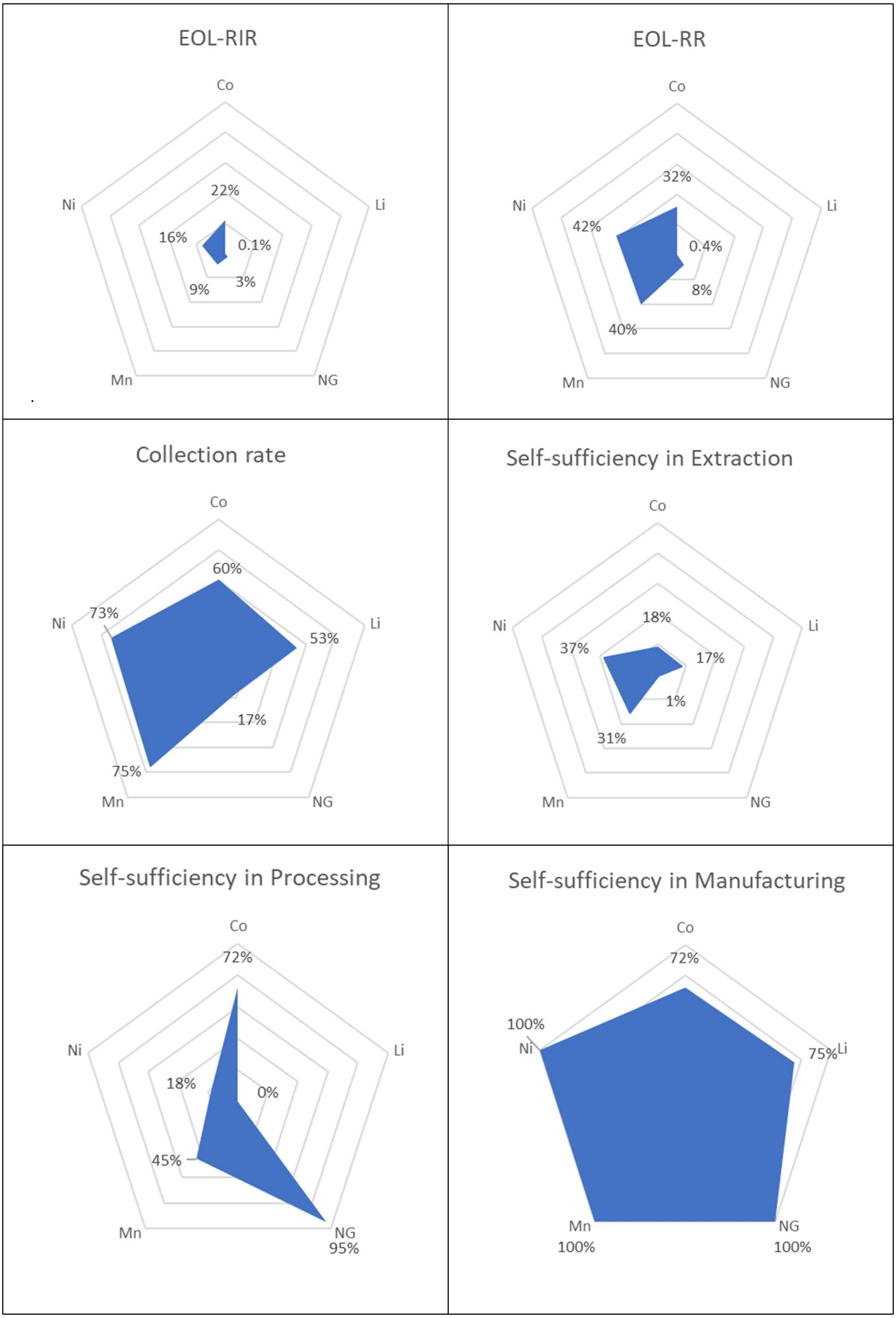

Figure 17. Graphic representation of the six indicators used to describe the cobalt, lithium, manganese, natural graphite and nickel situation in the EU.

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Annexes

Annex 1. Material Flow/Stock Parameters

Table A1. List of material flows and stocks parameters.

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

Annex 2. Workshop attendance list

Table A2. List of experts participating in the workshop.

Family Name	First Name	Organisation	Country
Almeida Azevedo	Joao Paulo	Sinergeo, SAGHA, Lda.	Portugal
Arvanitidis	Nikolaos	Geological Survey of Sweden (SGU)	Sweden
Braconi	Aurelio	The European Steel Association - EUROFER	Belgium
Buchholz	Peter	DERA	Germany
Burlet	Christian	Geological Survey of Belgium	Belgium
Carpantier	Jean-Francois	Universit Aix-Marseille	France
Carpels	Mark	Campine	Belgium
Chanson	Claude	Recharge	Belgium
Corti	Fabrizio	Imerys Graphite And Carbon	Switzerland
de la Feld	Marco	ENCO srl	Italy
de Oliveira	Daniel P.	LNEG - Laboratorio Nacional Energia e Geologia	Portugal
Deschamps	Yves	Orano Mining	France
di Girolamo	Giovanni	ENEA	Italy
Eriksen	Dag Oistein	Primus.inter.pares AS	Norway
Fontbote	Lluis	University of Geneva	Switzerland
Forrière	Barbara	RENAULT SA	France
Forsgren	Christer	Stena Recycling International	Sweden
Ganev	Iva	Euroalliages	Belgium
Garcia-Balbuena	David	Terrafame Oy	Finland
Gauss	Roland	EIT RawMaterials GmbH	Germany
Gautneb	Havard	Geologial Survey of Norway	Norway
Gloaguen	Eric	BRGM (French Geological Survey)	France
Gonzalez Sanz Francisco	Javier	Geological Survey of Spain	Spain
Huttunen-Saarivirta	Elina	VTT Technical research Centre of Finland Ltd	Finland
Kalvig	Per	GEUS	Denmark
Karas	Henryk	Advisory Mining Board; Ministry of Environment; Poland	Poland
Ledoux Pedailles	Vincent	Infinity Lithium	United Kingdom
Meier	Michael	Orano TN	France
Menad	Nour-Eddine	BRGM	France
Mistry	Mark	Nickel Institute	Belgium
Monnet	Antoine	LGI Consulting	France
Munteanu	Marian	Geological Institute of Romania	Romania
Oliveira	Jorge	Sinergeo.pt	Portugal
Papavasileiou	Konstantinos	National And Kapodistrian University Of Athens-Faculty Of Geology And Geoenvironment	Greece
Paulick	Holger	Geological Survey of Austria	Austria
Pereira	Bruno	Sinergeo	Portugal
Pettit	Carol-Lynne	Cobalt Institute	United Kingdom

Salo	Aleksi	GTK	Finland
Slupek	Kamila	Eurometaux	Belgium
Sundqvist Öqvist	Lena	Swerim AB	Sweden
Talens Peiro	Laura	ICTA-UAB	Spain
Vyboldina	Elena	Eurometaux	Belgium

Annex 3. List of commodities considered for Cobalt

Table A3. List of commodities containing Cobalt.

PRC 2019	CN 2019	Definition
07291905	26050000	Cobalt ores and concentrates (1988-2500)
24453035	81052000	Cobalt mattes and other intermediate products of cobalt metallurgy; unwrought cobalt; cobalt powders(2002-2500)
24451210	7501 10 00	Nickel mattes
	75030090	Waste and scrap, of nickel alloys (excl. ingots or other similar unwrought shapes, of remelted nickel alloys waste and scrap, ashes and residues containing nickel alloys)
20121930	28220000	Cobalt oxides and hydroxides; commercial cobalt oxides(1988-2500)
20133134	28273930	Cobalt chlorides(2007-2500)
20134162	28332930	Sulphates of cobalt and of titanium(1988-2500)
	81053000	Cobalt waste and scrap (excl. ash and residues containing cobalt)(2002-2500)
20302130	3207 10 00	Prepared pigments, opacifiers, colours and similar preparations for ceramics, enamelling or glass
20122450	3206 41 00	Other colouring matter; pigments and preparations based on inorganic or mineral colouring matter; inorganic products of a kind used as luminophores
20302215	3210 00 90	Prepared water pigments for finishing leather; paints and varnishes (including enamels, lacquers and distempers) (excluding of oil)
20302240	3212 90 00	Pigments, including metallic powders and flakes, dispersed in non-aqueous media, in liquid or paste form, of a kind used in the manufacture of paints; colorants and other colouring matter, n.e.c. put up for retail sale
20136450	2849 10 00	Carbides whether or not chemically defined
20595740	3824 30 00	Non-agglomerated metal carbides mixed together or with metallic binders
25736090	8209 00 80	Unmounted sintered metal carbides or cermet plates, sticks, tips and the like for tools (excluding indexable inserts)
25992995	8505 11 00	Permanent magnets and articles intended to become permanent magnets, of metal
24312010	7228 10 90	Bars and rods, of high-speed steel, not further worked than cold-formed or cold-finished, even further worked, or hot-formed and further worked (excluding forged, semi-finished or flat-rolled products, hot-rolled bars and rods in irregularly wound coils); bars and rods, of silico-manganese steel, on
24312030	7228 50 20	Bars and rods of tool steel, only cold-formed or cold-finished (e.g. by cold-drawing) (excluding semi-finished products, flat-rolled products and hot-rolled bars and rods in irregularly wound coils)
24106510	7227 10 00	Bars and rods of high-speed steel, hot-rolled, in irregularly wound coils

24103510	7225 30 10	Flat-rolled products, of tool steel or alloy steel other than stainless steel, of a width >= 600 mm, not further worked than hot-rolled, in coils (excluding products of high-speed or silicon-electrical steel)
24103520	7225 30 30	Flat-rolled products of high-speed steel, of a width >= 600 mm, hot-rolled or cold-rolled ‘cold-reduced’
24103530	7225 40 12	Flat-rolled products, of tool steel or alloy steel other than stainless steel, of a width >= 600 mm, not further worked than hot-rolled, not in coils (excluding organic coated products, products of a thickness < 4,75 mm and products of high-speed or silicon-electrical steel)
26121020		Bare multilayer printed circuit boards
26121050		Bare printed circuit boards other than multilayer
26115020	8534 00 11	Multilayer printed circuits, consisting only of conductor elements and contacts
26115050	8534 00 19	Printed circuits consisting only of conductor elements and contacts (excl. multiple printed circuits)
25621007		Turned metal parts for aircraft, spacecraft and satellites
30301600	8411 91 00	Parts of turbo-jets or turbo-propellers, for use in civil aircraft
85481029		Spent electric accumulators (excl. lead-acid accumulators)

Annex 4. List of commodities considered for lithium

Table A4. List of commodities containing Lithium.

CN8 and HS code	Definition
26179000	Ores and concentrates (excl. iron, manganese, copper, nickel, cobalt, aluminium, lead, zinc, tin, chromium, tungsten, uranium, thorium, molybdenum, titanium, niobium, tantalum, vanadium, zirconium, precious-metal or antimony ores and concentrates)
283691	Lithium carbonates
282520	Lithium oxide and hydroxide
340319	Lubricant preparations, incl. Cutting-oil preparations, bolt or nut release preparations, anti-rust or anti-corrosion preparations and mould-release preparations, based on lubricants and containing petroleum oil or bituminous mineral oil (excl. Preparations containing, as basic constituents, >= 70% of petroleum oil or bituminous mineral oil by weight and preparations for treating textiles, leather, furskins and other materials)
70131000	Glassware of glass ceramics, of a kind used for table, kitchen, toilet, office, indoor decoration or similar purposes (excl. goods of heading 7018, cooking hobs, leaded lights and the like, lighting fittings and parts thereof, atomizers for perfume and the like)
847130	Automatic data processing machines; portable, weighing not more than 10kg, consisting of at least a central processing unit, a keyboard and a display.
851712	Telephones for cellular networks or for other wireless networks
85211020	Video recording or reproducing apparatus, whether or not incorporating a video tuner, for magnetic tape of a width of <= 1,3 cm and allowing recording or reproduction at a tape speed of <= 50 mm/s (excl. video camera recorders)
85211095	Magnetic tape-type video recording or reproducing apparatus, whether or not incorporating a video tuner (excl. video camera recorders and those using magnetic tape of a width of <= 1,3 cm and allowing recording or reproduction at a tape speed of <= 50 mm/s)
85219000	Video recording or reproducing apparatus, whether or not incorporating a video tuner (excl. magnetic tape-type and video camera recorders)
85258091	Video camera recorders only able to record sound and images taken by the television camera
85258099	Video camera recorders able to record television programmes and sound and images taken by the television camera
85258030	Digital cameras
8703	Motor cars and other vehicles; principally designed for the transport of persons (other than those of heading no 8702), including station wagons and racing cars
870360	Vehicles; with both spark-ignition internal combustion reciprocating piston engine and electric motor as motors for propulsion, capable of being charged by plugging to external source of electric power
870370	Vehicles; with both diesel engine and electric motor as motors for propulsion, capable of being charged by plugging to external source of electric power
870340	Vehicles; with both spark-ignition internal combustion reciprocating piston engine and electric motor for propulsion, incapable of being charged by plugging to external source of electric power
870350	Vehicles; with both compression-ignition internal combustion piston engine (diesel or semi-diesel) and electric motor for propulsion, incapable of being charged by plugging to external source of electric power
850760	lithium-ion accumulators (excl. Spent)
401110	New pneumatic tyres, of rubber, of a kind used for motor cars, incl. station wagons and racing cars

Annex 5. List of commodities considered for manganese

Table A5. List of commodities containing manganese. Sources: (Jeong et al., 2009; Olivetti et al., 2011; Passarini et al., 2018; Pauliuk et al., 2013; Reidies, 2000; Risk & Policy Analysts Ltd., 2015; Wellbeloved et al., 2000)

HS codes and SITC	Definition
2601	Mn content in Iron ores and concentrates
7201	Mn content in Pig iron
2602	Manganese ores, concentrates, iron ores >20% Manganese. Manganese ores and concentrates, including ferruginous manganese ores and concentrates with a manganese content of 20 % or more, calculated on the dry weight
720211	Ferro-manganese, >2% carbon
720219	Ferro-manganese, <2% carbon
720230	Ferro-silico-manganese
282010	Manganese dioxide
720450	Remelting ferrous scrap ingots
720610	Iron & non-alloy steel in ingots
7207	Semi-finished products of iron or non-alloy steel
7208	Flat-rolled products of iron or non-alloy steel
7218	Stainless steel in ingots or other primary forms
7219	Flat-rolled products of stainless steel. of a width of 600 mm or more
7220	Flat-rolled products of stainless steel. of a width of less than 600 mm
7224	Other alloy steel in ingots or other primary forms
7325	Other cast articles of iron or steel
850610	Primary cells & primary batteries. manganese dioxide
7115	Internal combustion engines. not for aircraft
7294	Automotive electrical equipment
7321	Passenger motor cars. other than buses
7328	Bodies & parts motor vehicles ex motorcycles
7114	Aircraft incl. jet propulsion engines
7341	Aircraft. heavier than air
73492	Parts of aircraft.airships.etc.
7312	Electric railway locomotives. not self generat.
7313	Railway locomotives. not steam or electric
7314	Mechanically propelled railway and tramway cars
7315	Rail & tram passenger cars not mech propelled
7316	Rail.&tram.freight cars.not mechanically propd.
7317	Parts of railway locomotives & rolling stock
7322	Buses. including trolleybuses
7323	Lorries and trucks. including ambulances. etc.
7324	Special purpose lorries. trucks and vans
7325	Road tractors for tractor trailer combinations
7327	Other chassis with engines mounted
73291	Motorcycles.auto cycles.etc.& side cars
73311	Cycles.not motorized
73312	Parts of vehicles of heading 733 11 & 733 4
7333	Trailers & oth vehicles not motorized. & parts
7334	Invalid carriages
7351	Warships of all kinds
7353	Ships and boats. other than warships
7358	Ships.boats and other vessels for breaking up
7359	Special purpose ships and boats
7118	Engines. nes
8121	Central heating apparatus and parts
8123	Sinks.wash basins.bidets.baths etc iron/steel
7191	Heating and cooling equipment

723	Equipment for distributing electricity
7111	Steam generating boilers
7112	Boiler house plant
7116	Gas turbines.other than for aircraft
7117	Nuclear reactors
7121	Agricultural machinery for cultivating the soil
7122	Agricultural machinery for harvesting.threshing
7123	Milking machines.cream separators.dairy farm eq
7125	Tractors. other than road tractors
7129	Agricultural machinery and appliances. nes
715	Metalworking machinery
717	Textile and leather machinery
718	Machines for special industries
7192	Pumps and centrifuges
7193	Mechanical handling equipment
7196	Other non electrical machines
7197	Ball. roller or needle roller bearings
7198	Machinery and mechanical appliances. nes
7199	Parts and accessories of machinery. nes
7296	Electro mechanical hand tools
7297	Electron and proton accelerators
7299	Electrical machinery and apparatus. nes
861	Scientific.medical.optical.meas./contr.instrum.
89999	Catapults and sim.aircraft launching gear.etc.
95101	Armoured fighting vehicles
95102	Artillery weapons.mach.guns and arms.n.e.s.
95103	Parts of military ordnance
95104	Sidearms and parts thereof
95105	Revolvers and pistols
95106	Projectiles and ammunition.n.e.s.
7113	Steam engines and steam turbines
7222	Apparatus for electrical circuits
7293	Thermionic valves and tubes. transistors. etc.
695	Tools for use in the hand or in machines
7221	Electric power machinery
7143	Statistical machines cards or tapes
7142	Calculating & accounting machines etc
726	Elec.apparatus for medic.purp..radiological ap.
7295	Electrical measuring & controlling instruments
7141	Typewriters and cheque writing machines
81242	Lamps & lighting fittings & parts thereof
8951	Office and stationery supplies of base metals
7194	Domestic appliances. non electrical
72501	Domestic refrigerators. electrical
72502	Domestic washing machines whether or not elec.
72503	Electro mechanical domestic appliances nes
72504	Electric shavers & hair clippers
81243	Portable electric battery lamps
7195	Powered tools. nes
724	Telecommunications apparatus
72505	Electric space heating equipment etc.
7292	Electric lamps
696	Cutlery
6981	Locksmiths wares
6982	Safes.strong rooms.strong room fittings etc.
7149	Office machines. nes

864	Watches and clocks
8911	Phonographs. tape & other sound recorders etc.
8914	Pianos and other string musical instruments
8918	Musical instruments. nes
894	Perambulators.toys.games and sporting goods
8111	Manganese. articles thereof. waste or scrap
7204	Ferrous waste and scrap; remelting scrap ingots of iron or steel

Annex 6. List of commodities considered for natural graphite

Table A6. List of commodities containing natural graphite. Sources: (BIO by Deloitte, 2015; Kalyoncu and Taylor, 2002; Trinomics, 2018)

HS or PRODCOM code	Title
250410	Graphite; natural, in powder or in flakes
250490	Graphite; natural, in other forms excluding powder or flakes
23201430	Refractory ceramic goods, n.e.c., by weight > 25% graphite or other forms of carbon
20594175	Lubricating preparations not containing petroleum oil or bituminous mineral oils, used for treatment of textiles, leather, hides, furskins and other materials
20594179	Lubricating preparations not containing petroleum oil or bituminous mineral oils, excluding the ones used for treatment of textiles, leather, hides, furskins or other materials
20594175	Lubricating preparations not containing petroleum oil or bituminous mineral oils, used for treatment of textiles, leather, hides, furskins and other materials
850760	Electric accumulators; lithium-ion, including separators, whether or not rectangular (including square)
8506/ 27201100	Primary cells and primary batteries
26201100	Laptop PCs and palm-top organisers
26302200	Telephones for cellular networks or for other wireless networks
26403300	Video camera recorders
26701300	Digital cameras
27512200	Shavers, hair-removing appliances and hair clippers, with self-contained electric motor
28241113	Electromechanical hand drills operated without an external source of power
28241120	Electromechanical hand tools operated without an external source of power (excluding drills, saws)
29102400	Electric Vehicles
30921000	Bicycles and other cycles (including delivery tricycles), non-motorised

Annex 7. List of commodities considered for nickel

Table A7: List of commodities containing nickel. Sources: (Crundwell et al., 2011; International Stainless Steel Forum, 2018; Nickel Institute, 2019a, 2019b; Norgate et al., 2007; Reck et al., 2008)

HS code	Title
2604	Nickel ores and concentrates
750110	Nickel mattes
750210	Nickel unwrought, not alloyed
7504	Nickel powder and flakes
750220	Unwrought nickel, alloyed
720260	Ferro-nickel, in granular/powder form
750120	Nickel oxide sinters and other intermediates
282540	Nickel oxides and hydroxides
282735	Chlorides of nickel
283324	Sulfates of nickel
7218	Stainless steel in primary forms, semi-finished products
7219	Rolled stainless steel sheet, width > 600mm
7220	Rolled stainless steel sheet, width < 600mm
7221	Bar or rod of stainless steel, hot rolled, coiled
7222	Bar or rod of stainless steel, angles, shapes/sections
7223	Wire of stainless steel
7224	Alloy steel in ingots in primary form or semi-finished
7225	Flat-rolled alloy steel nes, width > 600mm
7226	Flat-rolled alloy steel nes, width <600mm
7227	Bar, rod, hot-rolled alloy steel, irregular coils nes
7229	Wire of alloy steel except stainless steel
720521	Alloy steel powder
730459	Alloy steel pipe or tubing, except cold rolled
730650	Pipes and tubing, alloy steel nes, welded
760120	Aluminium unwrought, alloyed
740323	Unwrought nickel silver or cupro-nickel base alloys
740722	Bars, rods, profiles of cupro-nickel or nickel-silver
740822	Wire of cupro-nickel or nickel-silver base alloys
740940	Plate, sheet, strip of cupro-nickel or nickel silver
741122	Tubes, pipes of cupro-nickel or nickel-silver
750511	Nickel bars, rods and profiles, not alloyed
750512	Bars, rods and profiles of nickel alloys
750521	Wire of nickel, not alloyed
750522	Wire of nickel alloys
750610	Nickel plates, sheets, strip and foil, not alloyed
750620	Nickel plates, sheets, strip and foil, alloyed
750711	Tubes and pipes of nickel, not alloyed
750712	Pipes and tubes of nickel alloys
750720	Tube or pipe fittings of nickel
7508	Other articles of nickel stranded wire
381511	Supported catalysts, nickel based
850650	Lithium primary cells
850660	Air-Zinc primary cells
850730	Nickel-cadmium storage batteries
850740	Nickel-iron storage batteries
730520	Oil/Gas casings (>406mm)
730721	Flanges (stainless steel)
730722	Pipe elbows (stainless steel)
730723	Pipe fittings-butt welded (stainless steel)
730729	Pipe fittings-not butt welded (stainless steel)
730830	Doors, windows, frames
732410	Sinks (stainless steel)

8403	Boilers
842810	Elevators
842820	Pneumatic Elevators
842840	Escalators
890520	Floating/Drilling platforms
8601	Rail locomotive - electric
8602	Rail locomotive - diesel
8702	Buses
8703	Cars, light trucks
8704	Trucks
870892	Exhaust Systems
8711	Motorcycles
8712	Bicycles
8802	Aircraft/Aerospace
8803	Aircraft/Aerospace, parts
890110	Cruise ships, ferries
890120	Tankers
890130	Refrigerated vessels
890391	Sailboats
890392	Motorboats
7309	Tanks, vessels (>300L)
7311	Containers for compressed, liquefied gas
8406	Steam turbines
8411	Gas turbines
8413	Pumps
841940	Distillation columns
841950	Heat exchangers
842219	Dishwashers (commercial)
8434	Milking machines, dairy machinery
8438	Food processing equipment
8439	Pulp & Paper machinery
8441	Pulp & Paper machinery, misc.
8445	Textile machinery
8481	Taps, cocks & valves
7321	Stoves
8210	Kitchen appliances
8418	Refrigerators/Freezers
842211	Dishwashers
8450	Washing machines
8471	Personal computers
850940	Food grinders, mixers & blenders
851650	Microwave ovens
7310	Tanks, containers, kegs (<300L)
7317	Nails, staples
7318	Fasteners
732393	Kitchen articles, misc. (stainless steel)
8211	Knives & blades
8215	Tableware (except knives)
841920	Medical/Surgical/Laboratory sterilizers
9018	Medical instruments
7503	Nickel waste and scrap
720421	Ferrous waste and scrap; of stainless steel
720429	Ferrous waste and scrap; of alloy steel (excuding stainless)

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