Deliverable 3.1: Report on data sources as input to WP4

23 December 2019

KAVA Reference (Number, Acronym, Full Title): PANORAMA - Physical AccouNts Of RAw MAterial stock and flow Information Service
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Version No: 1

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Content

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1. Introduction

In view of efficient resource management to ensure raw materials supply security and to enable the transition towards a circular economy and low-carbon energy matrix, a comprehensive and robust database on raw materials is required. This database should include data on economic aspects linked to physical stocks and flows of materials and products, covering the complete value chain of different raw materials. Existing databases provide information on mineral resources and are crucial for drawing strategies to achieve raw materials efficiency and circular economy goals. However, these databases contain information on economics or physical aspects focused on separate stages of the value chain, without the provision of a holistic overview. To complement the available data sources, a significant number of projects addressing resource-efficiency within Europe or even on a global scale have been developed in recent years. Each of these projects has specific objectives and make use of different methodologies, resulting in additional scattered data.

The objective of PANORAMA is to gather data from the currently available data sources and through a data harmonization process, provide a database that summarizes and delivers important physical and economic aspects for at least 10 different materials throughout their complete value chain. The first step towards the development of a complete and harmonized database was an assessment of the different data sources available and the type of data provided. Following this, an overview of the missing data was compiled, which guided the selection of possible data sources for data gap filling. These steps were carried out in Work Package 3 (data harvesting) and Work Package 4 (data processing) of the PANORAMA project.

Due to the vast amount of data to be potentially collected, an approach had to be chosen that keeps the workload of these work packages manageable. Therefore, the first set of substances were identified based on previous work of the partners of the consortium and for which data availability is therefore good. This set includes cobalt, copper and tantalum. It was then expanded to a total of 16 substances based on criteria relating to proliferation and criticality. The European project SCREEN, which is an acronym for "Solutions for Critical Raw Materials – a European Expert Network", provided useful information for this selection process, by summarizing the main applications of critical raw materials (CRM) in the European Union (EU), as illustrated in Figure A1 in the annex (Tercero Espinoza et al., 2019). The link between such a substance perspective and product flows are product compositions, which are also collected in the course of the two work packages mentioned above. Product flows eventually represent the link to national accounting statistics, which portray the linkages between industries or products and final demand.

The report is structured as follows. In Chapter 2, the relevant data types and sources are introduced, and the logic used in structuring the data is described with the help of a generic data model. Chapter 3 describes data availability for the different data types, while Chapter 4 lists the identified data gaps and the associated need for future work. Chapter 5 closes with a brief conclusion.

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2. Data types and sources

This chapter serves as a general introduction to the different data types used to describe materials in the industrial system (Section 2.1) as well as the data sources in which these data can be found (Section 2.2). The considered substances are briefly described in Section 2.3. The system used to structure the data for the later data collection is finally explained in Section 2.4.

2.1 Data types

A general distinction to be made is between **physical and monetary data**, mostly originating from separate fields of study, though sometimes reported alongside each other (as in the UN Commodity Trade Statistics Database). The connection between these two layers is **pricing**, which allocates monetary values to physical quantities of materials.

Most of these statistics are published as **flow data**, i.e. in terms of yearly values of extraction, production, trade etc., while data on (physical) **stocks** is relatively sparse. However, much of the materials are fixated in anthropogenic stocks in the form of products, infrastructure etc. This is illustrated in Figure 1, which compares the magnitudes of the worldwide copper stock with yearly in- and outflows of copper.

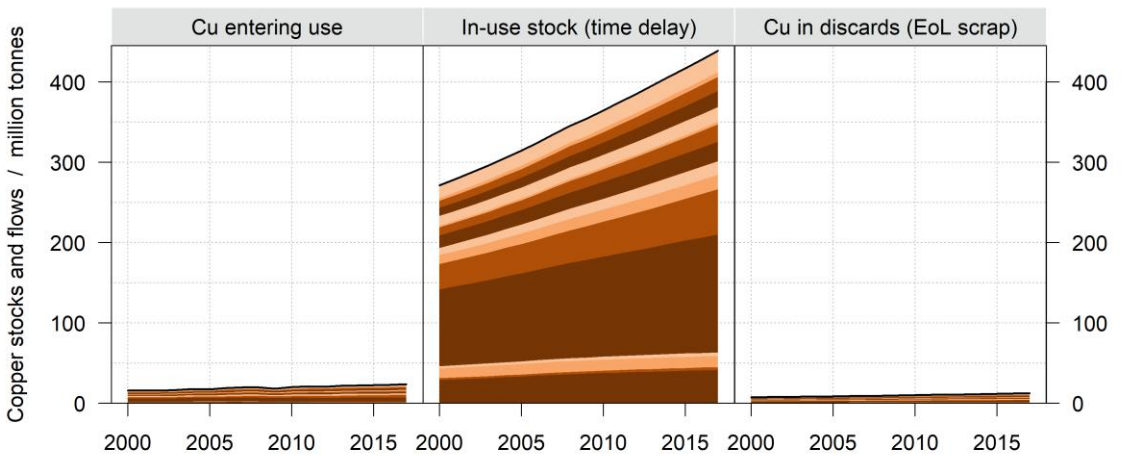

Figure 1. Worldwide flows and stocks of copper (source: Fraunhofer ISI)

When recording materials, two broad perspectives can be adopted. One is a **material flow perspective**, focusing on individual materials along the different stages of their supply chains, starting from extraction over-refinement to the production of end-use goods. The other perspective is **product-based**, tracing the production, flows and accumulation of products which contain a set of different materials. In order to determine the quantities of the materials contained in these products, their material **compositions** must be known.

Due to the vast quantity of data types and sources, it is important to have unique identifiers. Different **classification systems** have been introduced for this purpose for different fields of activity and at different geographical scales. Even though the fields of the study describing the physical and the

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economic layer of the industrial system, respectively, have developed somewhat independently, the layers can be connected through these classification systems. They are summarised in Figure 2.

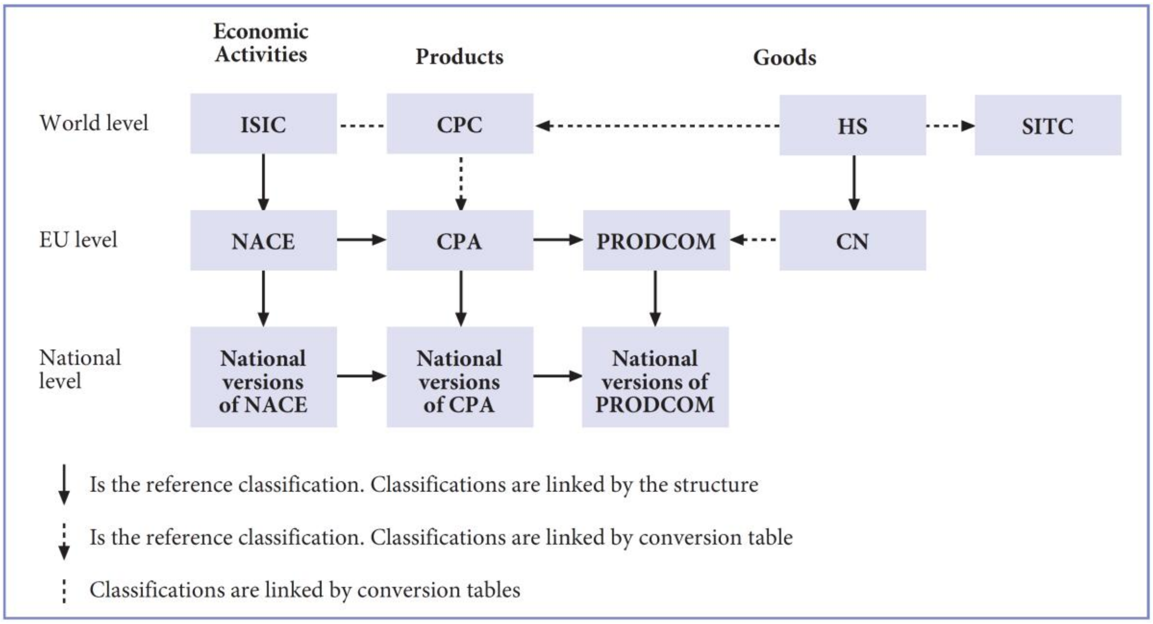

Figure 2. The international system of economic classifications (Eurostat 2008)

These classification systems exist in different vintages, which are characterised by re-organisations and additions of economic activities, products and goods. For example, as new technologies and services are developed, new codes must be introduced, or existing codes have to be adapted. Most of the presently available data are, however, recorded within a limited set of classifications. These are listed in Table 1.

Table 1. Most commonly used classification systems on different Geographical scales

	Economic activities	Products	Goods
World-level	ISIC Rev.4	CPC Ver.2.1	HS H0 (1992)
	ISIC Rev.3.1	CPC Ver.2	HS H1 (1996)
	ISIC Rev.3	CPC Ver.1.1	HS H2 (2002)
		CPC Ver.1	HS H3 (2007)
			HS H4 (2012)
			HS H5 (2017)
			SITC Rev. 4
Europe	NACE Rev.2	CPA 1993	CN 1992
	NACE Rev.1.1	CPA 1996	CN 1996
	NACE Rev.1	CPA 2002	CN 2002
		CPA 2008	CN 2007
		CPA 2.1	CN 2012
			CN 2017

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2.1.1 Prices

In the economic literature and in official statistics, different price concepts are applied, e.g., relative/real prices, nominal prices, price indexes and deflators. Ideally, prices reflect (in some sense) the values and the scarcity (supply-demand relations) of goods or services (in a market). However, speculations and market imperfections affect the price dynamics significantly (e.g., they induce price volatility), such that the prices reported in official statistics are imperfect indicators of values and scarcity in general. Nevertheless, nominal prices and the corresponding price indexes are of major interest in product/goods flow analyses, since they establish a relation between monetary and physical (volume) flow data. Simply speaking, if we divide the monetary value of a good/product flow by the price, we obtain (an estimate of) the quantity of the product/good associated with this flow. Often, the terms 'price' and 'price index' are used interchangeably. However, it makes sense to use the term 'price' such that it refers to the price of a product (i.e., the price of a specific variant of a good/service as traded on the market) and the term 'price index' such that it refers to the (weighted-average) price of a group of goods, services or products. The importance of price *indexes* is obvious since most data types refer to groups of products/goods and industries (in our project). While different variants of a commodity are traded daily at various prices at various (market) places, price statistics report only one price per commodity for the whole market in general. For example, the World Bank's 'Pink Sheet' reports the copper price as the settlement price for grade A, minimum 99.9935% purity copper in form of cathodes and wire bar shapes at the London Metal Exchange (LME). Thus, the prices reported in the statistics should be regarded (crude) indicators of the prices that are realised all over the world.

Commodity prices are available as daily, weekly, monthly or yearly data from various sources, e.g.:

- World Bank's "The Pink Sheet" (https://www.worldbank.org/en/research/commodity-markets#1)
- London Metal Exchange (https://www.lme.com/Market-Data)
- U.S. Geological Survey (e.g., https://pubs.usgs.gov/sir/2012/5188/).

2.2 Data sources

Several data sources are publicly available, besides specialized organizations providing refined paid data. Both physical and monetary data can be harvested from these sources, expressed as flows and stocks of materials or products, being flows reported as the trade of commodities. The data available can address different stages of the materials value chain, starting from the extraction of ore processing, throughout production and manufacturing of (semi)finished goods, up to the end-of-life (EoL) stage of the products and their following recycling or final disposal as waste.

The data sources can be classified in different types, such as:

- databases
- visualization/interactive tools and websites
- project deliverables
- scientific publications
- expert network and trade associations
- research organisations

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- experts and personal contacts
- specialized industries (e.g. recycling or material technology)
- industry associations
- governmental institutions and agencies
- national/regional statistic services

2.2.1 General versus specific data sources

Data harvesting platforms can be either general, providing multiple types of data, or specific, if the data is available for limited aspects. General data sources can provide both physical and monetary flow data, regarding one or several stages of the value chain. They can also deliver historical, economic or statistic values for different materials, products, countries and years. Some examples of general data sources within the scope of PANORAMA are listed in Table 2 with their respective data coverage. Specific data sources are considered the ones providing data regarding commodities trade, particular stages of the value chain, geological properties, economic or industrial activities and research findings. Some examples of specific data sources within the context of PANORAMA are reported in Table 3.

2.2.3 Geographical and temporal coverage

PANORAMA envisions the development of a data harvesting platform to enable data collection for the complete value chain of different materials, not only in Europe but worldwide. Therefore, data collection was aimed at projects, databases and additional data sources providing data on a global scale, rather than just in a European context. However, consistent data sources with such broad coverage are hard to find. Thus, national and regional data sources were also included in the data harvesting scope, which contains good data for specific countries or areas. Sometimes these sources can be challenging in terms of language and definitions, along with the fact that some countries have little reliable data publicly available. When no specific values can be collected for certain countries, data from other countries can be used as a proxy.

The temporal coverage is another aspect that imposes difficulties in the development of a complete and updated database. Some sources provide meaningful and detailed data but lack in representativeness for the current period. To overcome the lack of data up-to-date, the harvesting process was focused on the most recent data, ideally related to the previous five years. If no data for this period could be gathered from open sources, materials expert opinions were also considered.

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Table 2. General data sources, corresponding data provided and web page links

Data source name	Type of data source	Type of data available	Link
CARBON-CAP - Carbon emission mitigation by Consumption-based Accounting and Policy - address emissions related to consumption and production	EU Project (FP7)	Carbon emissions embodied in trade and consumption	http://www.carboncap.eu/
COST-Minea: The European Cooperation in Science and Technology - Mining the European Anthroposphere	EU Project (H2020)	Reporting of material resources/reserves in the anthroposphere	https://www.cost.eu/actions/CA15115/#tabs|Name:overview
CREEA - Compiling and Refining Environmental and Economic Accounts	EU Project (FP7)	Carbon, water, land, material use	http://www.creea.eu/
DESIRE - Development of a System of Indicators for a Resource Efficient Europe	EU Project (FP7)	Indicator for biodiversity and ecosystems impacts resulting from the use of raw materials	http://fp7desire.eu/
Directorate-General for Environment (DG ENV)	European Commission department responsible for EU policy on the environment	EU environment policy	https://ec.europa.eu/dgs/environment/index_en.htm
Eurostat	European statistics	Information on statistics for Europe	https://ec.europa.eu/eurostat/data/database
EXIOBASE - Environmentally Extended Supply and Use / Input Output (MR EE SUT/IOT) database	EU Project (FP7)	EEIOT data	https://www.exiobase.eu/
MICA - Mineral Intelligence Capacity Analysis	EU Project (H2020)	Raw Materials information	http://micaontology.brgm-rec.fr/MICAOntology/
Minerals4EU - Minerals Intelligent Network for Europe	EU Project (FP7)	Data for primary minerals production, trade, resources and reserves. For secondary materials, it contains data for	http://www.minerals4eu.eu/

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		mineral-based waste generation, treatment and trade	
Minfuture	EU Project (H2020)	A systems approach for the monitoring of the physical economy/ global material flows and demand-supply forecasting for mineral strategies	https://minfuture.eu/
Min-Novation - Mining and Mineral Processing Waste Management Innovation Network	EU Project (Baltic Sea Region Programme)	Waste management of the mining and ore processing for countries of the Baltic Sea region	http://www.eifi.info/min-novation/
ORAMA -Optimising data collection for Primary and Secondary Raw Materials	EU Project (H2020)	Primary and secondary raw materials	https://orama-h2020.eu/
POLFREE - Policy options for a resource-efficient economy	EU Project (FP7)	GDP, jobs, CO2 emissions, RM consumption, agricultural land footprint (business as usual and other scenarios)	https://www.ucl.ac.uk/polfree
ProSUM -Prospecting Secondary raw materials in the Urban mine and Mining wastes	EU Project (H2020)	Available data on products put on the market, stocks, composition and waste flows for all EU 28 Member States plus Switzerland and Norway. Iceland is also included for vehicles	http://www.prosumproject.eu/
RMIS - Raw Materials Information System	EC information platform	Information on different raw materials	https://rmis.jrc.ec.europa.eu/
SCRREEN - Solutions for Critical Raw Materials - A European Expert Network	EU Project (H2020)	An EU Expert Network that covers the whole value chain for present and future critical raw materials	http://scrreen.eu/results/
SmartGround	EU Project (H2020)	Secondary raw materials and landfill mining in the EU territory	http://www.smart-ground.eu/
The Organisation for Economic Co-operation and Development (OECD)	International policy organisation	Trade-in raw materials (exports, export restrictions, production, reserves)	http://www.oecd.org/tad/benefitlib/export-restrictions-raw-materials.htm

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UN International Resource Panel (UN IRP)	A panel consisting of eminent scientists, highly skilled in resource management issues	Resource efficiency, Global material flows (database), International trade in resources, Metal recycling, Global land use, Metal stocks in society	https://www.resourcepanel.org/

Table 3. Specific data sources, corresponding data provided and web page links

Data source name	Type of data source	Type of data available	Link
BGR - The Federal Institute for Geosciences and Natural Resources	The central geoscientific authority providing advice to the German Federal Government	Mineral commodities, marine resource exploration, final dispose of radioactive waste	https://www.bgr.bund.de/EN/Home/homepage_node_en.html
BGS - British Geological Survey	British Geological Survey	Production and trade statistics on a wide range of mineral commodities	https://www.bgs.ac.uk/mineralsuk/statistics/wms.cfc?method=searchWMS
Comtrade - United Nations International Trade Statistics Database	United Nations International Trade Statistics Database	International trade data	https://comtrade.un.org/
EEA - European Environment Agency	Environment agency	E-waste, resource efficiency and waste profiles per country	https://www.eea.europa.eu/
EGS - EuroGeoSurveys	The Geological Surveys of Europe	Mineral resources, superficial deposits, waste management and disposal	http://www.eurogeosurveys.org/
ERECON Network – European Rare Earths Competency Network	EC experts' network	Rare earth elements (REE)	https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/erecon_nl
PRODCOM - Production Communautaire	Survey for the collection and dissemination of statistics on the production of industrial (mainly manufactured) goods, both in value and quantity terms, in the European Union (EU)	Statistics on the production of manufactured goods	https://ec.europa.eu/eurostat/web/prodcom/data/database/
SNL Metals & Mining	Global mining information	Mining activities worldwide	https://www.snl.com/marketing/microsite/MEG/mm_pagetwo.html

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USGS - United States Geological Survey	United States Geological Survey	Raw materials relevant for USA	https://www.usgs.gov/

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2.3 Overview of considered substances

Since PANORAMA aims at a complete anthropogenic material cycle considering both stocks and flows, not all substances can be covered within the scope of the project. Thus, a limited set based on different criteria was chosen. Based on previous work conducted by the consortium, three substances were used for initial database identification and selection of parameters to be covered in this report. The criteria used for the later expansion of that list relate to production volumes, variety of uses and criticality. Finally, a list of 16 substances was defined and is summarized in Table 4, from which at least 10 should have their complete material cycle assessed within the timeframe of the project.

Table 4. List of substances considered in PANORAMA

Substance	Inclusion criteria
Aluminium (Al)	Volumes, variety of uses
Cerium (Ce)	Critical according to EU CRM list[1]
Cobalt (Co)	Critical according to EU CRM list
Copper (Cu)	Volumes, variety of uses
Dysprosium (Dy)	Critical according to EU CRM list
Germanium (Ge)	Critical according to EU CRM list
Indium (In)	Critical according to EU CRM list
Iron (Fe)	Volumes, variety of uses
Lanthanum (La)	Critical according to EU CRM list
Natural Graphite	Critical according to EU CRM list
Niobium (Nb)	Critical according to EU CRM list
Neodymium (Nd)	Critical according to EU CRM list
Palladium (Pd)	Critical according to EU CRM list
Platinum (Pt)	Critical according to EU CRM list
Tantalum (Ta)	Critical according to EU CRM list
Tungsten (W)	Critical according to EU CRM list

Previous research studies performed by some of the PANORAMA partners assessed entirely or partially the material cycle of 3 of the 16 substances listed in**Error! Reference source not found.** Leiden University (CML) developed a study focused on flows of Ta within Europe (Deetman et al., 2017), Fraunhofer Institute for Systems and Innovation Research (FhG-ISI) determined the stocks and flows of Cu at different geographical scales (cf. Glöser et al., 2013, Soulier et al., 2018a, Soulier et al., 2018b) and Ghent University (UGhent) performed a material flow analysis (MFA) focused on Co applications (Godoy León et al., 2019). Therefore, these 3substances were selected for an initial overview of data availability along their complete value chain. The data availability assessment considered physical and monetary flows data, composition or content in all their (semi)finished components and products as well as stocks and prices information. Material profiles and applications of Ta, Cu and Co are illustrated below:

[1] COM(2017) 490 final

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2.3.1 Tantalum

Tantalum (Ta) has high economic importance since several industrial sectors depend on the supply of this metal and in most of its applications, substitution by other elements is not yet possible. However, the supply of tantalum is concentrated in a few countries, representing a high supply risk. All these factors make this mineral a critical raw material, as defined by the European Commission in the most recent Critical Raw Materials (CRM) list, released in 2017. Of the 3 substances considered in detail, tantalum has relatively low overall production volumes, as illustrated in Figure 3.

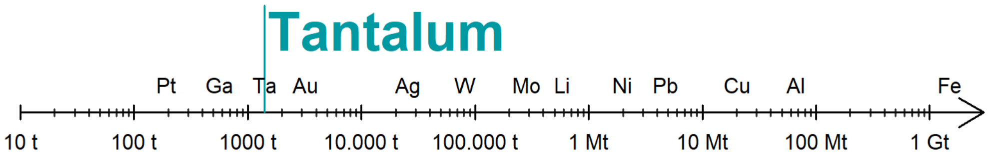

Figure 3. Mine production of tantalum in 2015 (BGR, 2017; EC, 2014; Marscheider-Weidemann et al., 2016; Tercero-Espinoza et al., 2015; USGS, 2017, World Bank, 2016)

This production has historically been relatively concentrated, as indicated by a high Herfindahl-Hirschman-Index (HHI, see Figure 4). While this situation has been changing somewhat in recent years, tantalum is still on the European Commission's CRM list, as stated above.

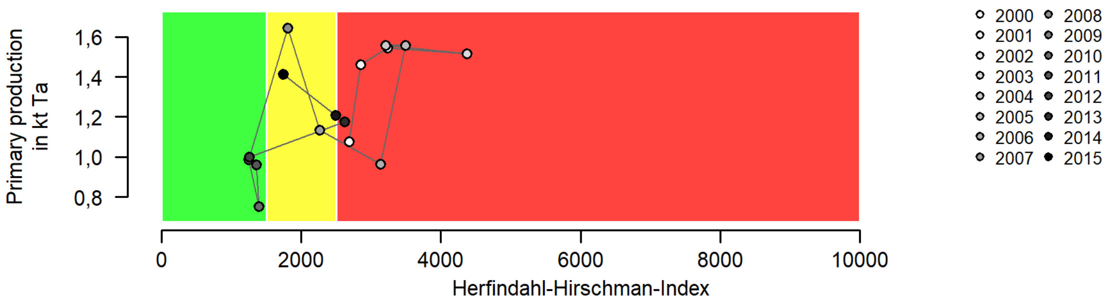

Figure 4. Quantities and market concentration of tantalum production (BGR, 2017; EC, 2014; Marscheider-Weidemann et al., 2016; Tercero-Espinoza et al., 2015; USGS, 2017, World Bank, 2016)

Deetman et al. (2017) describe how several applications rely on the properties of Ta, and report that this dependence increases in modern alloys and digital components. Capacitors represent a significant share of Ta use, which is a component needed in electronic devices such as mobile phones, cameras, computers, TVs, GPS devices, vehicles and others. In general, capacitors represent 33% of Ta total demand, followed by superalloys, with 22% of the total demand (BGS et al., 2017a). The typical uses of Ta are listed in Table 5.

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Table 5. Distribution of global end uses of tantalum (BGS et al., 2017a)

Typical uses	Fraction of total use in an application
Capacitors	33%
Superalloys	22%
Sputtering targets	17%
Chemicals	11%
Mill products	9%
Carbides	8%

According to Tercero-Espinoza and Erdmann (2018), tantalum can be fairly easily substituted in its main application, capacitors, while substitutability is limited for the other main applications (see Figure 5). This implies that the demand for tantalum is unlikely to decrease considerably due to material substitutions in the other main applications.

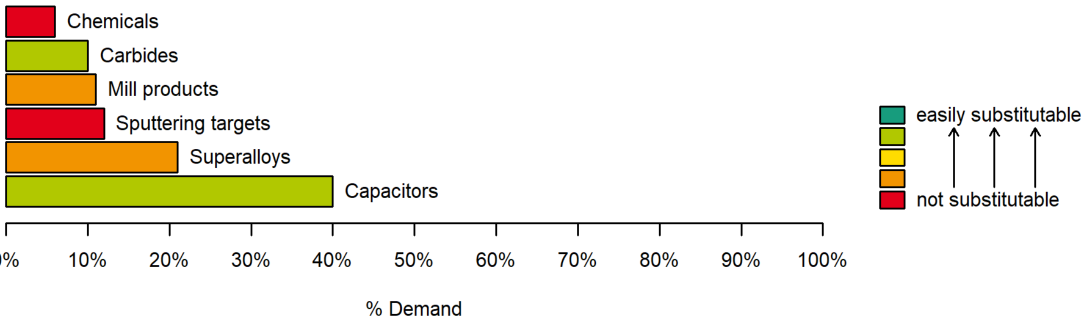

Figure 5. Main uses of tantalum and possibilities for substitution (BGR, 2017; EC, 2014; Marscheider-Weidemann et al., 2016; Tercero-Espinoza et al., 2015; USGS, 2017, World Bank, 2016)

In a study on raw material demand for future technologies, Marscheider-Weidemann et al. (2016) identified considerable potential tantalum demand increases until the year 2035 (see Figure 6). Based on current technological trends, the demand for tantalum can, therefore, be expected to increase considerably in the coming years.

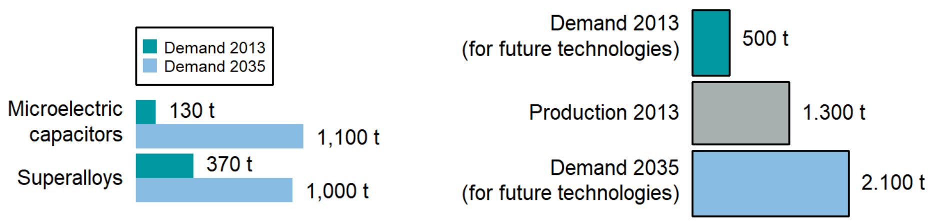

Figure 6. Use of tantalum in future technologies (BGR, 2017; EC, 2014; Marscheider-Weidemann et al., 2016; Tercero-Espinoza et al., 2015; USGS, 2017, World Bank, 2016)

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2.3.2 Copper

Copper (Cu) is a historically widely used material, due to its important metallic properties, such as resistance to corrosion, malleability, ductility and conductivity, being the best conductor of electricity after silver (BGS et al., 2017 b). Copper is among the metals with the highest production volumes, as indicated by Figure 7.

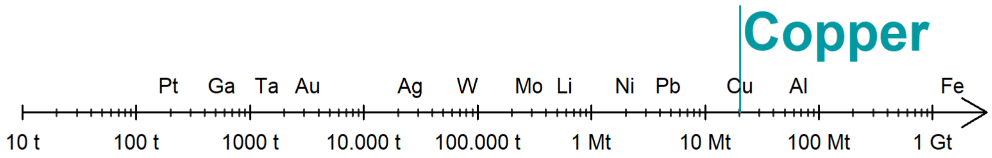

Figure 7. Mine production of copper in 2015 (BGR, 2017; EC, 2014; Glöser et al., 2013; ICSG, 2017; Marscheider-Weidemann et al., 2016; USGS, 2017, World Bank, 2016)

At the same time, copper production is not as concentrated as, for example, that of tantalum. As Figure 8 shows, the concentration of production has even been decreasing in recent years.

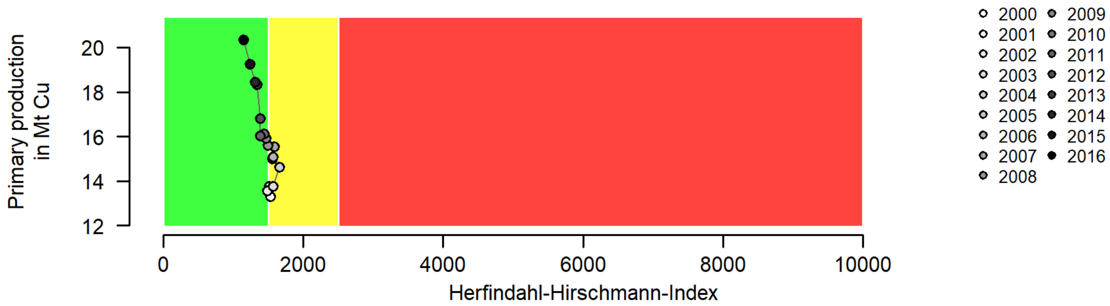

Figure 8. Quantities and market concentration of copper production (BGR, 2017; EC, 2014; Glöser et al., 2013; ICSG, 2017; Marscheider-Weidemann et al., 2016; USGS, 2017, World Bank, 2016)

The list of Cu applications is quite extensive if all the (semi)finished goods are considered, which includes alloys, wires, fittings, electrical outlets and switches, pipes and others. The main uses of Cu are in components and household appliances as well as tubes, plates and wires. An overview of the typical uses of this metal is listed in Table 6.

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Table 6. Distribution of global end uses of copper (BGS *et al.,* 2017b)

Typical uses	Fraction of total use in an application
Components and households	22%
Tubes, plates and wires	21%
Machinery	15%
Digital appliances	14%
Ships, trucks and armoured vehicles	10%
Automotive	6%
Jewellery	5%
Oxides and dopants	3%
Subparts of interior	2%
Electrolytic refined copper	2%

Copper is relatively indispensable in these applications, as it displays limited substitutability for most of them except construction (see Figure 9). This implies a certain risk with respect to future demand since the proliferation of these applications is likely to lead to proportional growth in copper demand without feasible substitutes.

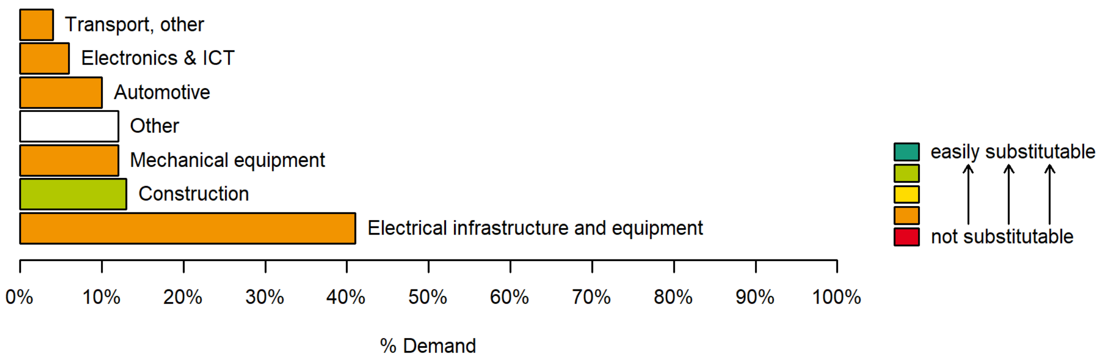

Figure 9. Main uses of copper and possibilities for substitution (BGR, 2017; EC, 2014; Glöser et al., 2013; ICSG, 2017; Marscheider-Weidemann et al., 2016; USGS, 2017, World Bank, 2016)

Future demand increases are mainly expected in the form of electric traction motors, mainly due to the electrification of the transport system (see Figure 10). However, the demand for these applications is relatively low compared to overall copper demand.

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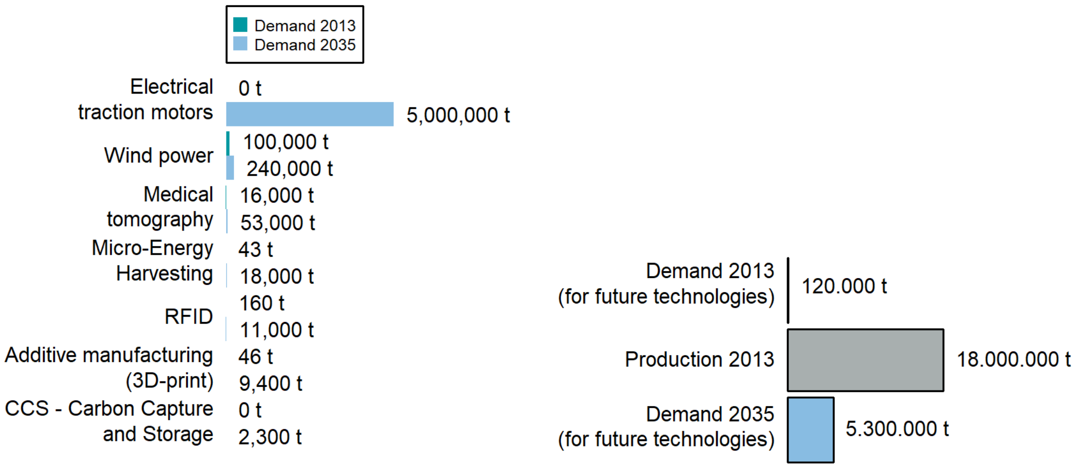

Figure 10. Use of copper in future technologies (BGR, 2017; EC, 2014; Glöser et al., 2013; ICSG, 2017; Marscheider-Weidemann et al., 2016; USGS, 2017, World Bank, 2016)

2.3.3 Cobalt

Like Ta, cobalt (Co) is also included in the CRM list released by the European Commission in 2017, due to its high economic importance, high supply disruption risk and difficult substitutability. In the last 20 years, cobalt production and use have experienced strong growth, its global refined production has increased more than fourfold, from approximately 27,000 to 119,000 tons per year (BGS, 2019, see also Figure 11).

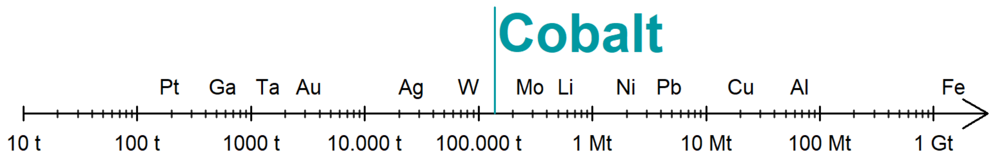

Figure 11. Mine production of cobalt in 2015 (BGR, 2017; DERA, 2017; Harper et al., 2012; Marscheider-Weidemann et al., 2016; Tercero-Espinoza et al., 2015; USGS, 2017, World Bank, 2016)

Cobalt is mostly a by-product of nickel and copper mining operations and only mined independently in some sites in North Africa and Canada. Around 55% of the global cobalt production comes from nickel ores (Cobalt Institute, 2019). While copper and nickel mining overall has become less concentrated in recent years, the ones associated with cobalt production have become more concentrated (see Figure 12). This is one of the reasons why cobalt is on the CRM list.

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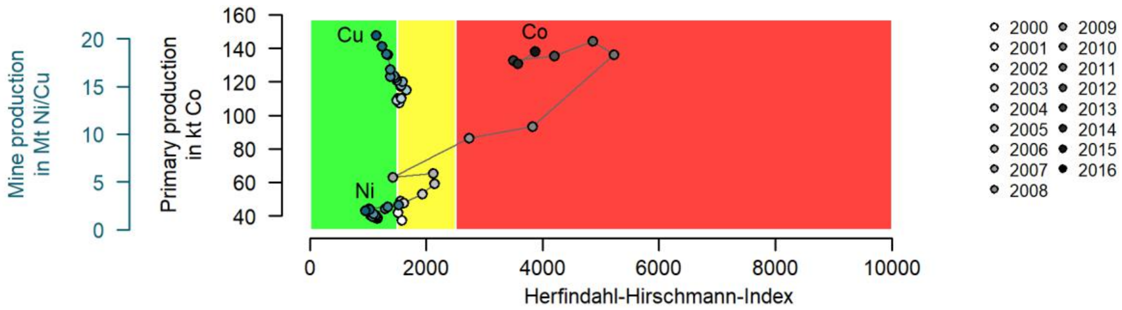

Figure 12. Quantities and market concentration of cobalt production (BGR, 2017; DERA, 2017; Harper et al., 2012; Marscheider-Weidemann et al., 2016; Tercero-Espinoza et al., 2015; USGS, 2017, World Bank, 2016)

The growth in cobalt demand has been mainly driven by the increasing use of Co in the production of superalloys, catalysts, hard metals, and especially of rechargeable batteries (Shedd, 2010; Shedd, 2017). Metallurgy represents important and classic uses of Co, more specifically in the manufacturing of (super)alloys and hard metals, which are then converted into machines, tools or used for aeronautic applications. Electronic devices are also an important and significant application of Co, either in laptops, phones, medical devices or rechargeable batteries, such as lithium-ion batteries. A boom in rechargeable batteries has been noticed in the past ten years, as a result of the transition towards a low-carbon energy supply. This increase has a direct impact on the demand for Co. In 2010, 15% of the total Co demand was for batteries (Rietveld et al., 2013), which increased to 42% in 2017 (Cobalt Institute, 2017). Therefore, batteries have become the main application for cobalt and this application share will most likely increase in the coming years. Other typical uses of Co are listed in Table 7. The Cobalt Institute is a good source for general and specific information on the different stages of the supply chain, specifically for end-use products.

Table 7. Distribution of typical uses of cobalt (BGS *et al.,* 2017a)

Typical uses	Fraction of total use in an application
Battery components	42%
Superalloys, hard facing/high strength steel and other alloys	23%
Hard materials (carbides and diamond tools)	10%
Catalysts	7%
Ceramic and pigments	5%
Magnets	5%
Tyre adhesives and paint dryers	4%
Others	4%

As shown in Figure 13, these applications possess limited substitutability for cobalt, underlining its categorisation as a critical raw material.

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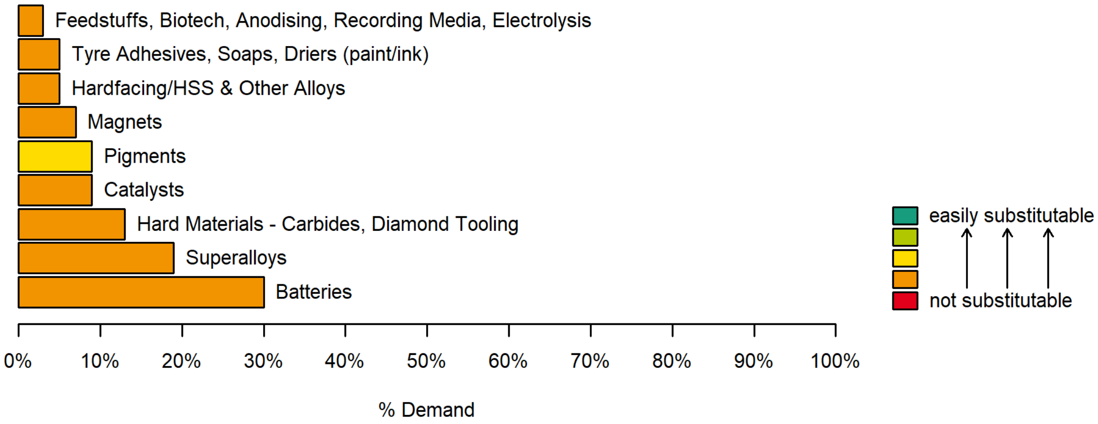

Figure 13. Main uses of cobalt and possibilities for substitution (BGR, 2017; DERA, 2017; Harper et al., 2012; Marscheider-Weidemann et al., 2016; Tercero-Espinoza et al., 2015; USGS, 2017, World Bank, 2016)

The application with the highest potential future demand for Co is lithium-ion batteries (LIB) for electric vehicles, which are assumed to grow considerably in the course of the electrification of the transport system. Future demand for cobalt for this technology alone comes close to current total demand.

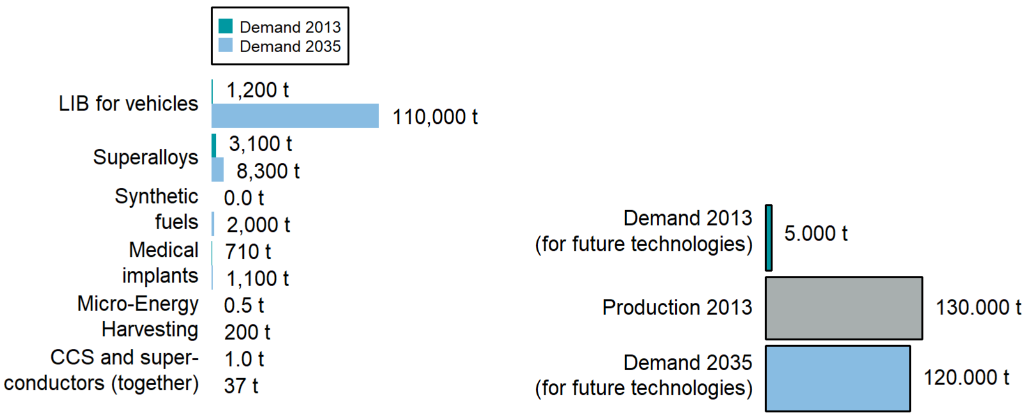

Figure 14. Use of cobalt in future technologies (BGR, 2017; DERA, 2017; Harper et al., 2012; Marscheider-Weidemann et al., 2016; Tercero-Espinoza et al., 2015; USGS, 2017, World Bank, 2016)

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2.4 Representation of data

2.4.1 Flows

The modern goods production process can be understood as a complex, geographically fragmented chain of production and trade activities (see also Figure 15).

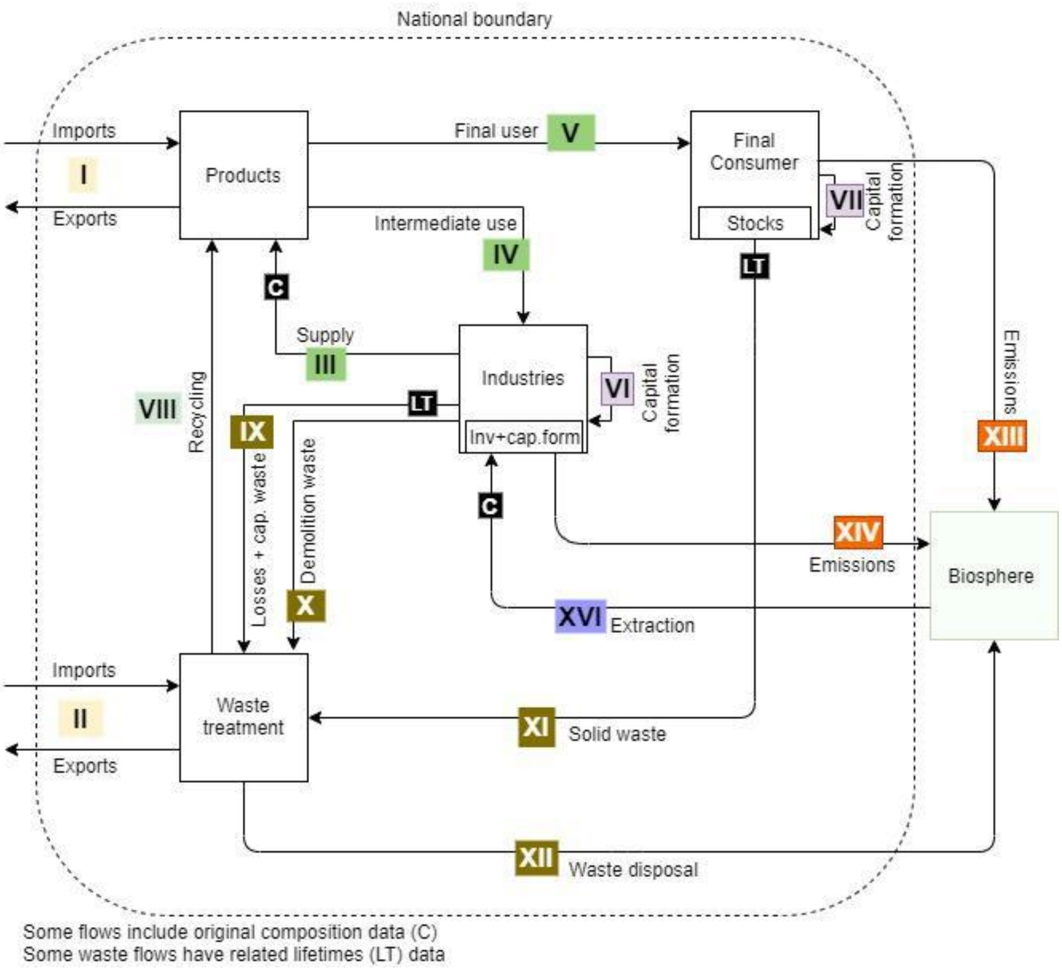

Figure 15. A simple data representation

At the beginning of this chain is the **extraction** of natural resources, which involves, e.g., quarrying, open-pit mining and underground mining. In general, the extracted resources (e.g., ores and brines) are processed to some extent at the site of extraction (crushing, grinding and concentration). The extraction and processing of resources require inputs such as labour, capital, energy and other natural resources (water, chemicals). As in the case of copper-cobalt ores and concentrates, an ore or concentrate can contain different substances that are of interest in our study. That is, there is no one-to-one correspondence between (processed) ore types and the substances considered in our study. The extracted (and processed) resources are **traded nationally and internationally** to varying extents. The different properties of these trade flows (in particular, the values and quantities) are captured by the data sources on intermediate/international goods/product flows and economic activities (e.g., input-output tables; see Section 2.2).

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The **production of final goods** - exactly speaking, the transformation of (processed) natural resources (e.g., ores, brines or concentrates) into final goods - involves **different intermediate steps/products** and the aforementioned inputs (labour, capital, energy). At the early stages of the production chain, the intermediate production deals with the *separation* of the desired substances (cf. Section 2.3) from other substances and waste products. This occurs in many ways (leaching, smelting, refining) and results in many different types of intermediate products (chemicals, powders, briquettes, cathodes) of varying substance content. At later stages, the intermediate production deals with the *combination* of different substances, materials and more complex intermediate products to obtain (even more) complex intermediate products and final goods. The intermediate products (from all stages of the production chain) and the final goods are **traded nationally and internationally** to varying extents and covered by the aforementioned data sources on intermediate, final and international goods/product flows and economic activities.

In general, (domestically produced and imported) final goods are **used** for **consumption**, **investment**, (net) **exports** (where the latter category includes consumption and investment goods) and **changes in inventories**. In other words, **final demand** includes household consumption, government consumption, investments, (net) exports and changes in inventories. When we consider the flow of products, it goes from producers to two different types of customers, i.e. industries (**intermediate consumption**) and final consumers **(final demand**). A customer can be another industry, which uses the products to create other products or services. For example, a fridge can be sold to a restaurant, which uses it to provide a service. Goods can also be sold to a final consumer. In the example of the fridge, the fridge can also be sold to households or any other of the final demand categories mentioned above.

At the **end of the life** of final goods, two major treatment alternatives exist, **recycling** (which yields **secondary materials/products**) and **waste disposal**. The corresponding commodity types (recyclates and waste) are **traded nationally and internationally**, and the corresponding end-of-life flows are covered by the aforementioned data sources. Waste can be defined as products that are not used anymore. There are several options for what happens with a product once it has become waste. First, if it is not discarded immediately, then it is in stock. There are several treatments of waste possible. These include recycling, incineration and landfilling. What type of treatment is used depends on how the waste was disposed of and the location where the disposal takes place. If it was disposed of with the municipal solid waste, the chances of recycling will be negatively affected. The separately collected waste will have higher chances of being recycled although its success depends on many external factors such as market prices, contamination, quality, etc.

All the stages of the production chain (extraction, processing, intermediate production, final production), uses (consumption, investment and exports), end-of-life treatment (recycling and waste disposal), as well as the corresponding national and international trade flows, are associated with **emissions** to varying degrees.

2.4.2 Compositions

The data sources discussed in Section 2.2 provide information (quantities and values) on **goods/product flows** and economic activities related to the different stages of the production, uses, end-of-life treatment and trade of goods. For translating the information on product/goods flows (quantities) into information on **flows of substances** (cf. Section 2.3), data on the **composition** of products/goods, in particular, information on the **substance contents** of goods/products is necessary. This composition data is collected in the course of our project from various sources (see Section 3.2) and can be used to derive the substance flows along the extraction-production-end-of-life chain.

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2.4.3 Lifetimes

Lifetimes is an important parameter for a dynamic system as it portrays the current and historical societal metabolism. In PANORAMA, the lifetimes have been studied for various commodities and applications. Although many published reports and articles have studied MFA (Material Flow Analysis)/MSA (Material Substance Analysis), a handful of studies have provided information about the lifetime of products. Information regarding a component or a material life is a little to non-existent.
Secondly, the provided lifetimes and static over the years. For a dynamic material flow analysis (dMFA), such static lifespans are unreliable.
Furthermore, there is confusion about the definition of lifetimes. Lifespan is different for all individuals. Murakami et al. (2010) have described lifespan as:

- Product age is defined as the time span from the beginning of a product's life to the present (or the time of interest).
- Residential time is defined as the duration of the existence of the goods in question, such as materials or substances in our society, regardless of whether the goods still function.
- Service lifespan is defined in terms of goods or parts, not in terms of the owners. It denotes the duration of the period when the goods function and use, including the duration of distribution for the next use.
- Possession span symbolizes for how long a consumer possesses the goods in question.
- Duration of use: for how long a consumer uses the goods in question. Because it is defined for an owner, the duration of use is different from the service lifespan.
  The difference between possession span and duration in use is the "dead-storage period" that indicates the duration of hibernation. Thus, the product in question is not in use during this period, it may not be included in the service lifespan of the product.

Within this context, the lifetime of a good/ product or commodity is often the possession span provided by the users. Such information is scattered in the literature and is mingled in terms of terminology. In PANORAMA, the possession span is considered as lifetimes.

2.4.4 Stocks

In general, the data on flows of substances/goods is not sufficient to calculate the stocks of substances/goods available in the economy or at the different stages of the substance life cycle (which ranges from extraction to end-of-life treatment). The reason for this is that a substance can stay within this cycle for relatively long periods due to the duration of production processes, a build-up of inventories and, most importantly, the length of the periods of use as a consumption or investment good (see also the copper example in Section 2.1). These period lengths (lifetimes) vary from product to product and depend on many different factors (see Section 2.4.3). In addition to the substance/goods flow data, lifetimes are the key ingredient in the calculation/estimation of substance/goods stocks. The methods/models (and lifetime concepts) used for estimation of stocks can differ significantly across different sources (see Section 3.3 for some examples).

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3. Data availability

In this chapter, data availability for the different data types will be described. Section 3.1 reports flow data availability along with the data representation introduced in Section 2.4. Data availability for compositions of products containing the three substances in focus is described in Section 3.2. This section also contains exemplary compositions of the main product groups. Section 3.3 discusses data availability regarding product lifetimes and exemplarily lists the average lifetimes of major product groups. The availability of stock data is briefly discussed in Section 3.5.

3.1 Flow data

3.1.1 Extraction

Mineral extraction is the first stage of the anthropogenic material cycle from which metals enter the economy. Extraction data is necessary for the material mass balance of economies, and therefore to generate the supply and use tables in PANORAMA. The necessary data comprises the global mineral production of the elements that were selected for the project (see Table 4).
Part of the data can be provided by several bodies. Some of the most prominent ones include reports like the World Mining Data, geological survey agencies such as the British Geological Survey (BGS) or the United States Geological Survey (USGS), and the Global Materials Flow Database by the International Resource Panel (IRP).

British Geological Survey (BGS)

The BGS has records of a variety of mineral, oxide and metal production, and trade data since 1913. There is an online tool where data between 1970 and 2017 can be retrieved. It is possible to retrieve production data for the following elements or groups selected in the project:

- Aluminium: bauxite, alumina and primary aluminium
- Cobalt: mined and refined
- Copper: mined, refined and smelter
- Germanium: metal
- Graphite: amorphous and crystalline
- Indium: refined
- Iron: iron ores, pig iron, ferro-alloys, crude steel
- Platinum Group Metals: platinum and palladium ores or metals
- Rare earth: minerals and oxides
- Tantalum and Niobium: minerals
- Tungsten: mine

The online tool also allows users to harvest trade data for a set of European countries from 2003 to 2014. These can include ores, oxides or metals. The following relevant categories are available:

- Bauxite, alumina and aluminium
- Cobalt

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- Copper
- Iron ore
- Iron, steel and ferro-alloys
- Platinum Group Metals
- Rare earth
- Tantalum and niobium
- Tungsten

United States Geological Survey (USGS)

The USGS compiled the United States and a wide range of countries mineral yearbooks. It provides information with mineral, oxide and metal production from 1994 to 2016. The database also contains American production and trade data between the United States and other countries for a number of minerals, oxide and metal commodities. The online tool allows to harvest the aforementioned statistics. The database for American production and trade covers the following relevant elements and groups for the project:

- Cobalt
- Copper
- Germanium
- Graphite
- Indium
- Platinum Group Metals
- Rare earth
- Tantalum and Niobium
- Tungsten

It is unknown at this stage the exact number of minerals that has been compiled by USGS in the other countries. However, such extensive work has been conducted by the IRP and will be discussed in the next section.

World Mining Data

The World Mining Data is an annual report issued by the Austrian Federal Ministry for Sustainability and Tourism (BMNT). It is possible to retrieve data as an Excel file between 2013 and 2017 both by country and mineral.
The mining data has been collected via questionnaires that were sent to "*the National Committees of member countries of the World Mining Congress as well as to other bodies such as Embassies, Foreign Trade Representatives etc."* (BMNT 2019). The compilation also includes data generated by geological surveys such as BGS and USGS.
The database has an extensive geographical comprehension and contains information for the following materials that will be covered in the project:

- Aluminium: bauxite and aluminium
- Cobalt
- Copper

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- Germanium
- Graphite
- Indium
- Iron
- Niobium
- Palladium
- Platinum
- Rare Earths Concentrates
- Tantalum
- Tungsten

Global Material Flows Database

The Global Material Flows Database is the product of the combined work of the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Vienna University of Economics and Business (WU Vienna), the Institute of Social Ecology Vienna (SEC), the University of Nagoya, the University of Sidney's Integrated Sustainability Analysis (ISA) and the UN Environment International Resource Panel.

It contains global data from 1970 to 2017 of diverse material flow accounts: biomass, fossil fuels, non-metallic minerals and metal ores. However, recent years can be based on projections for some accounts, as primary datasets used in the construction of the database did not englobe recent years. Therefore, it is recommended to utilize the data up to 2012.

In the case of domestic extraction of metal ores, the BGS, USGS and World Mining Data were integrated into one consistent data set. It facilitates the work of having to compile all the previous described databases. In Exiobase for instance, data from the Global Material Flows Database was used for the domestic extraction of metal ores. From the list of the elements that will be mapped in the PANORAMA project, data for the following ones are included in the database:

- Aluminium: bauxite
- Cobalt
- Copper
- Germanium
- Natural graphite
- Indium: as indium and thallium
- Iron
- Niobium + Tantalum
- Rare earth metals
- Platinum Group Metals (PGM)
- Tungsten

The database itself contains data not only of the domestic extraction, but also of the concentrations of the metals, and the unused extraction. The latter refers to the overburden of mining activities. According to the IRP, the database will be updated to 2017 with real datasets. Additionally, the aggregates such as indium and thallium, niobium and tantalum and platinum group metals will also be

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disaggregated into the domestic extraction of individual elements. However, this is not the case for rare earth metals. This updated database will be available at the beginning of 2020.

Mining and Quarrying from Production

It is also possible to find data of mining and quarrying in production statistics such as Prodcom, UN Industrial Commodity Statistics and several National Statistics Offices. This will be further discussed in the Production section.

3.1.2 Production

Statistics of the nation's manufacture sector are used to provide detailed supply and use tables in the PANORAMA project. Due to the high variability of concentration data in aggregated product groups, it is important to utilize highly detailed data. Industrial production records can be found at Prodcom, UN Industrial Commodity Statistics, and various national statistics offices.

Prodcom

In Europe, annual statistics of industrial output can be found at the Prodcom database. It covers both the mining and quarrying and manufacturing sectors. These correspond respectively to sections B and C of the Statistical Classification of Economy Activity in the European Union (NACE 2).
In this database, the manufactured goods are classified according to their own classification system, which is a combination of the NACE and the Statistical Classification of Products by Activity (CPA).
The list of products contains approximately 3900 commodities, and both monetary and physical data is provided in Excel files from 1995 to 2018. In the initial years, data only for the EU-15 has been collected, whereas in later years it is possible to find data not only for EU-28 but also countries such as Iceland, Norway, Turkey, Bosnia and Herzegovina, Montenegro, Macedonia and Serbia.
There are many data points that are omitted in this database due to country confidentiality issues within this database, although the aggregate value for Europe (from EU-15 to EU-28) is available.

UN Industrial Commodity Statistics

The UN compile global industrial statistics on a yearly basis through its Industrial Commodity Statistics Yearbook. Both physical and monetary data is available for a set of around 600 commodities. These cover sections B, C and D of ISIC Revision 4, englobing mining, manufacturing and electricity and gas, respectively. The Central Production Classification (CPC) 1.1 is used in order to define the different products available at the database.
The online tool allows the users to download data from 1995 to 2016, although historical data is possible to be retrieved upon request.
This impressive global database is however not extensive. It is possible to find missing physical or monetary data for some years and countries. For this reason, the UN Industrial Commodity Statistics should be combined with national statistics offices own databases whenever possible.

National Statistics Office Production databases

The PANORAMA project will be built upon the existing structure of Exiobase hybrid tables. In the latter, the multiregional tables cover 44 countries plus 5 rest of the world regions. A significant number of the

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44 countries are European. Therefore, their industrial output statistics are recorded in Prodcom. For the other remaining countries, it is possible to find data both at the UN Industrial Commodity Statistics and National Statistics Office. For the following countries and regions, it was possible to find some information:

- Brazil: physical and monetary data for industrial production and sales are collected by the Geography and Statistics Brazilian Institute (IBGE). Data of comprehensive list of about 3400 products were recorded and provided online from 2001 to 2016. These include both the mining and manufacturing sector and are grouped using its own classification system.
- Canada: only monetary data of the industrial output was found at the national statistics office - Statistics Canada. In total, 259 industries are covered via the North American Industry Classification System (NAICS).
- China: physical data is available at the National Bureau of Statistics of China. Data of only 88 products (mainly manufactured goods) are available from 1999 to 2018. These are grouped with its own classification system.
- Japan: physical and monetary data of manufacturing production is available at the Ministry of Economy, Trade and Industry (METI) of Japan. It is possible to find statistics for around 2000 products from 2007 to 2018. The sectors include chemical, metals, machinery, mining, paper, printing, plastics, rubbers, textiles and consumer goods
- South Korea: physical data of the mining and manufacturing sector can be found at the Korean Statistical Information Service (KOSIS). The database has records of production, shipment, inventory, domestic and export quantities for only 79 products from 1995 to 2018.
- United States: The Annual Survey of Manufactures conducted by the United States Census Bureau provides monetary data over 1000 manufacturing industries from 2004 to 2016. The industries are classified according to the North American Industry Classification System (NAICS). The database covers information such as costs and added value. It is not clear at this stage if it will be possible to convert the monetary information into physical values.
- Rest of the World regions: monetary and/or physical data was also available for a few countries that are classified as rest of the world regions: Africa, America, Asia and Pacific, Europe and the Middle East. The temporal and product coverage and the classification systems used vary amongst countries. It was possible to find industrial statistics for the following countries that belong to the Rest of the World regions:
    - Armenia
    - Azerbaijan
    - Bolivia
    - Colombia
    - Cuba
    - Kyrgyzstan
    - Mauritius
    - Moldova
    - Mozambique
    - Nepal
    - Singapore
    - Sri Lanka

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- Tunisia
- Ukraine
- Vietnam

3.1.3 Trade

Information regarding international trade of commodities is essential to create the multiregional supply and use tables. In the case of the PANORAMA project, the data must be highly detailed (order of thousands of commodities) to capture the flows of the selected elements (see Table 4). Such level of detail databases is maintained by Eurostat (Comext) and the UN (Comtrade).

Comext database

In the Comext database, international trade has been recorded since 1988. It not only provides physical and monetary bilateral trade data amongst the EU Member States but also amongst EU and non-EU countries. This database is public and bulk download is possible after creating an account.
The following fields are recorded:

- Reporter: the reporting country of the datum
- Partner: the country from/to which the Reporter is importing/exporting
- Product: the trade product, identified via a classification system
- Flow: the type of trade, i.e. import, export or re-export
- Period: year
- Indicators: the flow in euros or quantities (e.g. kg)

The available classification systems of products comprise:

- CN: Combined Nomenclature with 8 digits
- HS: Harmonized System with 2, 4 or 6 digits
- SITC: Standard International Trade Classification with 1 to 5 digits
- BEC: Broad Economic Categories with 3 digits
- CPA: Classification of products by activity with 2 to 4 digits

The data recorded CN classification system with 8 digits gives access to a very highly detailed international trade of commodities. In terms of geographical coverage, however, the database only presents records of non-EU countries when the Reporter is an EU member state. This means that bilateral trade data amongst non-EU countries are not included in the Comext database. As a consequence, the usage of this database in the project would be restricted to the European region.

COMTRADE database

The UN database of international trade has a higher temporal and geographical coverage than the Comext database. It includes physical and monetary bilateral trade data of commodities amongst non-EU countries, and depending on the classification system, it is also possible to retrieve records from 1962 onwards. In addition to commodity flows, it also contains monetary bilateral trade data of selected services. The database itself is public, although the bulk download is restricted. It is possible to harvest

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the database with a premium account, and a free one-month subscription is available for educational institutions.

In general, the records contain the following fields:

- Reporter: the reporting country of the datum
- Partner: the country from/to which the Reporter is importing/exporting
- Commodity Code: code that represents what is being traded
- Trade Flow: the type of trade, i.e. import, export, re-import or re-export
- Trade Value: monetary information in US$
- Net weight: mass information in kg
- Qty Unit: description of the unit of the quantities that are traded, e.g. kg, unit, m, etc.
- Qty: quantity of the commodity that is traded

There are four available classification systems:

- HS: Harmonized System with 2, 4 or 6 digits
- SITC: Standard International Trade Classification with 1 to 5 digits
- BEC: Broad Economic Categories with 1 to 3 digits
- EBOPS: Extended Balance of Payments Services Classification

Several versions of the aforementioned classification systems are used, depending on the year in which the data is recorded. For instance, the HS classification system has different versions for the years 1992, 1996, 2002, 2007, and 2012.
It is important to mention that the flows data available at Comtrade does not necessarily match between the Reporter and the Partner country. In other words, the Reporting country A could have recorded that it exported X amount of a commodity to their Partner country B, whereas the Reporting country B recorded that it imported Y amount of the same commodity from their partner A for a given year.

BACI database

The BACI database involves physical and monetary bilateral international trade data with global coverage and includes international trade data from 1998 to 2017. The database is provided by the French research institute Centre d'Études Prospectives et d'Informations Internationales (CEPII), and available for users who have a premium subscription of the COMTRADE database.
This database is originally based on values reported in Comtrade. However, procedures have been developed to reconcile the inconsistencies between the values declared by the importing and exporting. The methodology itself considers the differences between the CIF (cost, insurance and freight) import values and the export FOB (free on board) values. In addition, the reliability of the reporting country is also included.

There are only 6 fields for each record:

- v: value of trade in thousands of US$
- q: quantity of trade in tons

- i: exporting country code
- j: importing country code
- hs6: product code based on HS classification with 6 digits
- year: the year in which the commodity has been traded

In contrast to Comext and COMTRADE, BACI only uses the Harmonized System (HS) for the commodities classification. The versions for 1992, 1996, 2002, 2007 and 2012 are available.

Mineral & Metal trade data

Mineral and metal trade data could be found in the international trade databases like Comext, COMTRADE and BACI. Complementary to these, it is also possible to find total imports and exports of ores, oxides and/or metals for a few countries at BGS, and bilateral data of the United States at USGS. These have already been previously discussed (see section Extraction).

3.1.4 Final demand

Final demand data can be found within the System of National Accounts (SNA) framework in use tables for the different final demand categories mentioned above. Depending on the country in scope, the classification used changes accordingly. Use tables provide in a structured way the consumption of different products by different final demand categories and by industries (intermediate consumption). Knowledge of both consumptions flows is important for the correct allocation and distinction between consumption by final users and by industries. This will be crucial when using auxiliary datasets such as Consumer Expenditure Surveys (CES) to infer the consumption at the disaggregated level of the products in scope in PANORAMA.
While Put On Market (POM) data can be easily inferred at a detailed product level using COMTRADE and PRODCOM, the split between final users and industries remains unknown as this data is confidential (sales data). Looking into branch data such as trade unions might unveil more detail in sales data but so far efforts remained inconclusive. An important database for POM is given by CBS in collaboration with UNU (Van Straalen et al., 2016). The UNU classification does not contain all the products that we wish to consider in the scope of PANORAMA. For most of these products, data is absent. One of the products not contained in the UNU classification is batteries. Data on this product can be found separately, for example in the Netherlands (Stibat, 2018).

Consumer Expenditure Surveys

CESs give data according to the COICOP classification and they are available for several countries. Even though the classification is not disaggregated enough, it provides a good time series in a common classification.

Use tables

These tables are available under the SNA framework and provide data on intermediate consumption and final consumption for products under the CPC or CPA classifications. These are mostly available on a yearly basis for all the countries in PANORAMA.

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CBS/UNU database

This database provides POM data for EU28 in Kg per Inhabitant (KPI) and Pieces per Inhabitant (PPI), from 1980 to (expected POM in) 2021. The database uses UNU classification code for the definition of the appliances. It is possible that certain products that do contain the elements considered in PANORAMA are missing. This occurs when these products are not contained within the UNU codes. The CBS/ UNU database consists of mostly electrical equipment (EEE). Batteries are an example of products that are not included in the UNU codes.

FEA database

Fachverband Elektroapparate für Haushalt und Gewerbe Schweiz (FEA) supplies data on the sales figures for certain electronic products in Switzerland (FEA, 2006-2019). The listed products are Cooktops, built-in ovens, electric cookers, steamers and steam combi appliances, extractor hoods, tumble dryers, automatic washing machines, dishwashers, refrigerators, freezers, total large appliances, microwave ovens, food processors and blenders, ice cream machines, coffee machines, coffee grinders, bread makers, table ovens/table grill, grills/raclette ovens, toaster, \deep fryers, steamers, kettles, irons, vacuum cleaners, steam cleaners, shavers, hair care equipment, dental care equipment, fans, humidifiers/air purifiers, air conditioners, heaters, water heaters (boilers). The data is supplied from 2011 to 2019 and it is the most detailed open-source dataset found for electronic products.

3.1.5 Waste and recycling

Waste data is extensively described for Europe in EUROSTAT in different tables under the EWC-Stat classification. Data includes flows from industries at NACE rev. 2 level and households for different waste categories. A relationship of 1-n exists between EWC-Stat and List of Wastes (LoW) where the latter is made up of 891 waste types. For Waste Electrical and Electronic Equipment (WEEE), the UN collects under the Global e-waste monitor data on 54 categories of WEEE referred to as UNU-keys (Forti et al., 2018). A benchmark survey by Magalini et al. (2015) on the behaviour of final users towards WEEE in Romania will be used. Furthermore, a wealth of data on WEEE has been collected under ProSUM which will also be used for batteries, vehicles and electronic equipment. The breakdown between waste generated by industries and by households at the disaggregated product level will be done using ratios from EXIOBASE and other suitable datasets. The Dutch statistical office (CBS) in combination with UNU (van Straelen et al., 2016), has compiled an indicator referred as Waste over Time (WoT) providing time series on WEEE for different European countries. COMEXT also provides data for several waste codes.
Recycling data is collected in Europe by EUROSTAT under directive 2008/98/EC. Data on recycling is defined as recovery whereby the distinction between different recovery options, trade and landfill is described by country and by 51 wastes according to EWC-Stat. For other countries, data from national statistic bureaus is used and a coherent relationship is needed to group data from outside of the EU as the definitions between recycling and recovery might not match.

Romanian survey

The survey was carried out in Romania and consisted of a representative sample of 2002 individuals. For 25 products, individuals were asked to give more information about how much WEEE they

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generated, and in which manner they discarded these products. These are clustered as correct and incorrect ways of disposal.

CBS/UNU WoT database

This database provides WEEE data for EU28 in Kg per Inhabitant (KPI) and Pieces per Inhabitant (PPI), from 1980 to (expected WEEE in) 2021. The database uses UNU-keys for the quantification of WEEE.

3.2 Compositions

3.2.1 Tantalum

Tantalum presents a rare example of an element which concentration in various commodities has been systematically reported within one study. That allowed to obtain relatively quickly comprehensive composition data for the element.

The primary source of such inquiry within PANORAMA project is the study by Deetman and colleagues (2017). Firstly, the authors have collected qualitative data on Ta use from various existing sources. Out of the 24 product categories which have been identified to contain the element, 7 categories were not covered in the study because of either the absence of information or the vagueness of the category itself (see Table 8).

Table 8. Tantalum containing products for which there is no composition data available (Deetman et al., 2017)

Commodity	Not used in the study
X-rays diagnostic equipment	no information
Catalysts	too vague
Tools and machinery	too vague
Microelectronics in safety and military; military explosive missiles	no information
Lining, cladding, water tanks, valves, screws, nuts, bolts	too vague
Mobile phone signal masts, oil well probes	no information
Inkjet printers	no information

Secondly, for the rest of the products containing Ta, concentrations have been collected by the authors from various sources (Deetman, 2017). Finally, within the PANORAMA project, such products have been linked to the Harmonized Commodity Description and Coding Systems (HS 2017), see Table 9.

The HS codes for the product described in Table 9 have different levels of detail. In case the 4-digit HS code is used, it implies that all the 6-digit subcategories contain a given amount of the element. Additionally, it has to be underscored that in the original study Ta content have been derived for some products (concentrates and carbides) as a result of balancing the total mass of the element in the EU.

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Table 9. Tantalum content in products (Deetman et al., 2017) linked to HS classification

Commodity	HS2017 Codes	Ta Content (kg Ta/ kg Product)
Concentrates	261590	0,00211456
Articles	8103	1
Carbides	2849	0,00006794
Capacitors	853221	0,367
HDD	847170	0,019
Artificial joints	902131	0,175
Camera lenses	900211	0,046
Vision correction lenses & other lenses	9001-9002	0,00184
Mobile phone	851712	0,00041
Laptop PCs	847130	0,00103
Desktop PCs	847141	0,00088
Cameras	852580	0,00142
Hearing aid	902140	0,04667
Pacemakers	902150	0,0186
GPS	852691	0,0043
DVD players	8521	0,00001078
Furnaces	8417	0,000062
Carbide tools	2849, 382430	0,0007966
TVs	8528	0,000008
Automotive (vehicles)	8703	0,0000058
Wave filters	854160	0,3305
Semiconductors (excl. photovoltaic)	854110-854130	0,286

3.2.2 Cobalt

PANORAMA project focuses on the complete material/value chain of an element in question. Therefore, for cobalt, composition data focuses on **i)** cobalt-containing ores, **ii)** material/product (component) and **iii)** waste/by-product (see Table 10). UGhent has collected quantitative data on cobalt from various an exhaustive list of published reports, literature, research institutes and confidential sources. Composition values (in wt%) varies from a single value to a range. Thus, a lower and upper limit has been introduced. In the absence of data in the average/unique value column, the data model script will automatically read the range values. Also, composition data for waste/by-products are not available (symbolized as n.a.).

Secondly, within the project, such products/compositions have been linked to the Harmonized Commodity Description and Coding Systems (HS 2017), see

Table 10. For a handful of commodities, it was possible to find the HS codes. However, for catalysts, paints and pigments it was not possible to find an HS code. Here, it is advised to find a code in another classification system, i.e. SITC, CTC.

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Table 10. An illustration of cobalt composition in various end-use applications, linked to HS classification

Code	Commodity name (description)	Lifecycle stage	Lower limit (range)	Higher limit (range)	Content (average or unique value)	Unit	Source
HS260300	Copper ores and concentrates	Ore			2	wt.%	Nansai et al., 2014
HS252520	Lithium Nickel Manganese Cobalt Aluminium Oxide	Material	10	15		wt.%	Alves Dias et al., 2018
xxxxxx	Catalysts	Product - chemicals			1.5	wt.%	Harper et al., 2011
xxxxxx	Pigment Mazarine blue	Product - pigments			49.94	wt.%	Confidential 1
xxxxxx	Pigment Willow blue	Product - pigments			24.46	wt.%	Confidential 1
HS8450xx	Washing machine	Product - electronics	0	0.0045		wt.%	Deetman et al., 2018
HS846721 or HS850810	Drills	Product - tools			2.5	wt.%	Harper et al., 2011
HS720429	Waste and scrap, of alloy steel, other than stainless	waste/by-product			n.a.	wt.%	Nansai et al., 2014
HS720450	Remelting scrap ingots, of iron or steel	waste/by-product			n.a.	wt.%	Nansai et al., 2014

3.2.3 Copper

In general, composition data on copper-containing products is relatively sparse on an aggregated level. While composition data is mainly relevant for copper-containing products, compositions are also relevant for copper ores since this signifies the viability of mining deposits and the required degree of refinement. Concentration data on copper ores is sparse due to the specifics of mining sites around the globe. The International Wrought Copper Council (IWCC) provides information upon request. More general information on copper ores and concentrates can be found in the literature (Calvo et al., 2016; Frenzel et al., 2017; Langner, 2011; Lehne, 1993; van der Voet et al., 2018).

There is no central source for composition data on copper mattes, blisters, refined products and semi-finished products of copper and copper alloys, despite the relatively low number of products compared

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to copper-containing final products. Compositions of copper mattes are mainly described in Schlesinger et al. (2011) and Langner (2011), while Wittmer (2006) has compiled an extensive database on blisters, refined products and semi-finished products. This database also includes composition data for a large number of copper-containing end-user product groups (over 300 as denoted by six-digit HS codes). Additional information on certain product groups, such as household electric and electronic devices can be found in ECEEE (2015). The International Copper Association is a good source for general and specific information on the different stages of the supply chain, specifically for end-use products. The ranges of copper contents for broad product categories are summarised in Table 11.

Table 11. Copper content of different product groups

HS H0 Code	Cu content range	Product groups
26...	30-100%	copper ores, concentrates, ashes/residues
28...	25-69%	basic copper chemicals (oxides, hydroxides, sulphates)
31...	0.0004-0.0035%	copper compounds of very low copper content for final use (fertilizers...)
38...	1%	insecticides, fungicides, herbicides
74...	58-100%	copper intermediate products (mattes, cement, blister and refined copper, copper (alloy) waste/scrap, mills semi-products) and the high-copper content finished products that are similar to the copper intermediate products (springs, screws, washers, wires, grills, non-electric cooking apparatus...)
83...	10-80%	finished non-electric/non-electronic goods of medium copper content (locks, keys, mountings, bells, hooks, electrodes,...)
84... and 850...-853...	0.25-30%	Various electric and electronic devices, machines, equipment and parts thereof; low copper content
854...	25-65%	integrated circuits and parts thereof; electric conductors; wiring sets for vehicles/aircraft/ship
86...	2-40%	rail locomotives and (powered) railway cars/coaches
87...	0.7-3%	vehicles (tractors, buses, automobiles, trucks, motorcycles, non-motorized cycles), radiators for motor vehicles and mounted brake linings for motor vehicles
90...	4%	slide projectors; copyers and copying-equipment/apparatus; drafting tables and machines
91...	58%	clock/watch cases of metal and parts
92...	85%	brass-wind instruments
93...	95%	cartridges for (a) rivet etc. tools, (b) humane killers, etc., and (c) shotgun; munitions of war, ammunition/projectiles and parts
95...	4%	video games used with a television receiver

3.3 Lifetimes

To assess the flows of these materials in the technosphere, the lifetime of the products is a key parameter. Detailed lifetime profiles of end-use applications per selected element will be available in

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deliverable 4.2 - product compositions and lifetimes. As an example, the lifetime of cobalt batteries is given in Table 12. Batteries show well-documented lifetime. The overall found values range from 1 to 10 years. There are different reasons to explain this variation. First, many of these values are not specific for the battery itself, but for the device in which the battery is embedded. Cell phones, laptops, digital cameras, and other household products use rechargeable batteries for their functioning, each one having different periods of use. Second, some of the values are indicated as the first life, others consider the hoarding time, and others consider first life, hoarding time and second life of the battery. It is noteworthy that in a high number of cases, the source does not specify which type of lifetime is addressed (Godoy León et al., 2019).

Table 12. Lifetime profiles of cobalt batteries

Application	Data country/ region	Data year	Lifetime (years)	Source
Mobility batteries	USA	2011	10	Environmental Protection Agency (2013)
Mobility batteries	USA and others	2005	8	Harper et al. (2011)
Mobility batteries	EU	2014	10	EUROBAT (2014)
Mobility batteries	Global	2015	8	Ahmadi et al. (2017)
Mobility batteries	Global	2010	10	Ziemann et al. (2018)
Mobility batteries	Global	2014	10	Habib and Wenzel (2014)
Mobility batteries	Global	2016	8-10	Jiao and Evans (2018)
Portable battery	Global	2001	1-3	Contestabile et al. (2001)
Portable battery	EU 25	2006	5	EuP 2007
Portable battery	EU	2015	6.2	Desmet and Colin (2017)
Portable battery	South Africa	2015	3-5	Knights and Saloojee (2015)
Portable battery	Germany	2012	6.6	Buchert et al. (2012)
Portable battery	Not available	2017	2-4	Kumar and Suman (2017)
Portable battery	EU	2006	2-7	Müller and Friedrich (2006)
Portable battery	Not available	2002	2, 7	Heegn et al. (2003)
Portable battery	EU	2015	7.1	Desmet and Colin (2017)
Portable battery	Japan	2003	4.3	Oguchi et al. (2006)
Portable battery	EU5	2015	1.7	Kantar WorldPanel (2016)
Portable battery	USA and others	2005	2.5	Harper et al. (2011)
Portable battery	Japan	2012	7.4	Nomura and Suga (2013)
Portable battery	Japan	2012	10.2	Nomura and Suga (2013)
Portable battery	EU	2018	>10	EBRA (2018)
Unspecified Co batteries	Japan	2002	10.9	Nomura (2005)

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Lifetime data for copper-containing products have been mainly compiled in scientific papers (cf. Eckelman and Daigo, 2008; Glöser et al., 2013; Hatayama et al., 2007; Ruhrberg, 2008; Zeltner et al., 1999) but is also covered in publications of geological surveys (cf. USGS, 2010). In general, it is difficult to find reliable data on product lifetimes, especially since many different definitions of lifetimes are used and often not properly labelled (see Section 2.4). Another problem with lifetime data is the level of aggregation. While technological specifics may lead to different lifetimes across similar product categories, lifetimes are usually only reported for broad product ranges. In the case of copper, a total of 15 different applications can be distinguished regarding their average lifetimes. These are summarised in Table 13.

Table 13. Average lifetimes for copper-containing end-user goods

Product group	Average lifetime (years)
Building components, including plumbing	40
Architectural parts, such as mountings and fittings	50
Communications	30
Electrical power	40
Power utility	35
Telecommunications	30
Industrial electrical	15
Industrial non-electrical	20
Automotive electrical	13
Automotive non-electrical	15
Other transport	25
Consumer & general products	13
Cooling	12
Electronic	8
Diverse	15

3.4 Stocks

As discussed in Section 2, the estimation of product or substance stocks in the economy or at the different stages of the substance life cycle involves flow data, lifetime estimates as well as different methods/models and lifetime concepts. Therefore, in comparison to flow data, stock data is more problematic and, in general, difficult to obtain. For specific product groups, however, data can be found. For example, Magalini et al. (2015) and the CBS/UNU database provide data on electrical and electronic equipment owned by households and industries. Magalini et al. (2015) study a representative sample of 2002 individuals in Romania. For 25 products, the individuals were asked to provide information on their stock of appliances, in particular, the number of appliances, the age of stock and whether the appliance was new or second-hand at the time of sale. In the CBS/UNU database, the stock is defined

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as the sum of historic Put on Market (POM) minus the sum of all historic Waste Electrical and Electronic Equipment (WEEE). The database gives stock information for EU28 in kg per inhabitant, and pieces per inhabitant from 1980 to 2021. The database uses the UNU classification code for the definition of the appliances.

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4. Data gaps and future work

This chapter identifies data gaps and potential future work based on the findings of the previous chapter. Section 4.1 provides a detailed outline of gaps in flow data, while Section 4.2 summarises gaps in stock, composition and lifetime data. Section 4.3 closes with a note on classification challenges.

4.1 Flow data

4.1.1 Extraction

The databases for extraction are quite comprehensive. The updated version of the Global Material Flows Database, for instance, will contain global data of metal production from 1970 to 2017. These will be disaggregated into all the elements that need to be covered apart from the rare earth elements. The disaggregated information of the rare earth elements is not strictly a data gap per se. However, an understanding of the quantities of the selected elements in the project that belong to this category is necessary for improving the mass balance procedures. In other words, the amount of cerium, dysprosium, lanthanum and neodymium that are extracted is important. It is not clear yet how these will be estimated, but the information compiled by the Chinese Ministry of Environmental Protection (MEP) could be useful for a rough disaggregation (see Table 14).

Table 14. Production of major rare earth oxides (MEP 2009)

Year	La_2O_3	CeO_2	Pr_6O_{11}	Nd_2O_3	Sm_2O_3	Eu_2O_3	Gd_2O_3	Tb_4O_7	Dy_2O_3	Er_2O_3	Y_2O_3	Sum
1986	66	160	-	44	12	3	30	-	-	-	100	415
1987	126	142	25	122	40	4	18	2	3	-	214	696
1988	227	169	32	204	50	6	21	2	5	-	339	1055
1989	272	201	68	331	75	11	34	3	25	4	506	1530
1990	274	277	106	505	105	14	37	5	51	2	468	1844
1991	564	406	150	905	111	12	39	9	83	12	471	2762
1992	474	464	111	834	99	12	50	11	67	24	498	2644
1993	210	703	74	907	73	17	24	10	75	27	476	2596
1994	655	1352	157	1355	136	32	48	12	124	44	854	4769
1995	1342	2680	580	2036	208	30	83	17	212	43	1274	8505
1996	1548	3503	400	3090	252	40	102	29	255	28	2033	11280
1997	1678	4181	570	5256	165	41	120	28	262	32	2211	14544
1998	2888	4950	762	6200	248	125	90	64	292	98	2675	18392
1999	3249	5568	859	6950	275	140	101	72	328	110	3009	20661
2000	3954	6190	990	8500	322	162	117	83	365	123	3344	24150
2001	5367	7177	1104	8800	359	181	131	88	401	135	3678	27421
2002	5832	7425	1143	9000	372	187	135	96	438	147	4013	28788
2004	8400	9630	350	2200	922	208	170	69	120	180	5200	27449
2005	18750	15850	2470	2096	739	342	683	388	128	967	5591	47734
2006	19730	22579	2297	11343	1586	368	4625	607	2311	954	9027	75427

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4.1.2 Production

The production data contains a few gaps, depending on the country. In the case of countries that are covered in Prodcom, there are a considerable number of commodities for which data is omitted due to confidentiality issues. These must be estimated in order to provide highly detailed supply tables. For these, it might be possible to make estimations based on the production of each product at the EU level combined with trade data. Such an approach has similarly been used to calculate put-on-the-market (POMs) of electrical and electronic equipment at the ProSUM project.
In the remaining countries, it is preferable to utilise physical data when the information is available, such as the case of Brazil and Japan. However, this is not the case for other countries, where only monetary data is available from national statistical offices, e.g. Canada and the United States. It is necessary to evaluate which proxies can be used, especially where prices are not readily available.
The data from national statistics office should be combined with the UN Industrial Commodity Statistics, in particular cases when these are not comprehensive enough. Even though the UN Industrial Commodity Statistics cover about 600 commodities, there are both physical and monetary missing data. These could be for a particular year, country or product, which will require the creation of gap fillings procedures.

4.1.3 Trade

The global international trade databases Comtrade and its reconciled version BACI are both quite detailed, involving a list of around 5000 products. Even though the HS-6 classification system is highly detailed, some of the commodities are still aggregated.
This is a similar issue for the extraction data, which is not a data gap, but an insufficiency in the detail itself. Such problem arises is the case of some ores and metals (see Table 15). Especially for some of the elements considered, such as niobium, tantalum, germanium and indium, it is not possible to determine from the classification system, which particular ore or metal is traded. A procedure that takes into account the total amount of material extracted and or its origin will have to be created in order to better map the trade flows.

Table 15. Examples of ores and metals that are aggregated into a commodity code

HS Code	Description
261590	Niobium, tantalum, vanadium ores and concentrates
261690	Precious metal ores and concentrates; (excluding silver)
261790	Ores and concentrates n.e.c. in chapter 26; other than antimony
811292	Gallium, germanium, hafnium, indium, niobium (columbium), rhenium and vanadium; articles thereof, unwrought, including waste and scrap, powders
811299	Gallium, germanium, hafnium, indium, niobium (columbium), rhenium and vanadium; articles thereof, other than unwrought including waste and scrap and powders

4.1.4 Final demand

It is difficult to find qualitative data on final demand. National bureaus of statistics collect Put on Market (POM) data. However, most data is confidential, so it can only be given on an aggregated level. That is,

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a division between the sales to industry and final demand cannot be made. Furthermore, we cannot make a distinction between sectors within the industry. An important database for POM is given by CBS in collaboration with UNU (van Straelen et al., 2016). We then disregard other products that do contain the elements in which we are interested, but for which we have no data.

We describe two methods to estimate the final demand for products on the UNU classification level. We can then compare these estimates to see if they give the same result or use them as an upper and lower bound.
First, use aggregated (on the product level) monetary data from national use tables. This monetary data can be converted into physical data, using conversion factors from UN Comtrade data. Under the assumption that final demand product groups in countries outside the EU have similar product compositions as the average European country, an estimation for physical final demand on the product level is found.
A second approach is to get the number of a certain product per household from a data set and then use this number to estimate the number of the product in another country for which there is no data. For example, we know that there are X fridges per household in Denmark and do not know the number of fridges in Sweden. Then we can multiply X with the number of households in Sweden as an estimate. The assumption underlying this approach is that the share of fridges per households in Sweden is the same as in Denmark.

4.1.5 Waste and recycling

The website from CBS in collaboration with UNU also gives data on Waste Electrical and Electronic Equipment (WEEE). More specific data can be found by contacting recycling companies. However, here we run into the same issues regarding confidentiality. Another element of missing data is the stocks of waste in households. We have found only one (Romanian) survey that gives an estimation of this data (Magalini et al., 2015). Data split by economic activity is given by national bureaus of statistics and Eurostat, but it is not given for products on the UNU classification level. As for the final demand data, we can derive estimates on a more specific product level, or for regions which do not have data, using datasets on a more aggregated level or for other regions for which we do have the data.

4.2 Stocks, compositions, lifetimes

Data on stocks is limited, only two databases were found on the stock of Electrical and Electronic Equipment (EEE). These databases are described in section 3.4. One of the databases only provides information on households. The other database provides stock data for both households and industries but aggregated. That is, it does not distinguish which stock is dedicated to households (industries).
Regarding the data gaps in the product composition data collected, it is envisioned to employ LCI databases for further analysis. Specifically, Ecoinvent database has been investigated and has proved to be able to deliver composition estimation for specific goods. Such algorithms are currently under development. The other approach considered is to conduct several discard surveys in the regions where such data could be collected estimating discarded products' lifetimes based on the identified year of manufacturing (Oguchi et al., 2010).

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For the product lifetimes, it is planned to conduct a multi-regional large-scale survey to obtain such data. Particularly, an on-line platform to harvest such is currently under development and will be distributed the early year 2020.

4.3 Challenge of classifications

Following section 3.1.2, HS codes for commodities provide detailed trade information. However, while linking the cobalt composition to HS codes; it was realized that not all commodities can be linked-to HS codes due to the absence of specific terminology used for certain commodities (see Table 10). It has been advised to use another international classification such as SITC and CPC and link it to HS codes through corresponding tables. Moreover, it has been recently decided that PANORAMA will work with CPC codes instead of HS codes.

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5. Conclusions

The activities and results reported in this document are part of Work Package 3 of the PANORAMA project. It comprises different actions towards a harmonized physical and monetary stock/flows database, as the final product of the project. First, the identification of available data harvesting and classification systems was performed (task 3.1), followed by an initial data harvesting exercise for Co, Cu and Ta. The data collection revealed data gaps along the value chain of these materials, such as lack of information regarding the end-of-life (EoL) stage, element contents in final goods, products lifetimes, stocks and the trade of some commodities between different countries. The identification of data gaps guided the selection of additional databases to be used in gap-filling (task 3.2, see Table 2, Table 3and annex II). The concordances between different data sets (task 3.3) will be next step, to be addressed in the future and therefore, not covered in the scope of this report.

As discussed in Section 2.2, there are multiple sources providing data, either as physical or monetary stocks and flows for different phases of the materials cycle. From the earth sphere, where resources and reserves are found, to the technosphere, where extraction, manufacturing, use and disposal of goods occur, data can be harvested. Many data sources have good coverage of production and trade of different types of commodities, along with long historical series up to date. However, a complete material cycle assessment is still challenging for most elements.

Previous studies on Co (Godoy León et al., 2019), Cu (cf. Glöser et al., 2013, Soulier et al., 2018a, Soulier et al., 2018b) and Ta (Deetman et al., 2017) were used as a starting point for the data collection of (up to) 16 different materials (Table 4). In these studies, detailed data was gathered from different sources, providing a first overview of the available data harvesting platforms and classification systems. The studies also helped in the data gap assessment. For instance, the study on Co is a material flow analysis (MFA) reporting a significant amount of data on flows, lifetimes, hoarding time, EoL, collection rate and recycling rate for different Co applications. Nevertheless, the determination of the Co content in these applications is not part of the study, also because data on product composition is not extensively available, neither for Co nor for the other elements. Since composition data is needed for establishing the link between product and element flows, it was considered a data gap. Availability of data on extraction, production and trade of raw materials was considered good, with data sources providing values for most of the 16 materials considered. However, sometimes the data is focused on Europe or on specific countries, which in some cases hampers the determination of trade between European and non-European countries. Another difficulty when determining commodities trade is regarding the values reported by the exporter (producer) and importer (consumer) countries, which do not always match, even within the same database. Moreover, if data is only provided in monetary values, the physical quantification can be a challenge, since price information is not always readily accessible.

Final demand data is in most cases confidential, but it can be determined for several products considered within the scope of PANORAMA. An estimation for final demand can be found using POM data. This data is collected by national bureaus of statistics. A good example of this is a data source from CBS / UNU. However, it does not cover some important applications, such as batteries. This database also has relevant data for waste and recycling, being an important source along with Eurostat, which provides details for European countries. At the global level, data availability for waste and recycling is mostly focused on WEEE. For non-European countries, national statistics mostly provide enough data, but sometimes it is hard to differentiate recovery from actual recycling.

Regarding lifetimes, most of the available data assessed at this stage of the project came from scientific publications, but existing databases, such as ProSUM, report lifetimes for some important products considered in PANORAMA. A more detailed overview of lifetime data along with compositions will be elaborated in the upcoming months, as part of Deliverable 4.2. Lifetimes and product flows can be used for the quantification of stocks. Since the only database identified reporting stocks (CBS/UNU) is focused on WEEE, it is important to consider alternatives to estimate stocks of other product applications.

Several data sources have been identified for data harvesting, in order to complete the material cycle mapping within PANORAMA (see annex II). These data sources, provide data along the materials value chain and possibly help in filling the data gaps. Additionally, personal contacts and scientific publications might be helpful where data is not yet publicly available.

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

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ANNEX

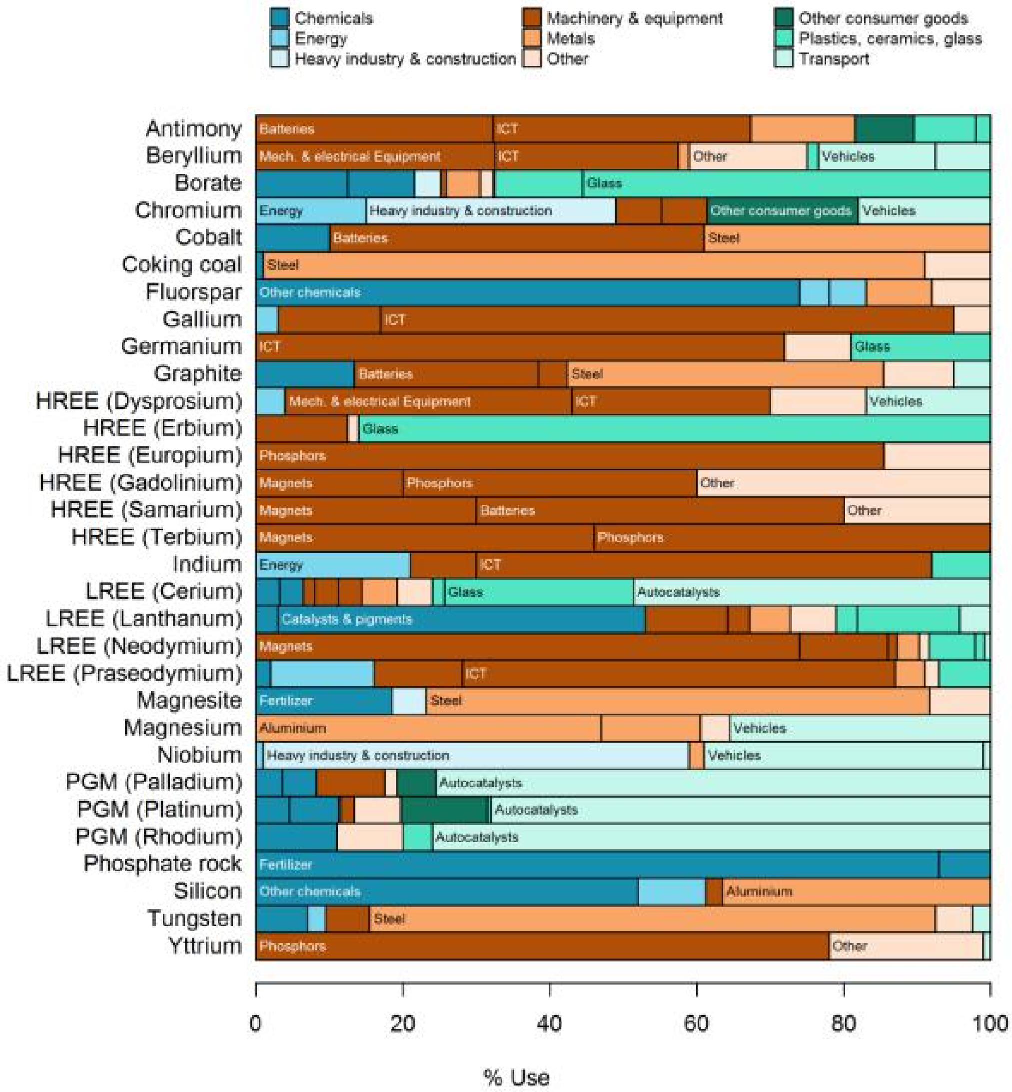

Figure A1. Summary of CRM applications in the EU (Tercero Espinoza et al., 2019

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ANNEX II. Projects considered as relevant for PANORAMA

Disclaimer: The mapping and screening of the databases are performed exclusively for the purpose of the PANORAMA project by applying filters designed for the objectives of PANORAMA. The resulting list of selected databases and available data sources does neither indicate a ranking/classification of these databases' performance nor a general disqualification of their relevance. The list of relevant databases does not include literature sources and personal contacts. This will follow in D4.2 - Product compositions and lifetimes (M16).

Source	**Type of source**	**Type of information**	**Spatial coverage**	**Temporal Coverage**	Link
ADB - Asian Development Bank	Database	Monetary	Bangladesh, Bhutan, Brunei, Cambodia, China, Fiji, Hong Kong, India, Indonesia, Lao People's Democratic Republic, Malaysia, Maldives, Mongolia, Nepal, Pakistan, Sri Lanka, Taipei, Thailand, Viet Nam.	2010, 2011, 2012, 2014	https://data.adb.org/search/field_tags/supply-and-use-tables-sut-141/type/dataset?sort_by=changed
ANM- Brazilian Mineral Yearbook	Database	Physical and monetary	Brazil	1972-2017	http://www.anm.gov.br/dnpm/publicacoes/serie-estatisticas-e-economia-mineral/anuario-mineral
Australian Bureau of Statistics	Database	Monetary	Australia	1998-2018	https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/8155.02017-18?OpenDocument
Badan Pusat Statistik	Database	Monetary	Indonesia	2000, 2005, 2010	https://www.bps.go.id/publication/2015/12/30/eb1ce54ade495db2654b85e2/tabel-input---output-indonesia-2010.html

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BEA - U.S. Bureau of Economic Analysis	Database	Monetary	United States of America	1997-2017	https://www.bea.gov/data/industries/input-output-accounts-data
BGR - The Federal Institute for Geosciences and Natural Resources	Reports	Physical and monetary	Global	2006-2015	https://www.bgr.bund.de/EN/Home/homepage_node_en.html
BGS - British Geological Survey	Database	Physical	Global	1970-2017	https://www.bgs.ac.uk/mineralsuk/statistics/wms.cfc?method=searchWMS
Brazilian Ministry of Economy	Database	Physical and monetary	Brazil	1977-2019	http://comexstat.mdic.gov.br/en/home
CBS - Statistics Netherlands	Database	Physical and monetary	Netherlands	1995-2018	https://opendata.cbs.nl/statline/#/CBS/nl/dataset/83115NED/table?fromstatweb
Census and Statistics - Sri Lanka	Database	Monetary	Sri Lanka	2007-2017	http://www.statistics.gov.lk/page.asp?page=Industry
Central Bureau of Statistics Nepal	Database	Monetary	Nepal	1996-1997, 2001-2002, 2006-2007	https://nada.cbs.gov.np/index.php/catalog
Central Statistical Bureau of Latvia	Database	Physical	Latvia	2002-2018	https://www.csb.gov.lv/en/statistics/statistics-by-theme/environment-energy/environment/tables/vig040/municipal-and-hazardous-waste-collection

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Central Statistics Office India	Database	Monetary	India	1968-1969, 1973-1974, 1989-1990, 1993-1994, 1998-1999, 2003-2004, 2007-2008, 2011-2016	http://mospi.nic.in/publication/supply-use-tables#
CEPII - Centre d'Etudes Prospectives et d'Informations Internationales	Database	Physical and monetary	Global	1995-2017	http://www.cepii.fr/cepii/en/bdd_modele/presentation.asp?id=1
Chilean Copper Comissions	Database	Physical	Chile	1960-2018	https://www.cochilco.cl/Paginas/English/Statistics/Data%20Base/Mining-Production.aspx
Cobalt Institute	Database	Physical	Global (69)	2011-2018	https://www.cobaltinstitute.org/statistics.html
Copper Development Association, Inc. (USA)	Database	Physical	United States of America	1996-2016	https://www.copper.org/resources/market_data/pdfs/annual_data.pdf
COST-Minea: The European Cooperation in Science and Technology - Mining the European Anthroposphere	Unknown	Physical	Europe	n.a.	https://www.cost.eu/actions/CA15115/#tabs|Name:overview

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CREEA - Compiling and Refining Environmental and Economic Accounts	Based on Exiobase, provide an insight into the environmental footprint of final consumption in the countries covered				http://www.creea.eu/
Croatian Bureau of Statistics	Database	Monetary	Croatia	2004, 2010	https://www.dzs.hr/default_e.htm
Czech Statistical Office	Database	Physical	Czech Republic	2008-2017	https://www.czso.cz/csu/czso/generation-recovery-and-disposal-of-waste-2017
Department for Environment Food & Rural Affairs	Report	Physical	United Kingdom	2015	https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/ukenvironmentalaccounts/2015-07-09#waste
DESIRE - Development of a System of Indicators for a Resource Efficient Europe	Database	Physical and monetary	Global (44 + 5RoW)	2000-2011	http://fp7desire.eu/about
Ecoinvent	Database	Physical	Global	n.a.	https://www.ecoinvent.org/home.html
EEA - European Environment Agency	Database	Physical	Europe	2004-2017	https://www.eea.europa.eu/
EGS - EuroGeoSurveys	Database	Physical	Europe	n.a.	http://www.eurogeosurveys.org/
ENF Recycling	Database with businesses	Neither	Global	2019	https://www.enfrecycling.com/industry-directory

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EPA - United States Environmental Protection Agency	Database	Physical	United States of America	1960-2017	https://archive.epa.gov/epawaste/nonhaz/municipal/web/html/
EPWRFITS - EPWRF India Times Series	Database	Physical	India	Since 1969	http://www.epwrfits.in/
EU KLEMS - EU level analysis of capital (K), labour (L), energy (E), materials (M) and service (S) inputs	Database	Monetary	Europe	1995-2017	http://www.euklems.net/
EU Science Hub	Inventory of databases	Physical	Global	n.a.	https://ec.europa.eu/jrc/en/scientific-tool/minventory
Euromines	Database	Physical	Global	1999-2016	http://www.euromines.org/mining-europe
Eurostat	Database	%, Physical and monetary	Europe	1995-2017	https://ec.europa.eu/eurostat/data/database
EXIOBASE - Environmentally Extended Supply and Use / Input Output (MR EE SUT/IOT) database	Database	Monetary	Global	1995-2011	https://www.exiobase.eu/

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FAO - Food and Agriculture Organization of the United Nations	Database	Physical and monetary	Global	1961-2017	http://www.fao.org/faostat/en/#data
FORAM - World Forum on Raw Materials	Inventory of databases	Physical	Europe	n.a.	http://www.foramproject.net/index.php/mapping-of-initiatives/directory-of-databases/
Hellenic Statistical Authority	Database	Physical	Greece	2004,2006,2008,2010, 2012-2015	http://www.statistics.gr/en/statistics/-/publication/SOP06/-
Hungarian Central Statistical Office	Database	Physical	Hungary	1991-2017	https://www.ksh.hu/docs/eng/xstadat/xstadat_annual/i_ur002.html
IBGE - Instituto Brasileiro de Geografia e Estatistica	Database	Physical and monetary	Brazil	1985, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 2000, 2005, 2010, 2015-2016	https://www.ibge.gov.br/en/statistics/full-list-statistics/16940-input-output-matrix.html?=&t=resultados
ICSG - International (Nice) Classification of Goods and Services	Database	Physical and monetary	Global	1900-2017	https://www.wipo.int/classifications/nice/en/
IEA - International Energy Agency	Database	Physical	Global	1971-2016	data.iea.org

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IIASA - International Institute for Applied Systems Analysis	Model	Physical	Europe, Asia and Global *	2005, 2008, 2009, 2010, 2050*	https://www.iiasa.ac.at/web/home/research/researchPrograms/air/GAINS.html
ILO - International Labour Organization	Database	n.a.	Global	1947-2018	https://www.ilo.org/ilostat/faces/ilostat-home/download?_adf.ctrl-state=6g9mk9f74_86&_afrLoop=2307410555153641#!
IMF - International Monetary Fund	Database	Physical and monetary	Global	2016-2019	https://www.imf.org/en/Research/commodity-prices
Indian Bureau of Mines, Ministry of Mines	Database	Physical and monetary	India	2000-2019	http://www.mospi.gov.in/statistical-year-book-india/2018/184
INEGI - National Institute of Statistics and Geography	Database	Physical and monetary	Mexico	1980-2019	https://www.inegi.org.mx/programas/cou/2013/
Instituto Nacional de Estadística	Database	Physical	Spain	n.a.	https://www.ine.es/dyngs/INEbase/en/operacion.htm?c=Estadistica_C&cid=1254736176841&menu=resultados&idp=1254735976612
ISRI - Institute of Scrap Recycling Industries	Database	Physical	Global	2007-2018	https://www.isri.org/recycling-commodities/international-scrap-trade-database
Kassel University,	Model	Physical	Global	up to 2010	http://www.watergap.de/

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Frankfurt University					
KOSIS - KOrean Statistical Information Service	Database	Physical and monetary	South Korea	1995-2018	http://kosis.kr/eng/
METI - Ministry of Economy, Trade and Industry	Database	Physical and monetary	Japan	2007-2018	https://www.meti.go.jp/english/statistics/tyo/kougyo/index.html
MICA - Mineral Intelligence Capacity Analysis	Knowledge base	n.a.	Europe	n.a.	http://www.mica-project.eu/?page_id=12
Min4EU - European Minerals Knowledge Data Platform	Database	Physical	Europe	2004-2013	http://minerals4eu.brgm-rec.fr/search/site/sm_field_subject%3Am4eu-myb?page=1
Minfuture - Global material flows and demand-supply forecasting for mineral strategies	n.a.	Physical	Europe	n.a.	https://minfuture.eu/
Ministry of Statistics and Programme Implementation	Database	Monetary	India	2007-2015	http://www.mospi.gov.in/statistical-year-book-india/2018/183

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Min-Novation - Mining and Mineral Processing Waste Management Innovation Network	n.a.	n.a.	n.a.	n.a.	http://www.eifi.info/min-novation/
National Bureau of Statistics China	Database	Physical and monetary	China	1999-2018	http://www.stats.gov.cn/english/Statisticaldata/AnnualData/
National Bureau of Statistics Moldova	Database	Physical	Moldova	1997-2017	http://statbank.statistica.md/pxweb/pxweb/en/10%20Mediul%20inconjurator/?rxid=b2ff27d7-0b96-43c9-934b-42e1a2a9a774
National Institute of Statistics	Database	Physical	Mozambique	2014-2017	http://www.ine.gov.mz/estatisticas/estatisticas-sectoriais/industria
National Statistical Committee of Kyrgyztan	Database	Physical	Kyrgyztan	1990-2018	http://www.stat.kg/en/statistics/promyshlennost/
National Statistics Office	Report	Physical	Malta	2006, 2019	https://nso.gov.mt/en/nso/Media/Salient-Points-of-Publications/Pages/Regional-Statistics-MALTA-2019-Edition.aspx
National Statistics Republic of Taiwan	Database	Monetary	Taiwan	1981-2017	https://eng.stat.gov.tw/ct.asp?xItem=29540&ctNode=1650&mp=5

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National Statistics System Bolivia	Database	Physical	Bolivia	1992-2017	https://www.dane.gov.co/files/investigaciones/boletines/eam/Anexos_EAM_desagregacion_variables_2017.xls
National Statistics System Colombia	Database	Physical	Colombia	1992-2017	https://www.dane.gov.co/files/investigaciones/boletines/eam/Anexos_EAM_desagregacion_variables_2017.xls
National Statistics Ukraine	Database	Physical	Ukraine	1990-2017	https://ukrstat.org/en/operativ/menu/menu_e/prom.htm
NSI - National statistical institute	Database	Physical	Bulgaria	2011-2017	https://www.nsi.bg/en/content/5096/municipal-and-construction-waste-statistical-region-and-district
NTNU - Norwegian University of Science and Technology	Unknown	n.a.	Unknown	n.a.	https://www.ntnu.edu/metpro
OECD - The Organisation for Economic Co-operation and Development	Database	%, Physical	OECD + Brazil, China, Colombia, Costa Rica, India Indonesia, Japan, Russia	2004-2017	https://stats.oecd.org/Index.aspx?DataSetCode=AEA
Oficina Nacional de Estadistica e Informacion	Database	Physical	Cuba	1985-2018	http://www.one.cu/aec2018.htm

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Open Government Data	Database	Monetary	India	Since 1950/1951	https://data.gov.in/catalog/production-selected-industries?filters%5Bfield_catalog_reference%5D=90388&format=json&offset=0&limit=6&sort%5Bcreated%5D=desc
ORAMA - Optimising data collection for Primary and Secondary Raw Materials	Report	Physical	Europe	2017-2019	https://orama-h2020.eu/
Plastic recycler Europe	Report	Physical and monetary	Europe	2019	https://www.plasticsrecyclers.eu/flexible-polyethylene-recycling-europe-accelerating-transition-towards-circular-economy
PlasticEurope	Report	Physical and monetary	Europe+Norway+Switzerland	2006, 20007, 2009, 2010, 2011, 2012, 2012, 2014	https://www.plasticseurope.org/en/resources/market-data
POLFREE - Policy options for resource-efficient economy	Report	% and monetory	Europe	2015-2050	https://www.ucl.ac.uk/polfree
ProSUM	Database modelled	Physical	Europe	2000-2020	http://www.prosumproject.eu/
recycledrubberfacts	Factsheets	Physical and monetary	USA (and the world)	2017	https://www.recycledrubberfacts.org/factsheets/

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RIETI - Research Institute of Economy, Trade & Industry	Database	Monetary	Japan	1990, 1995, 2000, 2005, 2011, 2015	https://www.e-stat.go.jp/en/stat-search/files?page=1&toukei=00200603&tstat=000001130583&year=20150&month=0
RMIS - Raw Materials Information System	Database	Physical	Global	n.a.	https://rmis.jrc.ec.europa.eu/
SCRREEN - Solutions for Critical Raw Materials - A European Expert Network	Report	n.a.	n.a.	n.a.	http://scrreen.eu/
SERI - Sustainable Europe Research Institute	Database	Physical	Global	1970-2017	http://www.seri.at/en/
SiStat - Statistical Office of the Republic of Slovenia	Database	Physical	Slovenia	2000-2017	https://pxweb.stat.si/SiStatDb/pxweb/en/30_Okolje/
SmartGround	Database	Physical	United Kingdom, Italy, Finland, Hungary	1800-2018	http://www.smart-ground.eu/
SNL Metals & Mining	n.a.	Monetary	n.a.	since 1991	https://www.snl.com/marketing/microsite/MEG/mm_pagetwo.html

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Statbel - the Belgian statistical office	Database	Physical	Belgium	2016	https://statbel.fgov.be/en/themes/environment/waste-production#figures
State Statistical Committee Azerbaijan	Database	Physical	Azerbaijan	2005-2017	https://www.stat.gov.az/source/industry/?lang=en
STATEC -Institut national de la statistique et des études économiques du Grand-Duché de Luxembourg	Database	Physical	Luxembourg	1984-2017	https://statistiques.public.lu/stat/TableViewer/tableViewHTML.aspx?ReportId=12726&IF_Language=eng&MainTheme=1&FldrName=3&RFPath=65
Statistical Bureau of Japan	Database	Physical	Japan	2010-2016	https://www.stat.go.jp/english/data/nenkan/68nenkan/1431-17.html
Statistical Committee of Armenia	Database	Monetary	Armenia	2005-2018	https://www.armstat.am/en/?nid=14
Statistical Office of the Slovak Republic	Database	Physical	Slovakia	1998-2018	http://statdat.statistics.sk/cognosext/cgi-bin/cognos.cgi?b_action=cognosViewer&ui.action=run&ui.object=storeID%28%22i4BF437919D274FB7B17927606927AAAB%22%29&ui.name=Material%20Flow%20Accounts%20-%20Import%20end%20Export%20%5bzp1004rs%5d&run.outputFormat=&run.prompt=true&cv.header=false&ui.backURL=%2fcognosext%2fcps4%2fportlets%2fcommon%2fclose.html&run.outputLocale=en#

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Statistical Service of Cyprus	Database	Physical	Cyprus	1996-2017	http://www.cystat.gov.cy/mof/cystat/statistics.nsf/energy_environment_82main_en/energy_environment_82main_en?OpenForm&sub=2&sel=1
Statistics Canada	Database	Physical and monetary	Canada	2002-2016	https://www150.statcan.gc.ca/n1/en/type/data?MM=1
Statistics Estonia	Database	Physical	Estonia	2000-2017	http://pub.stat.ee/px-web.2001/I_Databas/Environment/01Environmental_pressure/06Generation_of_waste/06Generation_of_waste.asp
Statistics Lithuania	Database	Physical	Lithuania	1991-present	https://osp.stat.gov.lt/statistiniu-rodikliu-analize?indicator=S1R117#/
Statistics Mauritius	Database	Monetary	Mauritius	2011-2018	http://statsmauritius.govmu.org/English/StatsbySubj/Pages/Manufacturing.aspx
Statistics Norway	Database	Physical	Norway	2008-2018	https://www.ssb.no/en/natur-og-miljo/statistikker/avfbygganl
Statistics Poland	Report	Physical	Poland	2018	https://stat.gov.pl/en/topics/environment-energy/environment/environment-2018,1,10.html
Statistics Portugal	Database	Physical	Portugal	2008-2018	https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_indicadores&indOcorrCod=0006061&contexto=bd&selTab=tab2
Statistics Singapore	Database	Monetary	Singapore	1980-2017	https://www.tablebuilder.singstat.gov.sg/publicfacing/createDataTable.action?refId=12415

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Statistics South Africa	Database	Monetary	South Africa	1998-2000, 2002, 2005, 2010-2011	http://www.statssa.gov.za/?s=input+output+table&sitem=publications
Statistics Sweden	Database	Physical	Sweden	2010-2017	http://www.statistikdatabasen.scb.se/pxweb/en/ssd/START__MI__MI0307/MI0307T1/
Statistics Tunisia	Database	Physical	Tunisia	2011-2013	http://www.ins.tn/fr/themes/industrie#sub-386
Statistik Austria	Database	Physical	Austria	1998-2004	https://www.statistik.at/web_en/statistics/EnergyEnvironmentInnovationMobility/energy_environment/environment/namea/index.html
Statistisches Bundesamt	Database	Physical	Germany	2011-2017	https://www.destatis.de/EN/Themes/Society-Environment/Environment/Waste-Management/Tables/liste-brief-overview-waste-balance.html
Swiss Federal Statistical Office	Database	Monetary	Switzerland	2001, 2005, 2008, 2011, 2014	https://www.bfs.admin.ch/bfs/en/home/statistics/national-economy/input-output.html
Technical Report Swico, SENS, SLRS	Report	Physical	Switzerland	2011-2019	https://www.swico.ch/en/recycling/basics/technical-report-publications/#technical-report
The Bank of Korea Economic Statistics System	Database	Monetary	South Korea	1995, 1998, 2000, 2003, 2005-2011, 2015	https://ecos.bok.or.kr/flex/EasySearch_e.jsp

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Tilastokeskus	Database	Physical	Finland	1997-2017	http://pxnet2.stat.fi/PXWeb/pxweb/en/StatFin/StatFin__ymp__jate/statfin_jate_pxt_001.px/
TNO - Netherlands Organisation for Applied Scientific Research	Model	Physical	Global	1960-2000	http://www.air.sk/tno/retro_pictures/criteria.php
Turkish Statistical Institute	Database	Physical	Turkey	2001-2018	https://biruni.tuik.gov.tr/medas/?kn=119&locale=en
UEPG -European Aggregates Association	Database	Physical	Europe	2008-2017	http://www.uepg.eu/statistics/estimates-of-production-data/data-2017
UN Environment	Database	Physical	Global (126)	1990-2016	https://www.resourcepanel.org/global-material-flows-database
UN Industrial commodities statistics	Database	Monetary	Global	1950-2016	https://comtrade.un.org/data/
UNIDO - United Nations Industrial Development Organization	Database	Monetary	Global (139 countries)	1990-2016	http://data.un.org/Data.aspx?d=UNIDO&f=tableCode%3a14
United States Census Bureau	Database	Monetary	United States of America	2004-2016	https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk

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UNSD - United Nations Statistics Division	Database	%, Physical and monetary	Global	1995-2016	http://data.un.org/Explorer.aspx
USGS - United States Geological Survey	Database	Physical and monetary	Global	1932-2016	https://www.usgs.gov/centers/nmic/mineral-commodity-summaries
Waste over Time Results	Database	Physical	EU28	1980-2015	https://statistics-netherlands.shinyapps.io/sales_and_waste/
Water Footprint Network	Database	Physical	Global	1996-2005	https://waterfootprint.org/en/resources/waterstat/product-water-footprint-statistics/
World Bank	Database	Physical and monetary	Global	2016	https://datacatalog.worldbank.org/dataset/commodity-prices-history-and-projections
World Mining Data	Database	Physical	Global	2013-2017	https://www.world-mining-data.info/?World_Mining_Data
World Steel Association	Database	Physical	Global	2000-2017	https://www.worldsteel.org/internet-2017/steel-by-topic/statistics/steel-data-viewer/MCSP_crude_steel_monthly/CHN/IND
WU Vienna	Database	Physical	Global	1970-2017	http://www.materialflows.net/

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