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SCRREEN

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Report on the current use of critical raw materials

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Solutions for CRitical Raw materials - a European Expert Network Dimitrios Biliouris

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Summary

The purpose of this study is to review and map the current use of critical raw materials (CRMs) in the European Union. We do so for the list of materials identified as being critical by the European Commission in 2014. The synthesis of this work is presented in a table on pages 13, that specifies the use of 31 critical materials in various sectors and applications at the highest possible level of detail, based on a review of available studies. This economy-wide overview of CRM use is then complemented with a bottom-up perspective by addressing the material composition of products. A growing selection of literature addresses the amounts or concentrations of CRMs in specific products. This approach often provides a much higher level of detail and is therefore more enabling for waste management practices and for defining substitution strategies for example. However most known studies focus exclusively on CRM concentrations in vehicles, consumer appliances or in energy technologies, thus addressing only a limited fraction of the total CRM use identified. In a second step, we added data on the share of European value added of sectors that are dependent on CRMs. This exercise helped to identify sectors with both a high economic importance and a high dependence on CRMs, such as the manufacturing of machinery & equipment. Other sectors with high CRM dependence, but relatively low coverage in current literature are the chemical industry and the steel sector. Finally, we attempt to disaggregate flows of CRMs in different phases of the European supply chain. This work is presented as a set of short case studies on 8 selected critical raw materials, including illustrative Sankey diagrams. This work highlights the importance of exploring material flows beyond the raw material stage because the use of CRMs in semi-finished and finished products in Europe seem to be subject to import dependence in many cases. In this report, we present three different views on European CRM use, being the economy-wide overview (Table 2), a detailed but incomplete bottom-up view on the CRM content of products (Section 1.2), and finally the supply-chain perspective of CRM flows through Europe (Chapter 3). These approaches could complement each other in shaping the foundation of a comprehensive knowledge base on the use of CRMs in Europe. They could also serve as a basis for further research on trends and future developments of the use and demand for critical raw materials, both within the ...

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SCRREEN

Solutions for CRitical Raw materials - a European Expert Network

DELIVERABLE 2.1:

REPORT ON THE CURRENT USE OF CRITICAL RAW MATERIALS

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LIST OF ABBREVIATIONS

BGS	British Geological Survey
CRM	Critical Raw Material
EoL	End-of-Life
EU	European Union
EU28	The European Union consisting of 28 member states (2017)
HEV	Hybrid Electric Vehicle
HREEs	Heavy Rare Earth Elements
ICT	Information and Communication Technology
Li-Ion	Lithium-ion (batteries)
LREEs	Light Rare Earth Elements
MSA	Materials System Analysis
NdFeB	Neodymium-Iron-Boron (magnets)
NiMH	Nickel-metal hydride (batteries)
PGMs	Platinum Group Metals
PM	Permanent Magnets
R&D	Research and Development
REE	Rare Earth Elements
RMIS	Raw Material Information System
SCRREEN	Solutions for Critical Raw Materials – a European Expert Network
SmCo	Samarium-Cobalt (magnets)
WEEE	Waste of Electrical and Electronic Equipment
WP	Work Package

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ABOUT THE SCRREEN PROJECT

Since the publication of the first list of Critical Raw Materials (CRM) in 2010 by the Ad-hoc Working Group on CRM, numerous European projects have addressed (part of) the CRMs value and several initiatives have contributed to gather (part of) the related community into clusters and associations. This led to the production of important knowledge, unfortunately disseminated. Numerous databases have also been developed, sometimes as duplicates.

The SCRREEN project aims at gathering European initiatives, associations, clusters, and projects working on CRMs into a long lasting Expert Network on Critical Raw Materials, including stakeholders, public authorities and civil society representatives.

SCRREEN will contribute to improve CRM strategy in Europe by:

(i) mapping primary and secondary resources as well as substitutes of CRMs,
(ii) estimating the expected demand of various CRMs in the future and identifying major trends,
(iii) providing policy and technology recommendations for actions improving the production and the potential substitution of CRM,
(iv) addressing specifically WEEE and other End-of-Life (EoL) products issues related to their mapping and treatment standardization, and
(v) identifying the knowledge gained over the last years and easing the access to these data beyond the project.

The project consortium also acknowledges the challenges posed by the disruptions require the development of new CRM strategies. For this reason, stakeholder dialogue is at the core of the SCRREEN project: policy, society, R&D and industrial representatives are involved to facilitate strategic knowledge-based decision-making to be carried out by these groups. Specific attention will also be brought on informing the general public on our strong dependence on imported raw materials, on the need to replace rare materials with substitutes and on the need to set up innovative and clean actions for exploration, extraction, processing and recycling.

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SUMMARY

The purpose of this study is to review and map the current use of critical raw materials (CRMs) in the European Union. We do so for the list of materials identified as being critical by the European Commission in 2014. The synthesis of this work is presented in a table on pages 13-15 that specifies the use of 31 critical materials in various sectors and applications at the highest possible level of detail, based on a review of available studies.

This economy-wide overview of CRM use is then complemented with a bottom-up perspective by addressing the material composition of products. A growing selection of literature addresses the amounts or concentrations of CRMs in specific products. This approach often provides a much higher level of detail and is therefore more enabling for waste management practices and for defining substitution strategies for example. However most known studies focus exclusively on CRM concentrations in vehicles, consumer appliances or in energy technologies, thus addressing only a limited fraction of the total CRM use identified.

In a second step, we added data on the share of European value added of sectors that are dependent on CRMs. This exercise helped to identify sectors with both a high economic importance and a high dependence on CRMs, such as the manufacturing of machinery & equipment. Other sectors with high CRM dependence, but relatively low coverage in current literature are the chemical industry and the steel sector.

Finally, we attempt to disaggregate flows of CRMs in different phases of the European supply chain. This work is presented as a set of short case studies on 8 selected critical raw materials, including illustrative Sankey diagrams. This work highlights the importance of exploring material flows beyond the raw material stage because the use of CRMs in semi-finished and finished products in Europe seem to be subject to import dependence in many cases.

In this report, we present three different views on European CRM use, being the economy-wide overview (Table 2), a detailed but incomplete bottom-up view on the CRM content of products (Section 1.2), and finally the supply-chain perspective of CRM flows through Europe (Chapter 3). These approaches could complement each other in shaping the foundation of a comprehensive knowledge base on the use of CRMs in Europe. They could also serve as a basis for further research on trends and future developments of the use and demand for critical raw materials, both within the SCRREEN project and elsewhere.

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INTRODUCTION

The identification of critical raw materials for the EU is based on three characteristics defined in the Raw Materials Initiative: "first, they have a significant economic importance for key sectors, second, the EU is faced with a high supply risks, associated with e.g. very high import dependence and a high level of concentration in particular countries, and third, there is currently a lack of substitutes" (European Commission 2008). Operationally, the Ad-hoc Working Group on defining Critical Raw Materials determined criticality following a two-dimensional approach with economic importance (based on raw material use in the EU) and supply risk (based on global primary and secondary supply as well as availability of substitutes), as shown in Figure 1. The determination of the "economic importance" score as well as the elaboration of actions to increase resilience to supply disruptions require a good knowledge of the quantities and applications of raw materials required by European industries.

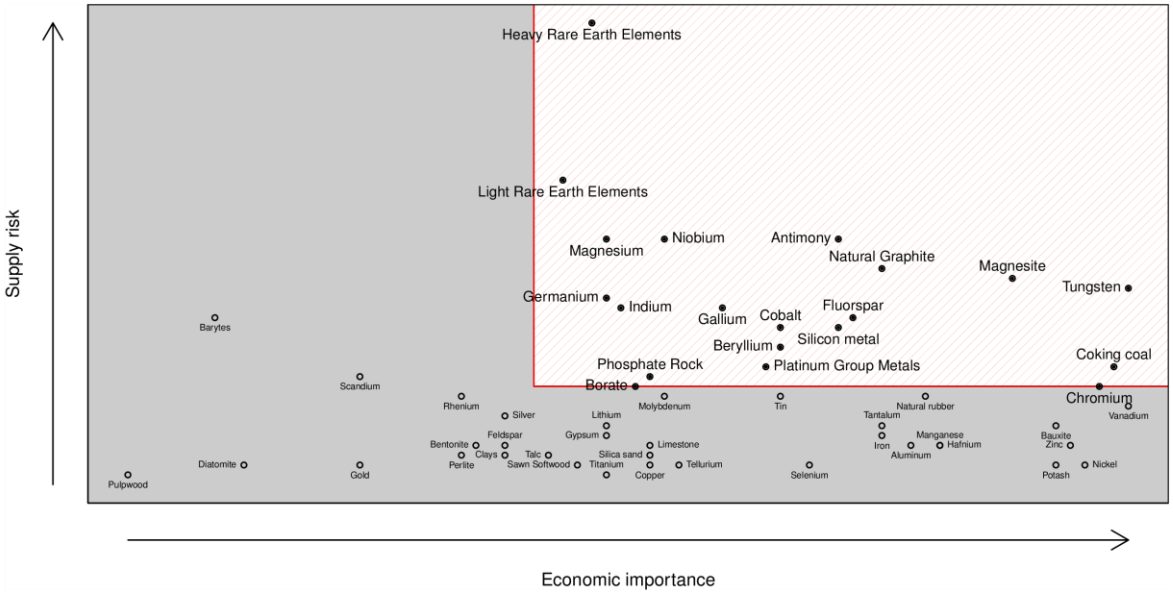

Figure 1: Current criticality matrix for the EU (European Commission 2014).

In order to contribute to the aims of the Raw Materials Initiative and in line with the goals of the European Innovation Partnership on Raw Materials, one of the key objectives of the SCRREEN project is to assess future European needs for critical raw materials. This objective is served through Work Package 2 "Current and future use of CRM", which in turn consists of three tasks:

- Task 2.1: Current use of CRM
- Task 2.2: Identify major trends in future demand
- Task 3.3: Future use of CRM

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This deliverable report summarizes work performed in Task 2.1 and provides an overview of current CRM use in the EU, together with relevant contextual information. The emphasis of the work was on synthesizing and viewing available data in new useful ways, in order to facilitate the work in the SCRREEN project (the following tasks in WP 2 but also other WPs and of the Expert Groups), as well as being useful to interested stakeholders not directly involved in SCRREEN.

We start in Chapter 1 by reviewing the use of CRMs and elaborating a synthesis table (Table 2 on pages 13-15) on the use of 31 CRMs in all economic sectors and applications, based on a review of various data sources listed individually in Annex 1. This is followed by a bottom-up view, addressing the CRM content of products, which complements the top-down overview of the synthesis table. Chapter 2 elaborates on the economic importance of CRMs by combining the data on the economy-wide use with the shares of European value added for sectors with a direct dependence on CRMs. Additionally, using EXIOBASE, we also discuss import dependence of specialty non-ferrous metals and precious metals. The import dependence as identified for raw materials also applies in further stages of the supply chain (i.e. not only raw materials but also semi-finished goods and intermediates). This is shown in Chapter 3 by means of a few case studies and flow diagrams for selected CRMs.

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1. A REVIEW OF CURRENT KNOWLEDGE ON EUROPEAN USE OF CRMS

At the moment, there are two main studies describing the use of critical raw materials (CRMs) in Europe in detail, being the 2014 Report on Critical Raw Materials for the EU (European Commission 2014) and the study about data for a Raw Material System Analysis (BIO by Deloitte 2015). In this chapter we complement some of the data from these two studies with other available publications on the use of individual CRMs, either at the global or the European level to constitute a synthesis of current knowledge of the use of CRMs in the EU. Though we are aware of the upcoming update of the critical raw materials list by the European Union (European Commission 2017), we are unable to incorporate these findings as it has not yet been published.

The main question covered in Section 1.1 is how and where individual CRMs are used (in which industry and for which application?) and to give an estimate of the fraction of the total use that is destined for these applications, based on a review of available data in various studies. As such we present a rather quantitative description with a top-down perspective, meaning that we look at the total CRM demand at the industry-level, without going into much detail about why and how much of these materials are used in specific products.

Section 1.2 provides a more product-level perspective by reviewing some of the main studies and sources detailing the use of CRMs in products, in particular focussing on their CRM content or concentrations per product or even per kg of product. This section should not be interpreted as an exhaustive review, but is intended to show how the two types of information presented in this chapter can complement each other.

1.1 A REVIEW OF SOURCES ON INDIVIDUAL CRMS

Using the list of critical raw materials of 2014 (European Commission 2014) and the MSA study (BIO by Deloitte 2015) reports as a basis, we did a review of literature and data sources, thus constructing a comprehensive overview of current knowledge on the use or critical raw materials in the EU. Table 1 lists the sources used for each of the CRMs in the (European Commission 2014) list as well as the regional and temporal scope of the study. Please note that the data available in the Raw Materials Information System (RMIS) for Europe as developed by the Joint Research Centre is not explicitly incorporated as their material factsheets rely on the data originally published in the two abovementioned studies (Joint Research Centre 2017).

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Table 1. The 2014 list of critical raw materials and the data sources used in this report. For detailed data from each of these reports, please see Annex 1 * PGMs are represented by individual metals with data availability, being platinum, palladium & rhodium. ** LREEs & HREE stands for Light/Heavy Rare Earth elements. These are covered by sources on individual elements as far as possible. The Light Rare Earth elements covered in this review are Lanthanum, Cerium, Praseodymium, Yttrium, Neodymium, Samarium and Europium. The Heavy Rare Earth elements are represented by Gadolinium, Terbium, Dysprosium and Erbium. Data from Hoenderdaal et al. (2013) is only used for Dysprosium.

	European use		Global use	
	Source	Year of data	Source	Year of data
Antimony	European Commission 2014	2011	Graedel & Erdmann, 2012	N.A
	BIO by Deloitte 2015	2012		
Beryllium	European Commission 2014	2011	Graedel & Erdmann, 2012	N.A
	BIO by Deloitte 2015	2012		
Borates	European Commission 2014	2011		
	BIO by Deloitte 2015	2012		
Chromium	BIO by Deloitte 2015	2013		
Cobalt	BIO by Deloitte 2015	2012	European Commission 2014	2012
			Graedel & Erdmann, 2012	N.A
Coking coal	BIO by Deloitte 2015	2012	European Commission 2014	2007
Fluospar	BIO by Deloitte 2015	2012	European Commission 2014	2010
			Bide et al 2011	N.A
Gallium	BIO by Deloitte 2015	2012	European Commission 2014	2010
			Graedel & Erdmann, 2012	
Germanium	BIO by Deloitte 2015	2013	Graedel & Erdmann, 2012	N.A
			Guberman 2014	N.A
			European Commission 2014	2011
Graphite	BIO by Deloitte 2015	2013	Merriman 2016	2014
			Olson 2014	N.A
			European Commission 2014	2010
Indium	BIO by Deloitte 2015	2013	Graedel & Erdmann, 2012	N.A
			European Commission 2014	2013
Magnesite	European Commission 2014	2010		
	BIO by Deloitte 2015	2012		
Magnesium	European Commission 2014	2010		
	BIO by Deloitte 2015	2012		
Niobium	BIO by Deloitte 2015		European Commission 2014	<2010
			Graedel & Erdmann, 2012	N.A
PGMs *	European Commission 2014	2012	European Commission 2014	2012
	BIO by Deloitte 2015	2012	Graedel & Erdmann, 2012	N.A
	Johnson & Matthey 2016	2015	Johnson & Matthey 2016	2015
Phosphate rock	BIO by Deloitte 2015	2012		
LREE**	BIO by Deloitte 2015	2013	Graedel & Erdmann, 2012	N.A
	Machacek and Kalvig 2016	2014	European Commission 2014	2012
HREE**	BIO by Deloitte 2015	2013	Graedel & Erdmann, 2012	N.A
	Machacek and Kalvig 2016	2014	European Commission 2014	2012
			Hoenderdaal et al., 2013	2011
Silicon metal	European Commission 2014	2012	European Commission 2014	2010
	BIO by Deloitte 2015	2012		
Tungsten	BIO by Deloitte 2015	2012	Graedel & Erdmann, 2012	N.A
			European Commission 2014	2010
			Pitfield & Brown, 2011	2010

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For each of the materials in Table 1 the market shares of the CRM use going into different applications are summarized in **Error! Reference source not found.**. In addition, we provide a graphical summary in Figure 2. In **Error! Reference source not found.**, CRM use categories are presented as rows, grouped hierarchically according to corresponding or overlapping sectors and products. The columns represent the individual critical raw materials and their reported use adds up to a 100% of the total European use for each material. This allows the assessment of use by material, but it also highlights which ranges of CRMs are important to a specific economic sector.

Table 2 provides a synthesis of the data shown in the 32 tables in Annex 1 using the following guiding criteria:

1. Use data on European use as much as possible. European estimates where therefore prioritized over global data (though for a few CRMs global numbers are the only ones available). Averages were applied where multiple studies were available.
2. Provide the highest possible detail of end-use application categories. Therefore, if a study provided a more detailed split in CRM applications, it was prioritized over data aggregated at a higher level. In some cases, the European use shares where further sub-divided according to the sub-shares of global studies if a more detailed global study was available. To give an example for the case of indium (Annex 1.10); the (BIO by Deloitte 2015) study reports that 62% of indium is used in "Electronic Equipment & Domestic Appliances", while (Graedel & Erdmann, 2012) report more detail for that product-category by specifying the specific shares of indium used for televisions, monitors & computers at the global level. In that case, we keep the original European share as a total, but disaggregate this number further based on the relative shares for the global data for individual products in the study by Graedel and Erdmann.
3. Indicate use even if quantitative information is missing. This was the case when the text of the studies suggested the use of a CRM in a sector or application but no figures were provided.

The aim of the combined approach of selection and averaging to construct a synthesis table like this is to ensure that the results are based on the most relevant and the most detailed data at the same time. The step-wise decision tree underlying the synthesis table can be found in Annex 2. In the process, we also chose to focus on the end-use as much as possible. Some studies reported estimates of CRM use for European manufacturing as well as for European final demand in products. In those cases we chose to focus on the CRMs used in European final demand as much as possible. However, as discussed in the previous section,

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this inevitably leads to some minor difficulties with the interpretation because not all use shares of CRMs are allocated towards the final demand of products. The synthesis table should thus be considered a constructed snap-shot of the most recent knowledge of European CRM use; without claiming to be complete or methodologically infallible, as the process of matching categories and selecting studies requires expert judgement to some extent.

When compiling data on CRM use (cf. Annex 1), two things stand out : First, the numbers on the shares of materials going into use in a particular application can vary considerably between studies, even when considering the same regional scope. For example, in Annex 1.19, according to (Johnson & Matthey 2016) 5% of European palladium is used in electronics, while the (BIO by Deloitte 2015) study states this is about 13%. Small discrepancies like that may exist because a different method is used to estimate the use shares, but also because the studies considered often describe the situation for different years. Secondly, the level of detail in the categorisation of end uses differs substantially between available studies. This is not surprising because no official classification exists to describe critical raw material use, so studies attempting to describe the use of CRMs tend to introduce their own classification based on the level of detail in their data sources.

The lack of a systematic description or classification of CRM applications and end-use categories introduces another more substantial problem: the use of CRMs could be described from a material perspective as well as from a product perspective. Imagine, for example, the use of a high-strength steel alloying element, like cobalt. The use of cobalt in alloyed steel makes up for about 39% of the total European demand of the critical material. However, the steel is eventually used in other applications, obviously. Some studies describe the CRM use up to the level material perspective (39% of demand is used in steel-alloys) while others describe the CRM use further up the supply chain, from the final demand or product perspective (how much of that steel is subsequently used in construction or cars, for example?). This makes it difficult to synthesise or compare the different sources into a common framework.

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					Metals										
					Antimony	Beryllium	Borate	Chromium	Cobalt	Gallium	Germanium	Indium	Magnesium	Niobium	Tungsten
					Sb	Be	B	Cr	Co	Ga	Ge	In	Mg	Nb	W
Metals	Metallurgy (3) / Other metals (2)					1,5	4,5								
	Other alloys	lead alloys (2)			14,2										
		superconductors (1)												2	
	Aluminium	Aluminium making (1)													
		Aluminium Alloys (2)	Alumiunium Packaging (1)										17,4		
			Aluminium alloy construction elements (1)										29,6		
	steel	Steel making	Steel desulphurisation (1,2)										13		
			Recarburising (6)												
			Foundries (6)												
			Refractory goods (1)												
			Nodular cast iron (2)										0,5		
		steel alloys	superalloys (2)						18						
			hard metals (1)	hardfacing metals/high strength steel (2)					5,8						6
				high temperature steel (1)											2
			hard materials (2)	Milling & cutting tools (1)											31
				Mining & construction tools (1)					15,2						21
				Other wear tools (1)											17
Transport (1)	Vehicles (1)	auto catalyst (3)													
		electric vehicles (7)													
		Oxygen sensors (1)						18							
		Magnesium die-casting (2)											35,5	38	
		Auto electronics				16									
		Automotive friction parts (2)													
	Aircraft, ships & trains (2)	Aircraft/defence (1)				4,8								1	2,5
		shipbuilding & trains				3,2									
Chemical	Animal Feed & Fertilizer (1) / Feed and Food additives (1)						12,5								
	Chemical products (2)						6,4							*	
	Industrial fluids (2)						2								
	Polishing (3) / Pickling & Etching (1)														
	Electrodes (1)														
	Detergents (2)						0,9								
	(Bio)medical, including dental (1,2)														
	Lubricants (2)														
	catalysts & pigments (1)	Pigments (1)							7						
		chemical catalysts (1)	Fluid Catalytic cracking (3)						3		*				7
Petro chemical & energy (1)	Petro-chemical	oil refining (1)													
	Energy	Uranium processing (5) / nuclear energy production (1)													
		Photovoltaic modules (1)						15		3	*	21			
		gas turbines (1)												1	2,5
		Wind turbines (4)													
Rubber, plastics, glasses, ceramics & others	Plastics: catalysts and heat-stabilizers (2)				5,5										
	(Plastic) wire & cable (1)				3,0										
	Glass, ceramics & others	Ceramics (3)					12								
		Others			1,5										
		Glass (3)	Fibre-optics (4)								19				
			Lasers (4)												
			Glass insulation			1,5	29,4								
			Architectural & automoitve glass (1)									8			
			Other glass				26,1								
Mechanical & Electrical	magnets (3)	permanent-magnets (1)								14					
	Batteries (3)	lead-acid batteries (2)			32,3				51			9			
	Phosphors (2,3)	Lighting (4)													
		Flat Panel Display (4)													
		Plasma (4)													
	Electrical & Electronic Equipment /appliances	Mechanical equipment (2) & Industrial motors (7)				22,5									
		Electrical equipment (1,2)				10	1	6,2							6
		carbon brushes (2)													
		Electronics & IT (2)	Sensors (1)							18					
			Monitors (4)									27,6			
			Televisions (4)									20,7			
			Computers (4)		35							13,8			
			Audio systems (26)			25		6,2							
			opto-electronics	IR Optics (1,2,4)						20	72				
			(semi)conductors	capacitors (7)											
				Integrated circuits (1)						40					
Heavy industry & construction	Cement industry (2)														
	Environmental (1) (= waste & flue gas treatment)							34							
	pipelines (1)													7	
	Building construction (1)						4							51	
Other consumer goods	Textiles (1)				8		0,2								
	Cutlery, tableware & kitchen items							20,6							
	Jewelery (1,2)														
	Investment (1)														
Others (1,2,3)						16	1,8			5	9		4		5
Totals					**99,5**	**101**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Table 2 Synthesis of the review of current use of critical raw materials in Europe. The numbers in the row descriptions refer to the CRM use categories as reported by the original studies, being 1) (BIO by Deloitte 2015) , 2) (European Commission 2014), 3) (Machacek and Kalvig 2016), 4) (Graedel & Erdmann, 2012), 5) (BGS 2011), 6) (Roskill Information Services 2016). Cells with an * indicate that some of the excluded global studies refer to the use in these sectors.

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				Minerals etc.						PGMs		
				Coking coal	Silicon quartz	Fluorspar	Natural Graphite	Phosphate rock	Magnesite	Palladium	Platinum	Rhodium
				C	Si	F	C	P	-	Pd	Pt	Rh
Metals	Metallurgy (3) / Other metals (2)											
	Other alloys	lead alloys (2)										
		superconductors (1)										
	Aluminium	Aluminium making (1)				9						
		Aluminium Alloys (2)	Alumiunium Packaging (1)		36.5							
			Aluminium alloy construction elements (1)									
	steel	Steel making	Steel desulphurisation (1,2)									
			Recarburising (6)				2.5					
			Foundries (6)			*	8.6					
			Refractory goods (1)				31.9		68.5			
			Nodular cast iron (2)									
		steel alloys	superalloys (2)	90								
			hard metals (1)	hardfacing metals/high strength steel (2)								
				high temperature steel (1)								
			hard materials (2)	Milling & cutting tools (1)								
				Mining & construction tools (1)								
				Other wear tools (1)								
Transport (1)	Vehicles (1)	auto catalyst (3)								75.2	68	76
		electric vehicles (7)										
		Oxygen sensors (1)										
		Magnesium die-casting (2)										
		Auto electronics										
		Automotive friction parts (2)					5.0					
	Aircraft, ships & trains (2)	Aircraft/defence (1)										
		shipbuilding & trains										
Chemical	Animal Feed & Fertilizer (1) / Feed and Food additives (1)							93	18.5			
	Chemical products (2)				52	68						
	Industrial fluids (2)											
	Polishing (3) / Pickling & Etching (1)					6						
	Electrodes (1)			1								
	Detergents (2)							7				
	(Bio)medical, including dental (1,2)									3.6	4.6	
	Lubricants (2)						13.4					
	catalysts & pigments (1)	Pigments (1)										
		chemical catalysts (1)	Fluid Catalytic cracking (3)							4.63	6.64	11
Petro chemical & energy (1)	Petro-chemical	oil refining (1)				4					0.3	
	Energy	Uranium processing (5) / nuclear energy production (1)				5						
		Photovoltaic modules (1)			9.2							
		gas turbines (1)										
		Wind turbines (4)										
Rubber, plastics, glasses, ceramics & others	Plastics: catalysts and heat-stabilizers (2)											
	(Plastic) wire & cable (1)											
	Glass, ceramics & others	Ceramics (3)										
		Others										
		Glass (3)	Fibre-optics (4)								0.5	4
			Lasers (4)									
			Glass insulation									
			Architectural & automoitve glass (1)									
			Other glass									
Mechanical & Electrical	magnets (3)	permanent-magnets (1)										
	Batteries (3)	lead-acid batteries (2)					25					
	Phosphors (2,3)	Lighting (4)										
		Flat Panel Display (4)										
		Plasma (4)										
	Electrical & Electronic Equipment /appliances	Mechanical equipment (2) & Industrial motors (7)										
		Electrical equipment (1,2)										
		carbon brushes (2)					4.0					
		Electronics & IT (2)	Sensors (1)									
			Monitors (4)									
			Televisions (4)									
			Computers (4)									
			Audio systems (26)							9.27	1.9	*
			opto-electronics	IR Optics (1,2,4)								
			(semi)conductors	capacitors (7)	2.3							
				Integrated circuits (1)								
Heavy industry & construction	Cement industry (2)								1.7			
	Environmental (1) (= waste & flue gas treatment)											
	pipelines (1)								3			
	Building construction (1)											
Other consumer goods	Textiles (1)											
	Cutlery, tableware & kitchen items											
	Jewelery (1,2)									3.3	10.3	
	Investment (1)									2.0	1.5	
Others (1,2,3)				9		8	9.6		8.3	1.7	6.3	9
Totals				**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Table 2. Synthesis of the review of current use of critical raw materials by various sectors (in percent) in Europe. The numbers in the row descriptions refer to the CRM use categories as reported by the original studies, being 1) (BIO by Deloitte 2015) , 2) (European Commission 2014), 3) (Machacek and Kalvig 2016), 4) (Graedel & Erdmann, 2012), 5) (BGS, 2011), 6) (Roskill Information Services 2016). As indicated in the text, cells with an * indicate that some of the excluded global studies refer to the use in these sectors.

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					Light Rare Earths							Heavy REs			
					Yttrium	Lanthanum	Cerium	*Praseodymium	Neodymium	Samarium	*Europium	Gadolinium	Terbium	*Dysprosium	*Erbium
					Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Er
Metals	Metallurgy (3) / Other metals (2)					5.5	4.83	4		*					
	Other alloys	lead alloys (2)													
		superconductors (1)													
	Aluminium	Aluminium making (1)													
		Aluminium Alloys (2)	Alumiunium Packaging (1)												
			Aluminium alloy construction elements (1)												
	steel	Steel making	Steel desulphurisation (1,2)												
			Recarburising (6)												
			Foundries (6)												
			Refractory goods (1)												
			Nodular cast iron (2)												
		steel alloys	superalloys (2)												
			hard metals (1)	hardfacing metals/high strength steel (2)											
				high temperature steel (1)											
			hard materials (2)	Milling & cutting tools (1)											
				Mining & construction tools (1)						3					
				Other wear tools (1)											
Transport (1)	Vehicles (1)	auto catalyst (3)				4.2	48.4		1						
		electric vehicles (7)												17	
		Oxygen sensors (1)			1										
		Magnesium die-casting (2)													
		Auto electronics													
		Automotive friction parts (2)													
	Aircraft, ships & trains (2)	Aircraft/defence (1)								*					
		shipbuilding & trains													
Chemical	Animal Feed & Fertilizer (1) / Feed and Food additives (1)														
	Chemical products (2)														
	Industrial fluids (2)														
	Polishing (3) / Pickling & Etching (1)					3	3.22	2							
	Electrodes (1)														
	Detergents (2)														
	(Bio)medical, including dental (1,2)														
	Lubricants (2)														
	catalysts & pigments (1)	Pigments (1)													
		chemical catalysts (1)	Fluid Catalytic cracking (3)			50	3.22								
Petro chemical & energy (1)	Petro-chemical	oil refining (1)													
	Energy	Uranium processing (5) / nuclear energy production (1)									*				
		Photovoltaic modules (1)													
		gas turbines (1)													
		Wind turbines (4)						14.1						4	
Rubber, plastics, glasses, ceramics & others	Plastics: catalysts and heat-stabilizers (2)														
	(Plastic) wire & cable (1)														
	Glass, ceramics & others	Ceramics (3)				2.8	1.6	7	6.25						
		Others													
		Glass (3)	Fibre-optics (4)												64.5
			Lasers (4)												17.2
			Glass insulation						1.25						
			Architectural & automoitve glass (1)												
			Other glass			14	25.8								4.3
Mechanical & Electrical	magnets (3)	permanent-magnets (1)					1.6		74	30		20	46		
	Batteries (3)	lead-acid batteries (2)				11.2	3.22		12	50					
	Phosphors (2,3)	Lighting (4)			78						45		54		
		Flat Panel Display (4)				3	3.22	12	1.25		28.8	40			12.5
		Plasma (4)									11.7				
	Electrical & Electronic Equipment /appliances	Mechanical equipment (2) & Industrial motors (7)												39	
		Electrical equipment (1,2)													
		carbon brushes (2)													
		Electronics & IT (2)	Sensors (1)												
			Monitors (4)												
			Televisions (4)												
			Computers (4)					35.3						9	
			Audio systems (26)											4	
			opto-electronics	IR Optics (1,2,4)								*			
			(semi)conductors	capacitors (7)										14	
				Integrated circuits (1)				23.5							
Heavy industry & construction	Cement industry (2)														
	Environmental (1) (= waste & flue gas treatment)														
	pipelines (1)														
	Building construction (1)														
Other consumer goods	Textiles (1)														
	Cutlery, tableware & kitchen items														
	Jewelery (1,2)														
	Investment (1)														
Others (1,2,3)					21	6.3	4.83	2	1.3	20	14.5	40		13	1.5
Totals					**100**	**100**	**99.9**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Table 2. Synthesis of the review of current use of critical raw materials by various sectors (in percent) in Europe. The numbers in the row descriptions refer to the CRM use categories as reported by the original studies, being 1) (BIO by Deloitte 2015) , 2) (European Commission 2014), 3) (Machacek and Kalvig 2016), 4) (Graedel & Erdmann, 2012), 5) (BGS, 2011), 6) (Roskill Information Services 2016). As indicated in the text, cells with an * indicate that some of the excluded global studies refer to the use in these sectors.

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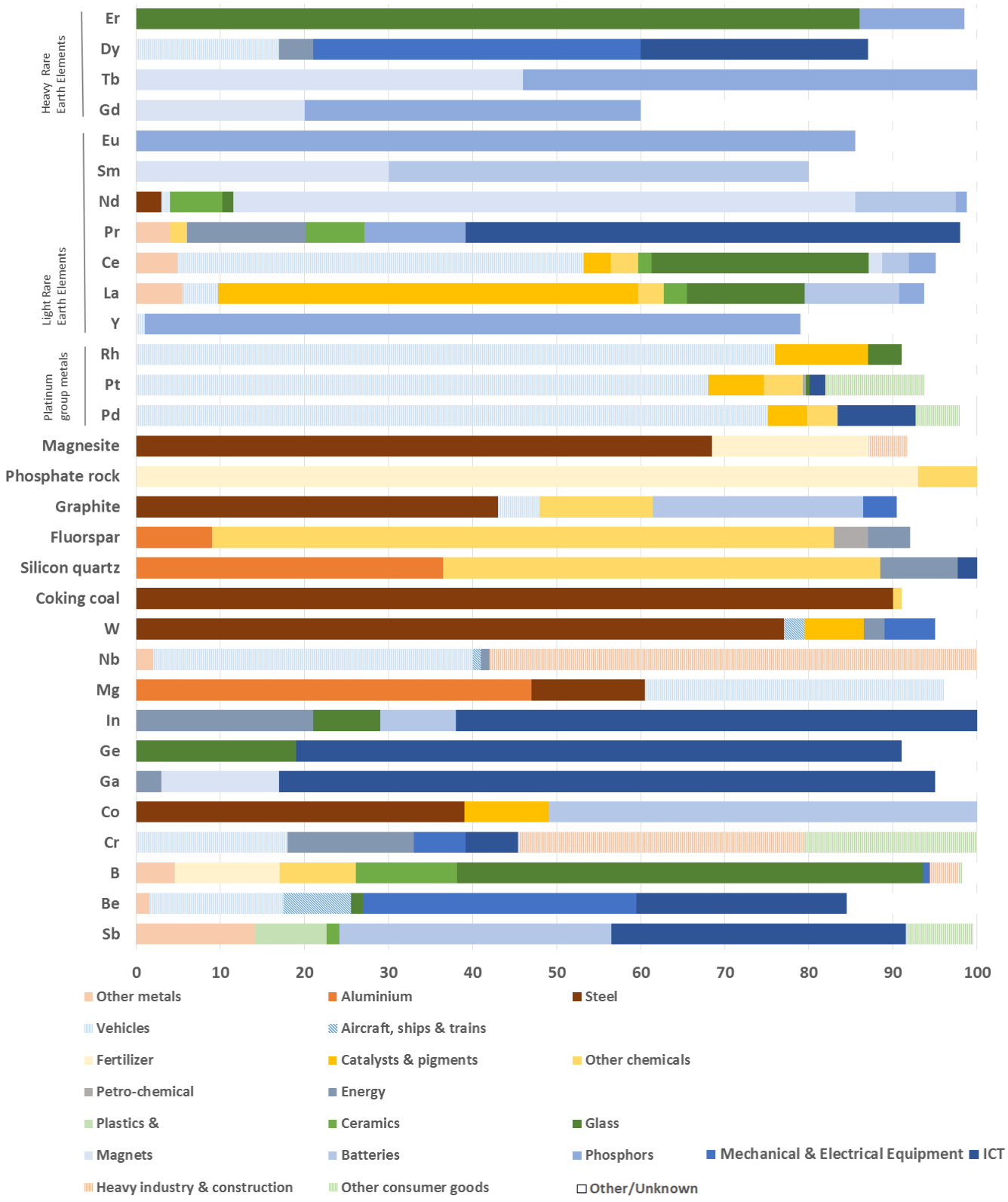

Figure 2. Shares of critical raw material use in Europe. The bar-chart above shows the shares of critical raw material use as reported in Table 2, based on the entire Annex 1.

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1.2 CRM COMPOSITIONS OF PRODUCTS

Complimentary to the data on the use of CRMs per economic sector, there is a whole range of literature and research available that describes the use of CRMs from an even more detailed product content perspective. These studies describe the amounts of the elements actually residing within a product like a smart-phone, a laptop computer or inside an electric car. However, since these studies apply a more bottom-up perspective, they do not always capture the full use of a CRM in the economy. This is because some applications are either dissipative (e.g. the application of phosphorous fertilizer) or they could be a specific requirement in a production or processing stage (like the cerium used in polishing glass surfaces). In both cases the CRMs used do not (or only partly) end up in the final product, while the CRM itself is either lost or recycled.

Even though a product content based perspective on the use of CRMs may not be suitable to cover the full use of CRMs, it is still highly valuable information for two distinct reasons.

- First, it could provide a bottom-up complement to a top-down estimate of CRM use. As the tables in Annex 1 show, data on the global use of a material per industry/application can vary strongly depending on the source and the method of the reporting study. Complementing such information with data that can actually be measured by chemical analysis or derived based on engineering knowledge and data, provides a valuable step in validating and reconciling our current knowledge of the use of critical raw materials.
- Second, and perhaps even more important, is the fact that material substitution happens at the product level, not at the industry-level. As substitutability is an important determinant of the criticality of materials, it makes sense to collect and connect knowledge on the use of CRMs at the level of products or even product-components.

Though it is not our intention to provide a full review of data-sources on the content of CRMs in products, we list a few useful quantitative studies in Table. The focus of these studies can either be on quantifying the use of a specific material (e.g. the concentrations of neodymium in all products that use it), or the use of several materials in a particular range of applications (e.g. CRMs in cars, or electricity generation). The list also contains estimates for product concentrations of non-critical raw materials.

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Table 3. Overview of selected data sources on the critical raw material content in products. These studies report product content data for multiple CRMs or at least multiple applications of a single critical material. Though CRM content estimates are not necessarily region specific, the "Region" column gives an indication of the focus area of the study.

Source	Materials	Applications	Region
Cullbrand and Magnusson 2012	REEs, PGMs & others	Cars	-
Habib 2015	Neodymium	Magnets in various applications	Denmark
Widmer et al., 2015	REEs, PGMs & others	Vehicles	Switzerland
Moss et al. (2011) and Moss et al. (2013)	REEs, PGMs & others	Energy technologies, (incl. lighting & residential)	Europe
Elwert et al. 2015	cobalt (& other non-critical materials)	(hybrid-)electric vehicles	-
U.S. Department of Energy 2011	REEs, PGMs & others	Mostly renewable energy & electric vehicles	United States
Oguchi et al., 2011	palladium, samarium (& other non-critical materials)	Electronics & appliances	Japan
Chancerel et al., 2015	cobalt, gallium, indium, palladium and REEs	ICT & Consumer equipment	Germany
Öhrlund 2012	REEs, indium, samarium	Solar energy & wind energy	Europe
Licht et al. 2015	gallium, indium, germanium	Mostly: solar energy & (opto)electronics	Global

The need to broaden the knowledge base on the use of critical raw materials in Europe is being addressed under the Raw Material Initiative (European Commission 2008). This has triggered and inspired a range of platform initiatives and research activities. A range of research projects and platforms worth mentioning in this respect are: ERECON, CRM_InnoNet, MSP-REFRAM, Minerals4EU, MICA, MIN-GUIDE, SmartGround, INTRAW and the PROSUM project.

Yet, despite all these efforts, the studies listed in Table suggest that the sources describing the CRM content are almost exclusively focused on vehicles, appliances and energy technologies. This is even true for what is probably the most ambitious project in mapping CRM use in Europe, the PROSUM project (see Box 1). At the same time, there are other important applications for CRMS, such as chemicals, ceramics and glasses or construction materials. Information on CRM product content in these applications are required too. At this moment detailed product content studies do not yet cover the full demand of CRMs

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presented in the previous section, which highlights an important gap in the knowledge thus far.

The PROSUM Project

The PROSUM project aims to create a knowledge platform for the 'urban mine' (Huisman et al. 2016); which is the concept of looking at societal stocks (e.g. infrastructure, buildings and consumer-products) as a potential source for critical raw materials, made available (mined) through enhanced recycling techniques.

Judging the potential of the urban material stocks as a source for CRMs ultimately requires some form of quantified data on the CRM content of various commodities. The PROSUM project is developing a database with the purpose of storing this type of product content data specifically. Efforts to fill the database are initially limited to CRM composition in vehicles, electronic equipment, battery applications as described by (Scheepens et al. 2016), but the database could be expanded further.

Though the project is currently ongoing, and no actual data has been made available through the project yet, databases like this are of interest to the SCRREEN project and CRM experts more broadly. Though the initial coverage of the PROSUM database does not seem to resolve the knowledge gaps yet (cf. Table), the proposed database could form a basis to cover more end-use applications in the future.

Box 1. A short description of the PROSUM project

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2. AN INDICATION OF ECONOMIC IMPORTANCE

The review of current use provided in Chapter 1 gives the shares of each industry or application in the total CRM demand, but it does not say anything about the economic consequences of a possible supply disruption. In the methodology used to prepare the list of Critical Raw Materials for the EU in 2010 and 2014 (European-Commission 2010; European Commission 2014), this question was approached by examining the value added of the sectors using the respective raw materials. Information pertaining to this is provided in Section 2.1, while Section 2.2 focuses on import dependence. Import dependence was not explicitly considered in the quantitative methodology for defining CRM for the EU in the 2010 and 2014 studies. However, it is widely acknowledged to be an important factor in criticality. The information given below is based on the data for 2011 in the latest version (version 3.3) of the EXIOBASE input-output model (Tukker et al. 2014).

2.1 VALUE ADDED OF CRM DEPENDENT INDUSTRIES

Where possible, we linked the CRM use shares from **Error! Reference source not found.** to their corresponding industries in the EXIOBASE input-output model as shown in Figure 3. The figure shows both the connection to the use of CRMs (colours) as well as the share in the value added within the entire European Union (EU28) of the relevant industry (the angles of the pie-chart, based on data for 2011). Since we have only linked industries with a direct CRM dependence as indicated in Annex 3, the chart covers only 18% of the total European value added, which is then normalized to 100% in the pie-chart. Therefore, the chart should be interpreted carefully, as both the value added and the colour scales express a relative indicator.

The colours in Figure 3 express the combined CRM dependence score. This score was constructed to give a rough aggregate indication of the dependence of different sectors on critical raw materials, considering both the number of critical raw materials on which the sector of interest relies, and how much of the total European demand for those critical raw materials is used in the sector of interest. The data behind Figure 3 as well as a description of the metric by example are given in Annex 3.

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Figure 3. Relative contribution of sectors to the European value added of CRM-dependent industries and their CRM dependency score (red=high). As emphasised in the text, the sectoral value added for the year 2011 is plotted as the angles of the pie-chart. However, the full chart represents only 18% of total European value added. The colour scale indicates the relative CRM dependency of each industry. The data used can be found in Annex 3.

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By providing data on both the economic importance and the CRM dependence of European industries in figure 3 and annex 3, we identify the manufacturing of mechanical & electrical equipment to be of particular interest. The sector has a seemingly high dependence on CRMs as well as a relatively high contribution to European value added. Another industry with a high share in the value added is the construction sector, however, Figure 3 shows that its CRM dependence is relatively low.

A chart such as Figure 3 could be used to identify key areas for knowledge development beyond the sectors commonly focussed on (like vehicles, energy and appliances, as discussed in the previous chapter). If this chart were to guide further research it would identify machinery & equipment as an important category to be explored further. The category is only partially covered by studies on consumer electronics and equipment. Other potential blind spots in the current knowledge on the use of CRMs are applications in metals (particularly steel), chemical applications and perhaps glasses.

2.2 IMPORT DEPENDENCE OF EUROPE

Though import dependence was not explicitly part of the definition of the material criticality score as defined for the European Union in 2010 and 2014 (European Commission 2010; European Commission 2014), it is certainly a relevant indicator when it comes to Europe's supply risk for raw materials. Figure 4 depicts the ratio between the weight of imports, exports and extraction in tonnes for two groups of materials, precious metals and other non-ferrous metals, based on data from the EXIOBASE database. The right-side part of the bar (without a destination) represents the amount of material used within Europe, or more specifically the European apparent consumption. This includes materials used to produce products for both internal demand as well as for exports, so it does not necessarily mean that these materials remain within European borders.

The figures (Figure 4a-b) show that for other non-ferrous metals (not copper, aluminium, zinc, lead, nickel, tin, but all others like cobalt, chromium, lithium, germanium, gallium etc.) the European domestic extraction is not enough to fulfil the European apparent consumption. European extraction of bulkier metals is often dominated by one or a few countries. For example, zinc is mostly mined in Ireland and Sweden, lead ores are also mostly mined in Sweden, nickel stems mainly from Finland while the larger volumes of bauxite and copper are mined mostly in Greece and Poland respectively. However, for the specialty metals listed under the 'other non-ferrous metals' the European economy is still rather dependent on imports, due to its large apparent consumption.

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For precious metals as a group, this is not the case because a large part of the demand is provided by domestic extraction of silver and some gold in Poland, Bulgaria, Finland, Greece, Romania, Slovakia, Spain, Sweden and UK, thus providing even a surplus, which is available to be exported, mostly to Mexico.

Detailed trade relations as shown in Figure 4 could highlight economic vulnerabilities and provide an overview of the global interdependencies in the supply chains of critical raw materials. However, it was not possible to derive these figures for other groups of critical raw material based on the EXIOBASE database alone. The reason is that the physical supply and use tables as developed by (Merciai et al. 2013) do not provide mining/extraction data for other relevant CRMs like phosphorous or coking coal.

However, we would like to emphasize that the overview in Figure 4 presents a limited view, based on the flows of raw materials only. As the knowledge-base of the use of CRMs in Europe grows we are starting to realize increasingly that CRM dependence goes beyond the dependence on materials in their raw material forms only. Imports of semi-finished and finished products may also be significant (cf. Section 3.2). Supply chain disruptions may eventually affect the prices of final products as well. The following chapter elaborates on how to distinguish these up-stream flows of CRMs specifically.

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a) Other non-ferrous metals **b) Precious metals**

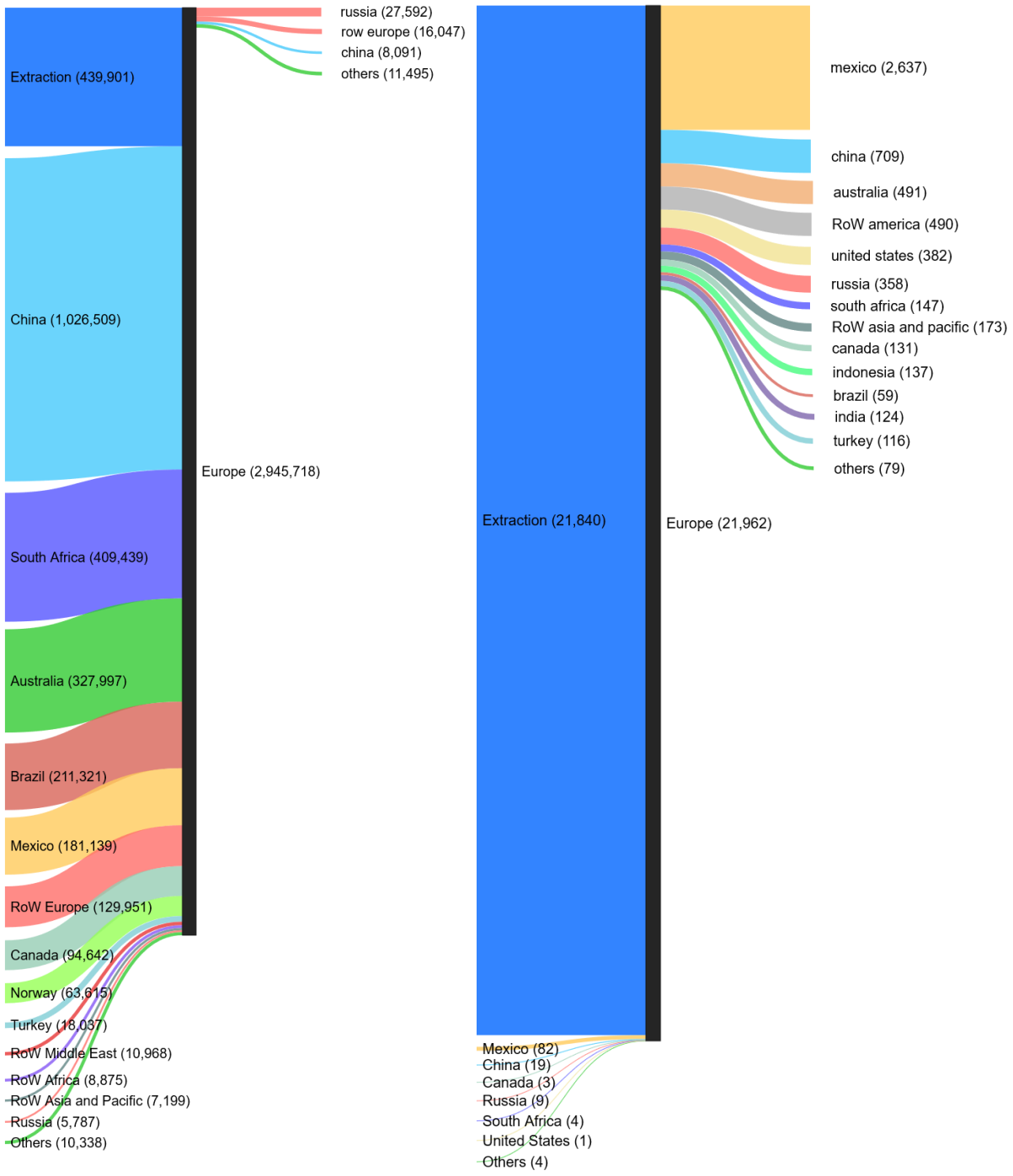

Figure 4. Imports, extraction and export of: a) other non-ferrous metals, i.e. not aluminium, copper, zinc, lead, nicker or tin but all others like cobalt, titanium, beryllium, tungsten, lithium, germanium, gallium (left) and b) precious metals (right) in the European union (in tonnes of metal). Imports and extraction are shown

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on the left side, and exports on the right. Data is based on the hybrid supply and use tables as part of EXIOBASE v3.3, further described by (Merciai et al. 2013).

3. ANALYSING FLOWS

The Study on Data for a Raw Material System Analysis (BIO by Deloitte 2015), commissioned by DG GROW, provides Sankey diagrams of the flows of selected materials across the value chain, considering extraction, export, import and stocks of critical raw materials within EU. In addition, it provides clues to the relative importance of different intermediate processing steps by distinguishing various material forms, such as raw materials, processed material and even wastes. However, this was not explicitly included in the Sankey diagrams.

Based on the textual information provided in the MSA study, we attempt to quantify and link the material flows across the manufacturing stages from extraction to the end product, thereby incorporating parameters such as EU production as input and EU consumption as output in the Sankey diagram along with exports and imports at the different stages of production. This is however an interpretation of the data as well as the text, requiring additional assumptions to link the involved production stages. This shows that the level of knowledge on the flows of CRMs in Europe is not yet sufficiently developed to provide an overview of all relevant material flows within Europe. This exercise is intended to illustrate some of the additional steps required to get there, and the potential insights that could be gained when the full inter-industry supply chain could be resolved.

Based on the ontology used in the MSA study (BIO by Deloitte 2015) study, we identify four major processing steps before the material reaches the final use phase for most of the selected materials from extraction/mining of materials, processing (oxides, metals etc.) intermediate production (alloys, semi-finished products/components etc.) and final production. Export and import of raw/primary, processed, intermediate and final products are also included in the Sankey diagrams. The individual raw materials are selected on basis of availability of the most accurate data across value chain and manufacturing steps. We have avoided those materials for which data on production, consumption, export and import of all four stages is not available or partially available. 8 commodities were selected for case studies on the basis that they fit a similar model to each other. We also omitted certain materials as they have less processing steps before they are used in a final application such as use of gold in jewelries. So the total list of selected CRMs for this section stand at 8 namely: antimony, chromium, cobalt, dysprosium, indium, neodymium, platinum and tungsten.

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In Section 3.1, we provide the data, figures and some background information for neodymium only, while the other case studies are presented in Annex 4. Please note that in most cases the material flows are not fully balanced, meaning that the reported values on imports and production of the CRMs in a particular production stage (the IN side) are either too small or too large to match the exports and the up-stream demand (the OUT side). This indicate the need for more elaborate data for defining intra-European CRM consumption.

3.1 A CASE STUDY ON NEODYMIUM

Neodymium is used in a variety of intermediate applications such as mining and construction tools, auto catalysts, ceramics, batteries (NiMH), phosphors and permanent magnets. These constitute around 80% of the overall Nd consumption in EU. Neodymium based permanent magnets (NdFeB) have become integral component of many electronic, energy and automobile systems such as wind energy turbines and hybrid and electric vehicles.

Table 4. European Neodymium flows (t), for 2013. Based on (BIO by Deloitte 2015). Data indicated with an * are derived from the quantitative *and* qualitative information in the MSA study.

	IN		OUT	
	Extraction/prod.	Import	Export	Output of processing
Raw/Primary	0	178	N.A	200
Processed/intermediate	*200**	275	83	*392**
Waste	21	11	8	N.A
Intermediate	*373**	570	8	935
Final	*935**	385	332	1060

The concentration of rare earth elements (REEs) including neodymium and other critical metals in China raises the issue of supply risk as Europe is the one of the top importers and consumer of these minerals both in mineral and processed forms (for the numbers, please see Table). These raw materials are fundamental to Europe's economy, growth and jobs. The criticality of these minerals was high in the 2014 reports of the European Commission's Ad hoc Working Group on defining critical raw materials (European Commission 2014).

Figure 5 shows that the total quantity of European import of REE metals decreased in the last 15 years and that the EU is increasingly dependent on China for the intermediate metal forms, which is an essential component in a number of intermediate products.

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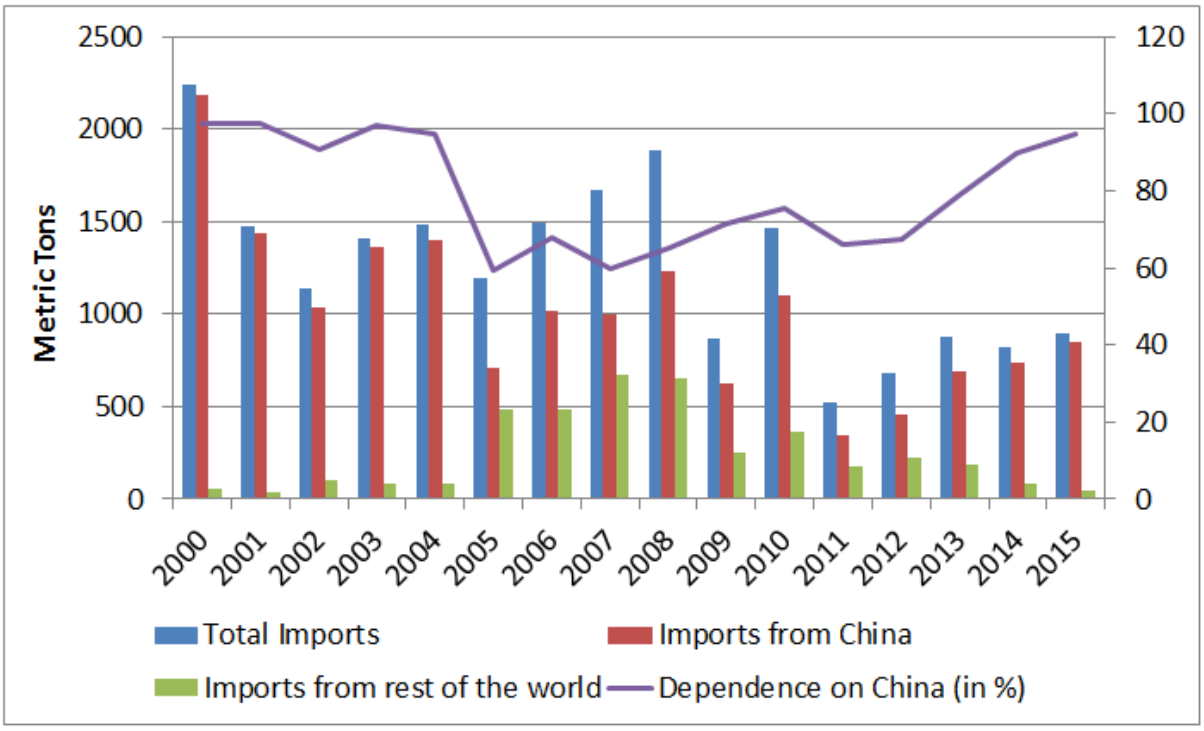

Figure 5. European import of rare earth metals and dependence on China. Source: Authors calculation based on UN Comtrade (United Nations 2016).

The decrease in total imports could be attributed to shifting of many multinational manufacturing companies including European ones to China. It is evident in the Sankey diagram at Figure 6 that Europe imports about 570 tons of neodymium contained intermediate products, much higher than the import of processed material. For example, Motors used in industry, cars and other applications now constitute the largest application group for NdFeB magnets (intermediate product) at around 25% by volume. Industrial applications for which PM motors are suitable include adjustable speed pumps, fans, extruders, conveyers, crane and hoist systems, winders and printing presses. Factory automation, including robotics and material handling, is currently the largest sector by revenue for PM motors. There are around 170 magnets and 20 sensors in a typical car as 70 electric motors used to drive a whole range of luxury and safety features. About 4.5 kilograms of REEs are used in a typical full Hybrid Electric Vehicle (HEV) which includes a NiMH battery and about 1 Kg of REEs are used if the vehicle is equipped with a Li-ion battery, whereas a conventional car uses about 0.44 kg of REEs (Bailey et al, 2017). Globally, the use of NdFeB magnets in PM motor applications is predicted to grow at an annual rate of above 10 from 2014 until 2020 (Kingsnorth 2017).

Figure 6 shows the elaboration of neodymium flows to, from and through Europe, as derived from the MSA study (BIO by Deloitte 2015). The Sankey diagram illustrates a few interesting points, which to a greater or lesser degree also apply to the case studies on seven other materials in Annex 4.

First, the data does not allow for a perfect match in terms of demand and supply of neodymium in intermediate steps in the supply chain. For example, the supply of

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neodymium going into the production of intermediates is slightly larger than the demand, defined by the sum of the exports (red) and the domestic consumption (blue) of intermediates. A possible explanation is that material losses occur at the production, while we could not account for losses based on the available information because we could not define the precise origin of the reported waste flows in the MSA study. The opposite situation (accounting for more outputs than inputs) is illustrated at the final product manufacturing stage, where the sum of the domestic consumption plus the final product exports (outputs), is larger than the sum of the reported product imports plus the domestic supply of intermediates (inputs). The latter could not be explained by process losses, indicating that, with the available data, currently we are not fully able to define a well-balanced account for neodymium flows in Europe at such level of detail. This applies to the CRMs presented in Annex 4 too.

Another observation for neodymium, as well as for the other case studies, is that reported waste flows are relatively small. This could be an indication that Europe is still far from reaching circularity in its CRM supply chains, but we cannot rule out other explanations like data gaps.

Finally we think that this quick scan of the supply chain for neodymium and other CRMs shows that upstream imports of processed materials, intermediates as well as final products are large compared to the raw material imports. This issue is discussed further in the following section.

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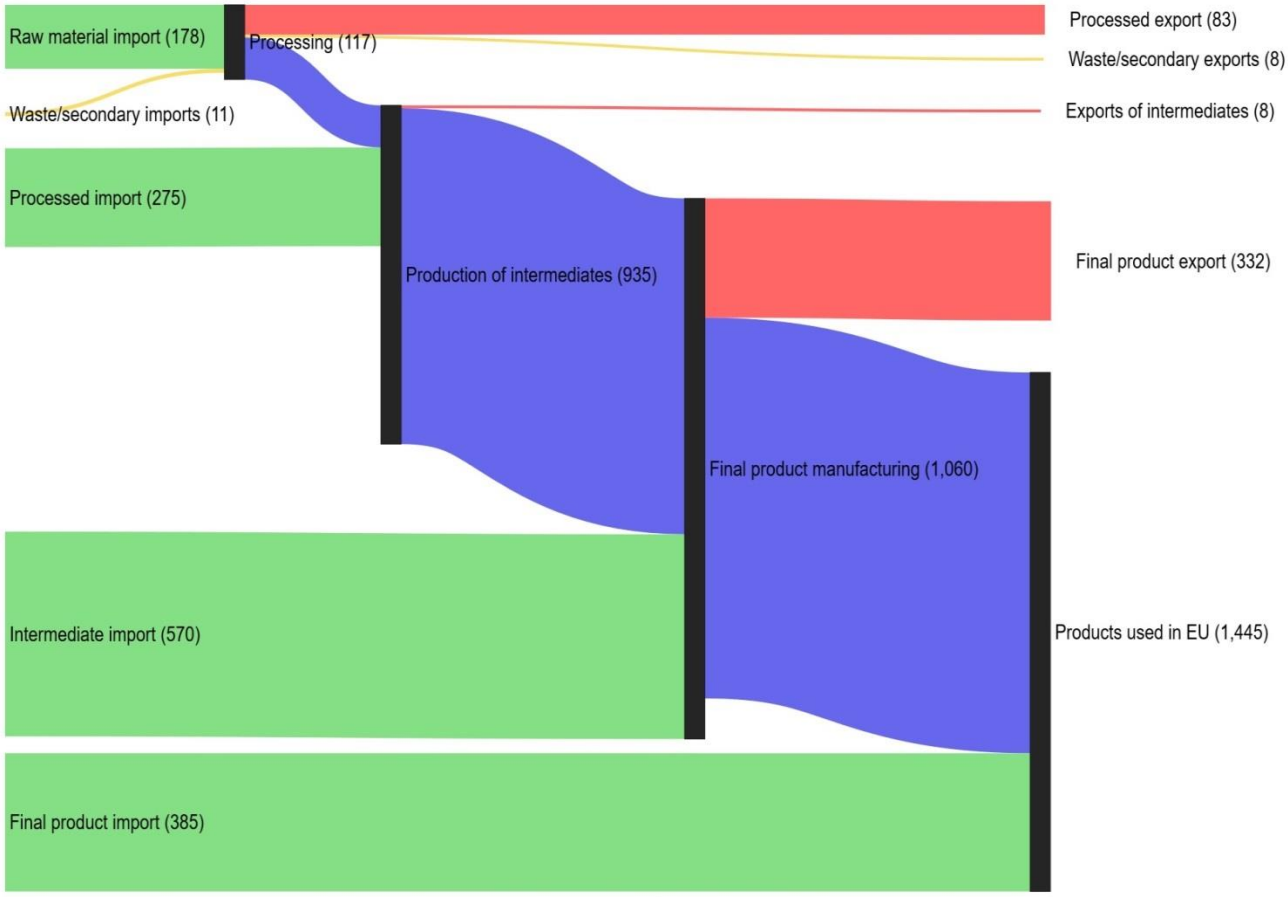

Figure 6. Illustrative Sankey diagram of neodymium flows in Europe in 2013, derived from the quantitative and qualitative information in the MSA study.

3.2 OTHER STUDIES ON EUROPEAN MATERIAL FLOWS

Even though the data and Sankey diagram on European CRM flows provided in the previous sections required some interpretation and assumptions, they show clearly that a focus on raw materials only (such as provided in Section 2.2) possibly provides a rather limited view on material criticality as it omits the trade in critical raw materials contained in semi-finished and finished products. Imports of CRMs embedded in products and their components seems to contribute a rather large share of the total European imports. With the exception of cobalt, most CRMs are in fact imported mainly through (semi-)finished products.

Another observation is that the import dependence found for the non-ferrous metals in their raw material forms (Figure 4a) also applies to the embedded CRMs further along the supply

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chain. In almost all cases Europe imports more CRM containing products than it exports. This shows that the issue of import dependence is relevant for all stages of the supply chain.

A few relevant studies have addressed the issue of import dependence throughout the full supply chain in more detail. However, their coverage is not comprehensive nor does it align with the selection of critical raw materials defined by the EU. Below we discus some examples.

The first example is the study by Tercero Espinoza and Soulier (2016), who discuss the global trade of copper, including numbers on copper imports and exports for the EU28. The study distinguishes four different stages relevant to the use of copper, being copper concentrate and metal as well as copper in semi-finished and finished products, and identifies the source of imports as well as the destination of the exports for copper in each of these production stages. Though copper is not identified as a critical material for Europe (European Commission 2014), this study is a good example of how metal imports embedded in intermediate and final products can be significant, as can be seen in Figure 7. In particular because the final products used in the EU will eventually become available for recycling.

Another example is the study by Deetman et al. (2016) discussing the flows of tantalum throughout Europe. Like copper, tantalum is not on the list of critical raw materials drafted in 2014, but it is considered a conflict-related metal, leading to associated supply risks. In contrast to the study on copper, the tantalum study does not provide details on the source or the destination of tantalum trade, but instead provides a much higher level of detail for tantalum flows for all production stages within the European Union. It disaggregates across different raw material forms and identifies which specific sub-components and final products actually contain the embedded tantalum, based on the level of detail in the EUROPROMS database by Eurostat. As such it could serve as an example of the potential benefits of developing fully detailed material flow accounts for CRMs. The high level of detail at the product level enables the benefits of all three approaches discussed in this deliverable: a) it covers the full use in different industries similar to the synthesis in Section 1.1. b) it uses actual product compositions, similar to the studies discussed in Section 1.2, to derive material flows; this ensures that results are practically useful for waste management policies. c) Similar to the Sankey diagrams presented in this chapter, it enables the assessment of import dependence not just for raw materials, but for the full supply chain, including embedded materials.

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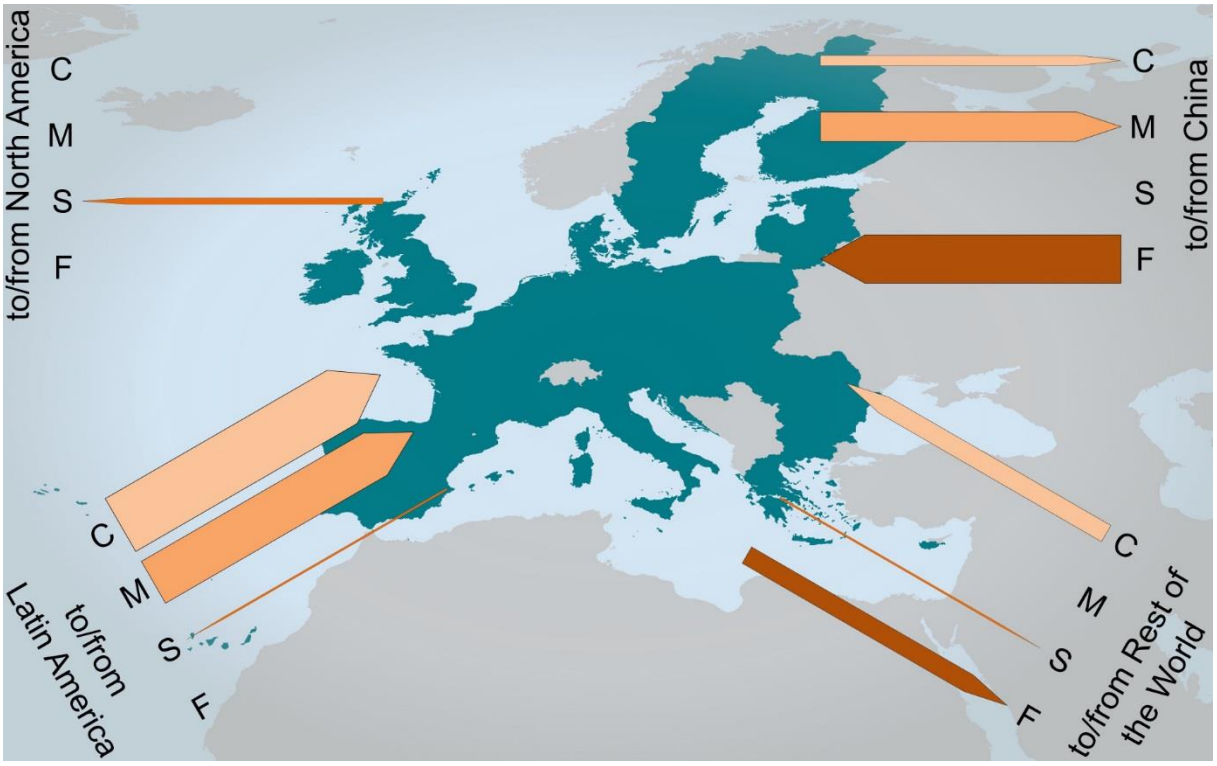

Figure 7. Net flows of copper in Europe, in (C) concentrate, (M) metal and (S) semi-finished products, as well as embedded in (F) final products. The thickness of the arrows scales linearly with tonnage: thickest arrow is (C) from Latin America to Europe at 670 kt; thinnest arrow is (S) from Europe to Latin America at 10 kt. Based on (Tercero Espinoza and Soulier 2016).

Interestingly, the study on tantalum uses a Eurostat database to derive material flows. Though Eurostat statistics generally do not report on the use of individual CRMs, some of the Eurostat data could be particularly useful for the purpose of studying parts of the CRM flows:

1) The Eurostat Environmental accounts as described by (Eurostat 2016) consist of a database on material flows and resource productivity, with a table reference of 'env_mrp' and in particular the Material Flow Accounts referenced under 'env_ac_mfa'. This dataset set contains imports, exports as well as domestic production data for a wide selection of (grouped) materials, including some CRMs, covering multiple years for each EU member state with a good quality (validation procedures are in place to guarantee consistency and plausibility). Unfortunately, the material classification does not reach the level of detail required to identify extraction and trade of all CRMs individually. Many of the individual CRMs are listed under aggregate indicators like 'other non-ferrous metals' (similar to the level of detail in the EXIOBASE database as discussed in Chapter 2).

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2) The Eurostat Environmental Data Centre on Waste provides an important set of tables related to the generation, management and recycling of wastes (Eurostat 2017a). Of particular interest are the tables on key waste streams (referenced under env_wasst), which cover a selection of relevant CRM containing product groups like batteries, end-of-life vehicles and waste electrical and electonic equipment (WEEE). For each of these product groups the database contains details on the annual sales, the weight of the generated wastes as well as the recycling, thus providing a rather complete view for three product categories responsible for a large share of demand and use of CRMs in Europe (See Table 2).
3) The example study on tantalum discussed above shows that highly detailed production and trade databases like PRODCOM or the combined set of trade and production statistics in the EUROPROMS database (Eurostat 2017b) could be used as a basis for analysis of the European CRM use. Potentially, such product-oriented databases could be combined with CRM use and content (like for example developed in the PROSUM project, see section 1.2).

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4. CONCLUSIONS

This report aimed to provide an overview of current use of critical raw materials. This was done by providing three different views on CRM use in Europe. Starting with Chapter 1 we reviewed various European and international studies on the use of individual CRMs in industries and applications from an economy-wide perspective. The benefit of this approach, is that it provides a full coverage of the use of critical materials, including dissipative uses, with data that applies to the EU specifically in almost all cases. The downside is that the detail in these studies is often limited to bulk economic sectors (e.g. 'electronics'), while only in few cases the data is linked to the product level in which the CRMs are actually embedded (e.g. 'Plasma TV screens'). By combining the highest level of detail in the available data we managed to draft a comprehensive synthesis table (**Error! Reference source not found.**) on the economy-wide use of critical raw materials.

Furthermore, Chapter 1 showed that increasing attention is paid to this product-level detail while studying CRMs. In particular the product content, in terms of grams CRM per product, is covered in recent reports and ongoing European research projects. One obvious reason is that product-oriented analysis allows for more practically enabling and policy relevant conclusions for waste management and substitution strategies for example. However, the current focus on product groups seems to be limited to cars, consumer appliances and energy technologies, while the review of the economy-wide use indicated quite a few other important CRM applications like in chemicals, glasses and construction materials for example. Expanding the knowledge base on CRM content of products would be an important step in closing the gap between bottom-up and top-down views on the use of critical raw materials.

Chapter 2 added to the numbers on physical material use by discussing the economic importance of producing sectors with a direct CRM-dependence. Obviously, the entire economy has an indirect dependence on critical raw materials somehow, but we presented the value added of selected sectors together with an indicator on their CRM-dependence, in order to identify or guide further research. For example, manufacturing of machinery & equipment appears to be an important category of CRM use, which also generates a high value added. Other applications with both a high CRM dependence and a high share in the European value added are metals (particularly steel), chemical applications and possibly the production of glasses.

The issue of economic dependence was further explored by analysing European trade flows for two CRM related raw material groups, being the 'other non-ferrous metals' and 'precious metals'. The results showed that Europe has a high import dependence for 'other non-

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ferrous-metals', as the domestic extraction is low compared to the imports (mainly from China). For 'precious metals' the situation is different, because domestic extraction provides enough supply to fulfil European demand and some exports.

This view on import dependence was further expanded by short case studies on the European flows of 8 critical raw materials, which attempted to disaggregate flows throughout the full supply chain. Though the reliability of the presented data is limited due to various assumptions made, the illustrative exercise shows clearly that for many CRMs the European import dependence is not only high for the raw materials, but it also exists when looking at the production and trade of semi-finished and finished products. Properly identifying these CRM dependencies throughout the full supply chain is a challenge that cannot yet be met with the reports and databases that are currently available. Expanding and linking existing Eurostat databases with knowledge in platforms like the JRC Raw Material Information System could be a first logical step into that direction.

We provided three different viewpoints on the current European CRM use, which together serve as a starting point for the assessment of trends in CRM use and the expected future CRM demand; which is the focus of two further deliverables in the SCRREEN project. For this purpose, the synthesis **Error! Reference source not found.** could provide a shortlist of uses to be covered, while sections 1.2 and 2.1 can be used to identify gaps and prioritize research efforts.

We would like to reiterate that this report constitutes a snapshot of the current European situation, based on the most recent literature and the list of critical raw materials as published in the year 2014.

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ANNEX 1. TABLES ON THE USE OF INDIVIDUAL CRMS

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A1.1 ANTIMONY

			European studies			Global studies
			(European Commission 2014)	(BIO by Deloitte 2015)		(Graedel and Erdmann 2012)
		Year published →	2014	2015		2012
		Year of data →	2011	2012		N.A
Product/Application				use	Manuf.	
	Glass, ceramics & others	Other uses	5%	3%	3%	
		Wire and cable		6%	8%	
Flame retardants	Flame retardants	Electrical & electronic equipment	43% (use in electronics is not just as flame retardant in plastic casings, but also in n-type semiconductors)	35%	21%	40%
		Textiles		8%	9%	
	Lead alloys	Alloys, including batteries	14% (lead & tin alloys)	47%	59%	
Transportation	Lead-acid batteries		32%			20%
Chemicals	Plastic: catalyst and heat stabilizer		6%			15%
Total coverage			100%	99%	100%	75%

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A1.2 BERYLIUM

			European studies			Global studies
			(European Commission 2014)	(BIO by Deloitte 2015)		(Graedel and Erdmann 2012)
	Year published →		2014	2015		2012
	Year of data →		2011	2012		N.A
Product/Application				use	Manufa.	
Aircraft, shipbuilding & trains	Aerospace / Defence	Aerospace	10%	6%	10%	20%
Mechanical equipment	Industrial components		25%	20%	25%	
Electronics and IT	Telecom / electronics	Electronics	20%	30%	35%	60%
Electronic equipment & domestic appliances		Appliances	20%			10%
Road transport	Auto electronics		15%	17%	20%	
Metals			3%			
Rubber, plastics and glasses			3%			
Others	Others		4%	28%	10%	
Total coverage			100%	101%	100%	90%

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A1.3 BORATE

		European studies	
		(European Commission 2014)	(BIO by Deloitte 2015)
	Year published →	2014	2015
	Year of data →	2011	2012
Product/Application			
Glass (insulation)	Glass	27%	60%
Glass		24%	
Frits & Ceramics	Frits & ceramics	14%	10%
Agriculture	Fertilizers	13%	12%
Chemicals	Other products	7%	18%
Metallurgy		5%	
Construction materials		4%	
Industrial fluids		2%	
Detergents		1%	
Flame retardants		1%	
Other		2%	
Total coverage		100%	100%

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A1.4 CHROMIUM

		European studies			USA
		(BIO by Deloitte 2015)			(European Commission 2014)
	Year published →	2015			2014
	Year of data →	2013			2012
Product/Application		use	Manufa.	type	
stainless steel products	Stainless steel			74%	88%
Alloy steel products	Steel			19%	9%
Casting molds	Superalloys			3%	2%
Refractory bricks & mortars				1%	
Chromium chemical products	Other			3%	1%
Consumer goods		33%	32%		
(petro)chemical & energy		15%	16%		
Transport		18%	17%		
Building & Construction		19%	20%		
Industrial & Heavy Industry		15%	15%		
Total coverage		100%	100%	100%	100%

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A1.5 COBALT

			European studies		Global studies	
			(BIO by Deloitte 2015)		(European Commission 2014)	(Graedel and Erdmann 2012)
		Year published →	2015		2014	2012
		Year of data →	2012		2012	N.A
Product/Application			Products used in EU	Manufactured in EU		
Superalloys & hard metals	Hard metals	Hardfacing/HSS & other metals	21%	31%	5%	63%
		Hard materials			13%	
	Superalloys	Superalloys (e.g. Gas turbines*, Carbon capture & storage*)	18%	44%	19%	
Batteries	Batteries	Batteries	51%	3%	30%	-
Chemicals	Catalysts	Catalysts	3%	5%	9%	27%
	Pigments	Pigments	7%	17%	9%	
		Tyre adhesives, soaps, driers (paints/inks)			5%	
		Feedstuffs, biotech, anodizing, recoring media, electrolysis			3%	
		Magnets			7%	
Total coverage				**100%**	**100%**	**90%**

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A1.6 COKING COAL

		European studies	Global studies
		(BIO by Deloitte 2015)	(European Commission 2014)
	Year published →	2015	2014
	Year of data →	2012	2007
Product/Application		Use = manufacturing	
Steel production	Steel production	90%	90%
Other metallurgy & niche markets	Electrodes	1%	10%
	Other markets	9%	
Total coverage		100%	100%

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A1.7 FLUORSPAR

		European studies (BIO by Deloitte 2015)		Global studies (European Commission 2014)	Global studies (Bide, Gunn, Brown and Rayner, 2011)
	Year published →	2015		2014	2011
	Year of data →	2012		2010	N.A
Product/Application		Use	Manufactured		End-use (indicative)
Hydrofluoric acid	Pickling / etching		6%	52%	60% (as a basis for farmaceuticals & agro-chemicals)
	Alkylation for oil refining		4%		
	Nuclear energy production[1] (Uranium processing[3])		5%		
	Fluorocarbons & fluoropolymers	72%	54%		
	Fluoraromatics	5%	6%		
Aluminium	Aluminum making[1] (as metallurgical grade fluor[3])		9%	18%	12%
Steel				25%	24%
Other	Other dissipative applications	11%	8%	5% (glass & ceramics, consumed during production of magnesium/calcium metal, welding rod coatings, optics, fluoropolymers)	4% (aerosol can propellants, foam blowing agents, fire extinguishers, refrigerant agents, evaporating cleaning agents)
	Inorganic fluorine compounds	12%	8%		
Total coverage		100%	100%	100%	

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A1.8 GALLIUM

		European studies		Global studies	
		(BIO by Deloitte 2015)		(European Commission 2014)	(Graedel and Erdmann 2012)
	Year published →	2015		2014	2012
	Year of data →	2012		2010	N.A
Product/Application		Use	Manufactured		
Electronics	Integrated Circuits	40%		41%	68%
	Sensors (mostly military)	18%	58%		
	Photovoltaic modules (GaAs)	3%		17%	
Opto-electronics	light emitting diodes	20%		25%	31%
	Other opto-electronics				
Alloys, batteries and magnets	Permanent magnets	14%	42%	17%	
	Other (incl. power devices)	5%			
Total coverage		100%	100%	100%	99%

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A1.9 GERMANIUM

				European studies		Global studies		
				(BIO by Deloitte 2015)		(Graedel and Erdmann 2012)	(Guberman 2016)	(European Commission 2014)
			Year published →	2015		2012	2014	2014
			Year of data →	2013		N.A	N.A	2011
Product/Application				Products used in EU	Manufactured in EU			
Fibre Optics	Fiber Optics	Optical Fibres	Optical Fibres	19%	23%	35%	30%	30%
Infra Red Optics	IR Optics	IR Optics	IR Optics	72%	52%	30%	20%	25%
Polymerisation Catalysts	polymerization catalysts	Catalysts				15%	20%	25%
Electronics and Solar Electric Applications	electronics and solar applications		Satelite solar cells		12%		15%	15%
Other	Other (phosphors, metallurgy, and chemotherapy		Other Applications	9%	13%		15%	5%
Total coverage				**100%**	**100%**	**80%**	**100%**	**100%**

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A1.10 INDIUM

			European studies		Global studies	
			(BIO by Deloitte 2015)		(Graedel and Erdmann 2012)	(European Commission 2014)
		Year published →	2015		2012	2014
		Year of data →	2013		N.A	2013
Product/Application			Products used in EU	Manufactured in EU		
Flat Panel Displays	Monitors	Electronic Equipment& Domestic Appliances	62%	70%	32%	56%
	Televisions				24%	
Solders	Computers				16%	10%
Compound Semiconductors & LEDs						3%
Photovoltaics		Photovoltaics	21%	1%		8%
Thermal Interface Materials		Architectural and Automotive Glass	8%	18%		6%
Batteries		Batteries	9%	11%		5%
Alloy/ compounds						4%
Other						8%
Total coverage			**100%**	**100%**	**72%**	**100%**

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A1.11 MAGNESITE

		European studies		
		(BIO by Deloitte 2015)		(European Commission 2014)
	Year published →	2015		2014
	Year of data →	2012		2010
Product/Application		Use	Manufactured	End-use
Refractory goods		54%	65%	83%
Animal feed & fertilizer		32%	24%	5%
Other products (incl. cements)	Cement industry	14%	14%	1%
	Other			5%
	Environmental			6% (in waste, effluent & flue gas treatment)
Total coverage		100%	100%	100%

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A1.12 MAGNESIUM

		European studies		
		(BIO by Deloitte 2015)		(European Commission 2014)
	Year published →	2015		2014
	Year of data →	2012		2012
Product/Application		Use	Manufactured	End-use
Aluminium alloys	Aluminium packaging	20%	22%	40%
	Aluminium alloy construction elements	34%	37%	
Magnesium die-casting	Vehicles	32%	41%	39%
Steel desulphurisation	Powders for steel desulphurisation	14%		12%
Nodular cast iron				1%
Other				8%
Total coverage		100%	100%	100%

* Graedel, 2012 study combines magnesium metal and minerals, so it is not comparable to the numbers for the European studies

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A1.13 NATURAL GRAPHITE

				European studies		Global studies		
				(BIO by Deloitte 2015)		(Merriman 2016)	(Olson 2014)	(European Commission 2014)
		Year published →		2015		2015	2013	2014
		Year of data →		2013		2014	N.A	2010
Product/Application				Products used in EU	Manufactured in EU			
Carbon brushes	Friction Products		Friction Products	9%	9%	5%		11%
Automotive parts		Brake linings & refractories					60%	14%
Steel , Foundries & Refractories	Refractories		Refractories	43%	59%	52%		41%
	Recarburising					4%		
	Foundries	Foundries and lubricants				14%	5%	
Lubricants	Lubricants		Lubricant & Others	23%	25%	5%	2%	14%
Others	Other					12%		10%
Batteries	Batteries	Batteries	Batteries	25%	7%	8%		10%
Total coverage				**100%**	**100%**	**100%**	**67%**	**100%**

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A1.14 NIOBIUM

		European studies		Global studies	
		(BIO by Deloitte 2015)		(European Commission 2014)	(Graedel and Erdmann 2012)
	Year published →	2015		2014	2012
	Year of data →	2013		2010	N.A
Product/Application		Use	Manufactured	End-use	
Steels	Vehicles	38%	44%	28%	75%
	construction	51%	43%	31%	
	Pipelines	7%	8%	24%	
	Chemical industry			3%	
Superalloys	Aero-engines & gas-turbines	2%	1%	8%	25%
	Superconductors (MRI)	2%	4%		
Total coverage		100%	100%	100%	100%

For further information: on Niobium alloys, please see (Kurylak et al. 2016).

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A1.15 PHOSPHATE ROCK

	European studies* (BIO by Deloitte 2015)	
Year published →	2015	
Year of data →	2012	
Product/Application	Use	Manufactured
Mineral fertilizer	87%	85%
Feed and Food additives	6%	7%
Detergent & other chemicals	7%	8%
Total coverage	100%	100%

* Other studies describing the use and flows of phosphorous are available. However, they are either relatively old, such as the study by (Cordell et al. 2009), or they do not necessarily apply to Europe, such as the study by (Hamilton et al. 2015) with a case study on Norway.

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A1.16 SILICON METAL

		European studies			Global studies
		(BIO by Deloitte 2015)		(European Commission 2014)	
	Year published →	2015		2014	
	Year of data →	2012		2010	
Product/Application		Use	Manufactured	End-use	
Chemical applications (shampoos, fixing materials, cable insulation etc.)		50%	53%	54%	35%
Aluminium alloys for automotive & construction		35%	42%	38%	45%
Electronic & PV applications	Solar PV	15%	5%	8%	12%
	Semiconductors				3%
	Other				5%
Total coverage		100%	100%	100%	100%

* The criticality of silicon is mostly due to the scarcity of high purity, metallurgical or electrical grade silicon, originating from vein quartz & quartz pebbles.

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A1.17 TUNGSTEN

			European studies		Global studies		
			(BIO by Deloitte 2015)		(Graedel & Erdmann, 2012)	(Pitfield & Brown, 2011)	(European Commission 2014)
		Year published →	2015		2012	2011	2014
		Year of data →	2012		?	2010	2010
Product/Application			Products used in EU	Manufactured in EU			
Alloys	Tungsten Alloys	Aeronautics & Energy applications (e.g. airplane engines*)	5%	6%	16%	27%	4%
	Alloy steels						13%
Superalloys	Superalloys	High speed steel	6%	6%	10%		6%
		High temp. Steel	2%	2%			
Hard metal cutting tools	Cemented carbides	Mill and cutting tools	31%	30%	60%	54%	60%
		Mining & construction tools	21%	20%			
		Other wear tools	17%	17%			
Mill products	Fabricated products					13%	17%
		Catalysts & pigments	7%	9%			
		Lighting & electronic uses	6%	5%			
		Other (e.g. nuclear fusion*)	5%	5%		6%	
Total coverage			100%	100%	86%	94%	100%

* as found in a qualitative assessment from (Bolin et al. 2014)

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A1.18 PLATINUM GROUP METALS

		Global studies		Iridium	Ruthenium
		(European Commission 2014)	(Graedel and Erdmann 2012)	(Johnson & Matthey 2016)	
	Year published →	2014	2012	2016	2016
	Year of data →	2012	N.A	2015	2015
Product/Application		End-use	Based on weighted use of individual PGMs		
Industrial	Chemical	6%	3%	23%	8%
	Electronics	10%	10%	48%	32%
	Electrochemical	1%	<1%	5%	23%
	Glass	1%	<1%		
	Petroleum production	1%			
	Medical (incl. dental)	3%			
Others	Autocatalysts	55%	51%		
	Jewellery	17%	16%		
	Other	5%		4%	37%
Total coverage*		100%	80%	100%	100%

*excluding 'investment' purposes as an end-use (27 tonnes in 2012, according to EU, 2014)

Further information on Platinum-group metals: Please see chapter 12 in (Gunn 2013) and (Gunn and Benham, 2009).

Separate Annexes A1.19-21 are dedicated to Palladium Platinum & Rhodium. The numbers on Iridium & Ruthenium provided here are indications of global use. According to (Gunn 2013), the main use of ruthenium is "in perpendicular magnetic recording technology which is employed in hard disk drive manufacture". It is also used in the production of flat plasma display screens, jewellery, fountain pen nibs (Gunn and Benham, 2009) and as contacts for thermostats and relays (Johnson & Matthey 2016). According to (Gunn 2013) Iridium is used in the chemical industry (as a catalyst, ed.) and in spark plug tips. Furthermore it is used as crucibles in the electronics sector for growing single crystal sapphire which provides a substrate for gallium nitride used in LEDs as well as in exhaust emission control systems of gasoline direct injection engines (Johnson & Matthey 2016).

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A1.19 PALLADIUM

		European studies				Global studies	
		(BIO by Deloitte 2015)		(Johnson & Matthey 2016)	(European Commission 2014)		(Graedel and Erdmann 2012)
	Year published →	2015		2016	2014	2014	2012
	Year of data →	2012		2015	2012	2012	N.A
Product/Application		use	manufactured	Gross demand	Application demand	End-use (incl. investment)	
Chemical	Chemical catalysis	5%	4%	4%	5%	5%	
Electronics	Electronics	13%	9%	5%	10%	13%	17%
Medical (incl. dental)	Dental aplications	4%	4%	3%	4%	6%	
Autocatalysts	Autocatalysts	65%	71%	87%	75%	67%	55%
Jewellery	Jewellery	3%	3%	3%	4%	5%	12%
Other	Other	1%	1%	2%	2%	1%	
	Investment	9%	8%	-5%*		4%	
Total coverage		100%	100%		100%	101%	100%

* market share has a negative value due to invested palladium re-entering the market in 2015.

For further information on Platinum-group metals: Please see chapter 12 in (Gunn 2013) and (Gunn and Benham, 2009). The latter sates that "Currently palladium is the major consituent of catalysts used in gasoline-powered vehicles" (while platinum is the chief active component in catalysts and filters in diesel-powered vehicles). In jewellery palladium is used either as a component of white gold or as palladium jewellery itself. Palladium is further used in multi-layer ceramic capacitors (MLCC) and hybrid integrated circuits (HIC) mainly in the automotive sector, and in plating of connectors inside computers. Also, according to (Gunn and Benham, 2009) palladium is an important component of dental alloys used in inlays, bridges and crowns.

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A1.20 PLATINUM

		European studies					Global studies	
		(BIO by Deloitte 2015)		(Johnson & Matthey 2016)	(European Commission 2014)		(Graedel and Erdmann 2012)	(Johnson & Matthey 2016)
	Year published →	2015		2016	2014		2012	2016
	Year of data →	2012		2015	2012		N.A	2015
Product/Application		use	manufactured		Demand	End-use (incl. investment)		
Chemical	Industrial Catalyst	8%	6%	6%	6%	6%	5%	7%
Electronics	Electronics	4%	1%	0.6%	1%	2%		3%
Glass	Glass			0.4%	1%	3%		2%
Petroleum production				0%	1%	2%		2%
Medical (incl. dental)	Medical and biomedical	6%	4%	3%	5%	3%		3%
Autocatalysts	Autocatalysts	58%	67%	79%	68%	38%	48%	39%
Jewellery	Jewellery	11%	1%	10%	10%	34%	24%	34%
Other	Other	6%	6%	5%	8%	6%		5%
	Investment	7%	7%	-4%*		6%		5%
Total coverage		**100%**	**100%**	**100%**	**100%**	**100%**	**77%**	**100%**

* The (Johnson & Matthey 2016) study reports a net negative investment, meaning that previous platinum investments were sold/brought onto the market to fulfill in the demand. For further information on Platinum-group metals: Please see chapter 12 in (Gunn 2013) and Gunn and Benham, 2009). The latter states that platinum is the chief active component in catalysts and filters fitted to diesel-powered vehicles. Furthermore, (Gunn and Benham, 2009)indicate that platinum is used as a catalyst in the manufacture of fertilisers, plastics, explosives, silicones for water repellant coatings, pressure sensitive adhesives (PSA) and petroleum products. It is an important component of the magnetic coating on computer hard disks, and "platinum-based equipment is used in the manufacture of a large range of glass products, the most important of which are flat panel screens and fibre glass". Other applications are (a.o>) the electrodes of spark plugs in gasoline engines, oxygen sensors , anti-cancer drugs and some biomedical implants such as heart pacemakers.

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A1.21 RHODIUM

		European studies		Global studies		
		(BIO by Deloitte 2015)		(European Commission 2014)	(Graedel and Erdmann 2012)	Johnson & Matthey
	Year published →	2015		2014	2012	2016
	Year of data →	2012		2012	N.A	2015
Product/Application		use	manufactured	End-use (incl. investment)		Gross demand
Chemical	Chemical Catalyst	11%	8%	11%	8%	11%
Electronics				1%		0.3%
Glass	Glass	4%	3%	4%	4%	4%
Autocatalysts	Autocatalysts	76%	81%	78%	88%	81.5%
Other	Other	9%	8%	7%		3.5%
Total coverage		100%	100%	100%	100%	100%

For further information on Platinum-group metals: Please see chapter 12 in (Gunn 2013) and (Gunn and Benham, 2009). These studies elaborate that the largest use of rhodium is in autocatalysts. Platinum-rhodium alloys are used in equipment that hold, channel and form molten (specialist) glasses.

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A1.22 CERIUM

			European studies	Global studies	
			(Machacek and Kalvig 2016)	(Graedel and Erdmann 2012)	(European Commission 2014)
		Year published →	2016	2012	2014
		Year of data →	2014	N.A	2012
Product/Application					
Polishing	Polishing		3.22%		36%
Auto Catalysts	Auto Catalysts	Auto Catalysts	48.38%	35%	13%
Metallurgy	Metallurgy	Alloys	4.83%	30%	19%
Batteries	Batteries		3.22%		3%
Glass	Glass additives	Glass	25.8%	15%	12%
FCC	FCC		3.22%		2%
Ceramics	Ceramics		1.6%		1%
Phosphors	Phosphors		3.22%		4%
Other Catalysts					3%
	Magnets		1.6%		
Other	Other		4.83%		8%
Total coverage			**100%**	**80%**	**100%**

For further information on Rare Earth Elements: Please see (Gunn 2013) and (Walters and Lusty 2010). The latter describes a few more detailed applications of Cerium to be: Autocatalysts, fluid cracking catalysts, flint ignition of lighters, blue colors in LCD & PDP displays, decolourising agents in glass, polishing of glass products like mirrors, toughness enhancer in ceramics & ceramic capacitors, coating of lead-chrome paints, to reduce color fading and an additive to titanium dioxide pigments to make them more durable and resistant to sunlight.

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A1.23 DYSPROSIUM

			Global studies		
			(Graedel and Erdmann 2012)	(European Commission 2014)	(Hoenderdaal et al. 2013) **
		Year published →	2012	2014	2013
		Year of data →	N.A	2012	2011
Product/Application					
Magnets	Computers	Computers (HDD, DVD, CD)	32%	98%	9%
	Audio Systems	Speakers	26%		4%
	Wind Turbines	Wind Turbines	15%		4%
		Industrial motors			39%
		Electric vehicles			17%
		Ceramic capacitors (ML*)			14%
Other		Other		2%	13%
Total coverage			**73%**	**100%**	**100%**

* ML stands for Multi-Layer. ** Numbers from (Hoenderdaal et al. 2013) are interpretations based on provided figures.

For further information: Please see (Gunn 2013) and (Walters and Lusty 2010). The latter states that the addition of dysprosium or terbium prevents magnets to lose their magnetism at higher temperatures.

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A1.24 ERBIUM

		Global studies	
		(Graedel and Erdmann 2012)	(European Commission 2014)
	Year published →	2012	2014
	Year of data →	N.A	2012
Product/Application			
Glass	Fibre Otics	75%	72%
	Lasers	20%	
	Other Glasses	5%	
Phosphors			25%
Other			3%
Total coverage		**100%**	**100%**

For further information: Please see (Gunn 2013) and (Walters and Lusty 2010). The latter mentions that one of the major uses for erbium is in medical and dentistry. “Erbium lasers are used in cosmetic treatments to ablate the epidermis revealing the smoother and younger looking underlying skin. In dentistry, the erbium lasers have proven safe and effective for the removal of tooth decay and cavity preparation in addition to many soft-tissue and and hard-tissue surgical procedures.”. Also, erbium is color glass pink.

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A1.25 EUROPIUM

		Global studies	
		(Graedel and Erdmann 2012)	(European Commission 2014)
	Year published →	2012	2014
	Year of data →	N.A	2012
Product/Application			
Phosphors	Lighting	50%	96%
	Flat Panel Displays	32%	
	Plasma	13%	
Others			4%
Total coverage		**75%**	**100%**

For further information on Rare Earth Elements: Please see (Gunn 2013) and (Walters and Lusty 2010). The latter states that europium-yttrium phosphors are used to create a red color in various computer/tv displays, Also, plasma screens were developed with the aid of a new europium-based blue phosphors. Other applications of europium as a neutron absorber are for example the use in control rods to regulate nuclear reactor operation.

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A1.26 GADOLINIUM

		European studies	Global studies	
		(Machacek and Kalvig 2016)	(Graedel and Erdmann 2012)	(European Commission 2014)
	Year published →	2016	2012	2014
	Year of data →	2014	N.A	2012
Product/Application				
Magnets	Magnets	20%		35%
Other Metallurgy				28%
Phosphors	Phosphors	40%		23%
Other	Other	40%		14%
MRI Contrast Agents			100%	
Total coverage		**100**	**100%**	**100%**

For further information on Rare Earth Elements: Please see (Gunn 2013) and (Walters and Lusty 2010). The latter further states that optical lenses containing gadolinium are used for magneto-optical and electro-optical systems. Gadolinium is used as a neutron absorber in nuclear power plants and in many medical applications, for example in imaging of tumors.

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A1.27 LANTHANUM

			European studies	Global studies	
			(Machacek and Kalvig 2016)	(Graedel and Erdmann 2012)	(European Commission 2014)
		Year published →	2016	2012	2014
		Year of data →	2014	N.A	2012
Product/Application					
FCC	FCC	Catalysts	50%	30%	44%
Auto Catalysts	Auto Catalysts		4.2%		1%
Batteries	Batteries	Batteries	11.2%	15%	26%
Glass	Glass	Alloys	14%	20%	5%
Polishing	Polishing		3%		2%
Ceramics	Ceramics		2.8%		1
Phosphors	Phosphors		3%		2%
Other Metallurgy	Metallurgy		5.5%		10%
	Magnets				
Other	Other		6.3%		9%
Total coverage			**100%**	**65%**	**100%**

For further information on Rare Earth Elements: Please see (Gunn 2013) and (Walters and Lusty 2010). The latter describes a few more detailed applications of lanthanum to be: Fluid cracking catalysts, mischmetal, some nickel and cobalt superalloys, In batteries: "lanthanum is the main REE used in the NiMH battery [...] it has been calculated that each Toyota Prius battery uses 10–15 kg of lanthanum.". Other applications are camera lenses and capacitors.

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A1.28 NEODYMIUM

			European studies		Global studies	
			(BIO by Deloitte 2015)		(Graedel and Erdmann 2012)	(European Commission 2014)
		Year published →	2015		2012	2014
		Year of data →	2013		N.A	2012
Product/Application			Products used in EU	Manufactured in EU		
Magnets	Computers	Magnets	74%	79%	30%	88%
	Audio Systems				20%	
	Wind Turbines				12%	
Auto Catalysts		Auto Catalysts	1%	1%		2%
		Batteries	12%	5%		
Other Metallurgy		Alloys	3%	5%		2%
Phosphors		Other	10%	10%		1%
Ceramics						5%
Glass						1%
Other						1%
Total coverage			**100%**	**100%**	**62%**	**100%**

For further information on Rare Earth Elements: Please see (Gunn 2013) and (Walters and Lusty 2010). The latter states that Neodymium is (a.o.) used as high-performance & miniaturized magnet applications, such as earphones & larger speakers, harddisk-drives, windmills & hybrid cars. Also, it is used in mischmetal, used for flint ignition in lighters, as an activator in lasers, red glasses, UV protection in sunglasses and capacitors.

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A1.29 PRASEODYMIUM

		Global studies	
		(Graedel and Erdmann 2012)	(European Commission 2014)
	Year published →	2012	2014
	Year of data →	N.A	2012
Product/Application			
Magnets	Computers	30%	73%
	Audio Systems	20%	
	Wind Turbines	12%	
Phosphors			12%
Ceramics			7%
Polishing			2%
Other Metallurgy			4%
Other			2%
Total coverage		**62%**	**100%**

For further information on Rare Earth Elements: Please see (Gunn 2013) and (Walters and Lusty 2010). The latter states that Praseodymium is used (a.o.) in green colored glasses, and to provide UV protection in sunglasses, as an anti-reflection coatings on lenses and as a constituent of tinted glass filters for selective light absorption. It is also used as a yellow pigment colorant in ceramics and it's used in small amounts in capacitors.

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A1.30 SAMARIUM

			European studies	Global studies	
			(Machacek and Kalvig 2016)	(Graedel and Erdmann 2012)	(European Commission 2014)
		Year published →	2016	2012	2014
		Year of data →	2014	N.A	2012
Product/Application					
Magnets	Magnets		30%		87%
	Batteries	Batteries	50%	25%	
Other Metallurgy					10%
		Defense Applications		70%	
Others	Others		20%		3%
Total coverage			**100%**	**95%**	**100%**

For further information on Rare Earth Elements: Please see (Gunn 2013) and (Walters and Lusty 2010). The latter states that samarium-cobalt magnets are used in high temperature applications.

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A1.31 TERBIUM

			European studies		Global studies	
			(BIO by Deloitte 2015)		(Graedel and Erdmann 2012)	(European Commission 2014)
		Year published →	2015		2012	2014
		Year of data →	2013		N.A	2012
Product/Application			Products used in EU	Manufactured in EU		
Magnets	Computers	Magnets	46%	49%	16%	24%
Phosphors	Lighting	Fluorescent Lamps	54%	51%	28%	71%
	Flat Panel Displays				24%	
Others						5%
Total coverage			**100%**	**100%**	**68%**	**100%**

For further information: Please see (Gunn 2013) and (Walters and Lusty 2010). The latter states that terbium is used to prevent magnets from losing their magnetism as they heat up. Also, the terbium-fluoride-zinc sulphide phosphor is used in liquid crystal display or plasma display panel technologies to create a green color.

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A1.32 YTTRIUM

			European studies		Global studies	
			(BIO by Deloitte 2015)		(Graedel and Erdmann 2012)	(European Commission 2014)
		Year published →	2015		2012	2014
		Year of data →	2013		N.A	2012
Product/Application			Products used in EU	Manufactured in EU		
Phosphors	Lighting	Fluorescent lamps	78%	77%	44%	78%
	Flat Panel Displays				34%	
		Vehicle Oxygen Sensors	1%	1%		
	Glasses				12%	
Ceramics						21%
Other		Other	21%	22		1%
Total coverage			**100%**	**100%**	**90%**	**100%**

For further information on Rare Earth Elements: Please see (Gunn 2013) and (Walters and Lusty 2010). The latter states that Yttrium is used in corrosion resistant alloys and coatings, in europium-yttrium phosphors for red colors in various displays. Yttrium is also used in strengthened and toughened ceramics or crucibles, and it is also used to give ceramics an orange color.

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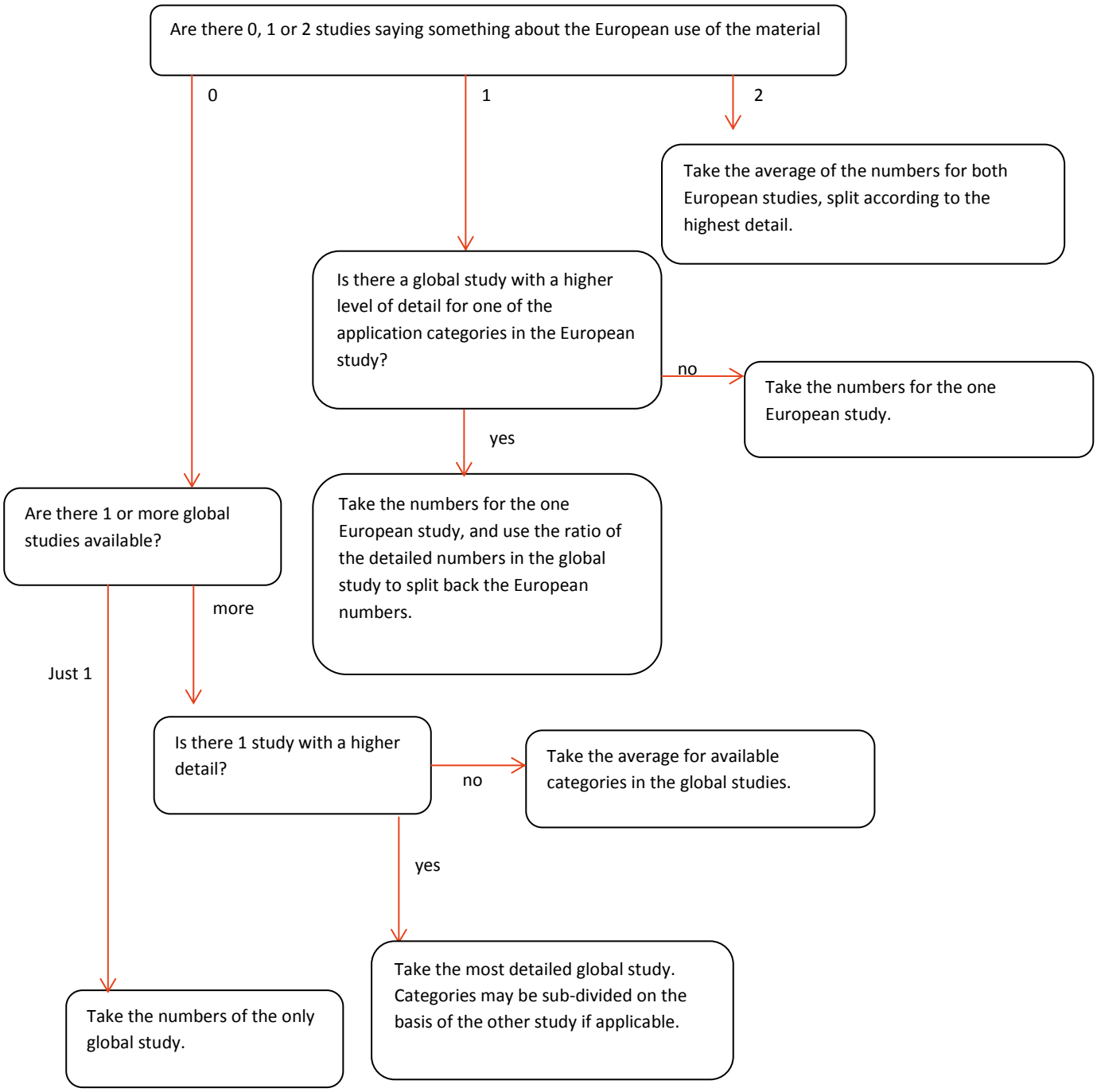
ANNEX 2. DECISION TREE FOR SYNTHESIS TABLE



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In order to allocate the use to end-use products and applications as much as possible:

a. Flame retardants (borate) is split back to electronics and textiles based on the Antimony example
b. Both for tungsten and niobium, the respective categories “aero engines & gas-turbines” and “aeronautic & energy applications” are split back to the categories “aircrafts” and “gas turbines” with an assumed equal share for each end-use category.
c. Split Chromium in “consumer goods” to 3 catergories based on (Rossi 2014). Categories being: a) household appliances, b) Electronics and c) other metal goods (cutlery, tableware and kitchenware etc. according to (Johnson et al. 2006))
d. Element specific chemicals (fluorocarbons, fluoroaromatics etc.) are grouped under Chemical products.

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ANNEX 3. TRANSLATION TABLE BETWEEN CRM USE & EXIOBASE INDUSTRIES

We linked the CRM use shares from Table 2 to their corresponding industries in the EXIOBASE input-output model (see main text). Table A3 gives the data behind Figure 3 in the main text.

The "average percentage of total use" is calculated by the mean of the shares in demand for each CRM in each sector considered. For example, the sector "Vehicles" (part of "Transport") uses on average 31% of total demand for the CRMs it requires (16% of total Be demand, 18% of total Cr demand, 36% of total Mg demand, 38% of total Nb demand, 5% of total natural graphite demand, and so on, see Table 2 in the main text).

The "number of metals used" refers to the number of CRM that are used by the sector. Continuing the example for "Vehicles", this number is 13: Be, Cr, Mg, Nb, natural graphite, Pt, Pd, Rh, Y, La, Ce, Nd and Dy.

The "dependency score" is then built by multiplying the "average percentage of total use" by the "number of metals used", and then normalizing the results so that the maximum possible score is 100 ("normalized score"). This metric, though rough, is intended to emphasize sectors that use comparatively large shares of many CRM.

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Table A3.Correspondence table between CRM use (Table 2) & EXIOBASE industries, including the share of European Value Added (VA) and indicators on CRM dependency used for Figure 3.

					% of total European value added	EXIOBASE industry code	Average percentage of total use	Number of metals used	Dependency score	Normalized score
Metals	Metallurgy (3) / Other metals (2)				0.14%	i27.43; i27.43.w; i27.44; i27.44.w; i27.45; i27.45.w; i27.41.w; i27.41	5.2	7	36.5	6.03
	Other alloys	lead alloys (2) superconductors (1)								
	Aluminium	Aluminium making (1)			0.09%	i27.42; i27.42.w	41.8	3	125.3	20.68
		Aluminium Alloys (2)	Aluminium Packaging (1) Aluminium alloy construction elements (1)							
	steel	Steel making	Steel desulphurisation (1,2) Recarburising (6) Foundries (6) Refractory goods (1) Nodular cast iron (2)		0.39%	i27.a; i27.a.w	47.7	7	334	55.14
		steel alloys	superalloys (2)							
			hard metals (1)	hardfacing metals/high strength steel (2) high temperature steel (1)						
				hard materials (2)	Milling & cutting tools (1) Mining & construction tools (1) Other wear tools (1)					
Transport (1)	Vehicles (1)	auto catalyst (3) electric vehicles (7) Oxygen sensors (1) Magnesium die-casting (2) Auto electronics Automotive friction parts (2)			1.69%	i34	31.0	13	403.3	66.58
	Aircraft, ships & trains (2)	Aircraft/defence (1) shipbuilding & trains			0.50%	i35	3.8	3	11.5	1.90
Chemical	Animal Feed & Fertilizer (1) / Feed and Food additives (1)				0.02%	i24.b; i24.c	41.3	3	124.0	20.47
	Chemical products (2) Industrial fluids (2) Polishing (3) / Pickling & Etching (1) Electrodes (1) Detergents (2) (Bio)medical, including dental (1,2) Lubricants (2)				0.21%	i24.d	19.0	15	284.5	46.96
	catalysts & pigments (1)	Pigments (1)								
		chemical catalysts (1)	Fluid Catalytic cracking (3)							
Petro chemical & energy (1)	Petro-chemical	oil refining (1)			0.41%	i23.2	1.4	3	4.3	0.71
	Energy	Uranium processing (5) / nuclear energy production (1)			0.24%	i23.3; i40.11.c	2.5	1	74.8	12.353
		Photovoltaic modules (1)			0.011%	i40.11.h	8.3	4		
		gas turbines (1)			0.06%	i40.11.b	1.2	3		
		Wind turbines (4)			0.043%	i40.11.e	6.0	3		
Rubber, plastics, glasses, ceramics & others	Plastics: catalysts and heat-stabilizers (2) (Plastic) wire & cable (1)				2.2%	i24.a; i24.a.w; i25	4.2	2	8	1.40
	Glass, ceramics & others	Ceramics (3) Others			0.09%	i26.b	4.9	7	35	5.71
		Glass (3)	Fibre-optics (4) Lasers (4) Glass insulation Architectural & automoitve glass (1) Other glass		0.09%	i26.a; i26.a.w	21.4	10	214	35.33
Mechanical & Electrical	magnets (3)	permanent-magnets (1)			2.9%	i29; i31	37.9	16	606	100
	Batteries (3)	lead-acid batteries (2)								
	Phosphors (2,3)	Lighting (4) Flat Panel Display (4) Plasma (4)								
	Electrical & Electronic Equipment /appliances	Mechanical equipment (2) & Industrial motors (7) Electrical equipment (1,2) carbon brushes (2)								
		Electronics & IT (2)	Sensors (1) Monitors (4) Televisions (4) Computers (4) Audio systems (26)		1.5%	i32; i33; i30	34.3	11	377	62.31
			opto-electronics	IR Optics (1,2,4)						
			(semi)conductors	capacitors (7) Integrated circuits (1)						
Heavy industry & construction	Cement industry (2)				0.25%	i26.d	1.7	1	2	0.275
	Environmental (1) (= waste & flue gas treatment)				0.54%	i90.1.a; i90.1.b; i90.1.c; i90.1.d; i90.1.e; i90.1.f; i90.1.g; i90.4.a; i90.4.b; i90.5.a; i90.5.b; i90.5.c; i90.5.d; i90.5.e; i90.5.f	3	1	3	0.495
	pipelines (1)				0.07%	i60.3	12	2	24	3.962
	Building construction (1)				5.75%	i45	23.9	3	72	11.825
Other consumer goods	Textiles (1) Cutlery, tableware & kitchen items Jewelery (1,2) Investment (1)				0.62%	i17; i18	4.1	2	8	1.349
Others (1,2,3)					*Not Covered*					

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ANNEX 4. FLOW DIAGRAMS OF CRMS IN EUROPE

Chapter 3 in the main document gives an example of disaggregated European neodymium flows based on the study on Raw Material System Analysis (BIO by Deloitte 2015). This Annex presents the overviews & additional data for 7 other critical raw materials in the following sections:

A4.1 Antimony p.75
A4.2 Chromium..... p.76
A4.3 Cobalt..... p.78
A4.4 Dysprosium..... p.80
A4.5 Indium..... p.82
A4.6 Platinum..... p.84
A4.7 Tungsten..... p.86

This Annex contains the following Table & Figures:

Table A4.1. European antimony flows..... p.75
Table A4.2. European chromium flows..... p.77
Table A4.3. European cobalt flows..... p.79
Table A4.4. European dysprosium flows..... p.81
Table A4.5. European indium flows..... p.83
Table A4.6. European platinum flows..... p.85
Table A4.7. European tungsten flows..... p.86

Figure A4.1. Sankey diagram of antimony flows in Europe..... p.76
Figure A4.2. Sankey diagram of chromium flows in Europe..... p.78
Figure A4.3. Sankey diagram of cobalt flows in Europe..... p.80
Figure A4.4. Sankey diagram of dysprosium flows in Europe..... p.82
Figure A4.5. Sankey diagram of indium flows in Europe..... p.84
Figure A4.6. Sankey diagram of platinum flows in Europe..... p.85
Figure A4.7. Sankey diagram of tungsten flows in Europe..... p.87

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A4.1 ANTIMONY

Antimony is not extracted in the EU but about 500 tons of ore are processed in the EU. Along with the processed material, about 16 kilotons of processed material is imported into EU to produce various intermediate and final products with an estimated antimony content of 16 kilotons in intermediate product levels and 15 kilotons in final products. Antimony is an important component in semiconductor integrated circuits, lead alloys and lead-acid batteries. Major share of EU's consumption of antimony is in semiconductor integrated circuits, which is about 35% of total consumption of antimony followed by lead-acid batteries of about 32%. However, replacement of lead-acid batteries particularly in automobiles with more efficient battery systems such as NiMH and Li-Ion may reduce demand for antimony in this sector. However demand from other sectors such as semiconductor integrated circuits and catalysts and heat stabilizers are expected to generate a modest growth rate of 3% in the coming years. On supply side, the European import dependence on a handful of countries makes antimony prone to supply risk and score high on the criticality index of European Commission report 2014.

Table A4.1. European antimony flows (kt), for 2012. Based on (BIO by Deloitte 2015). Data indicated with an * are derived from the quantitative *and* qualitative information in the MSA study.

	IN		OUT	
	Extraction/prod- in EU	Import of EU	Export of EU	Output of processing in EU
Raw/Primary	0	0,456	0	0,5
Processed/intermediate	0,5	16	0,654	16
Secondary	11	0,018		
Waste		0,988	2,01	
Intermediate	*16**	9	4,8	20,2
Final	*15**	12	21,1	*5,9**

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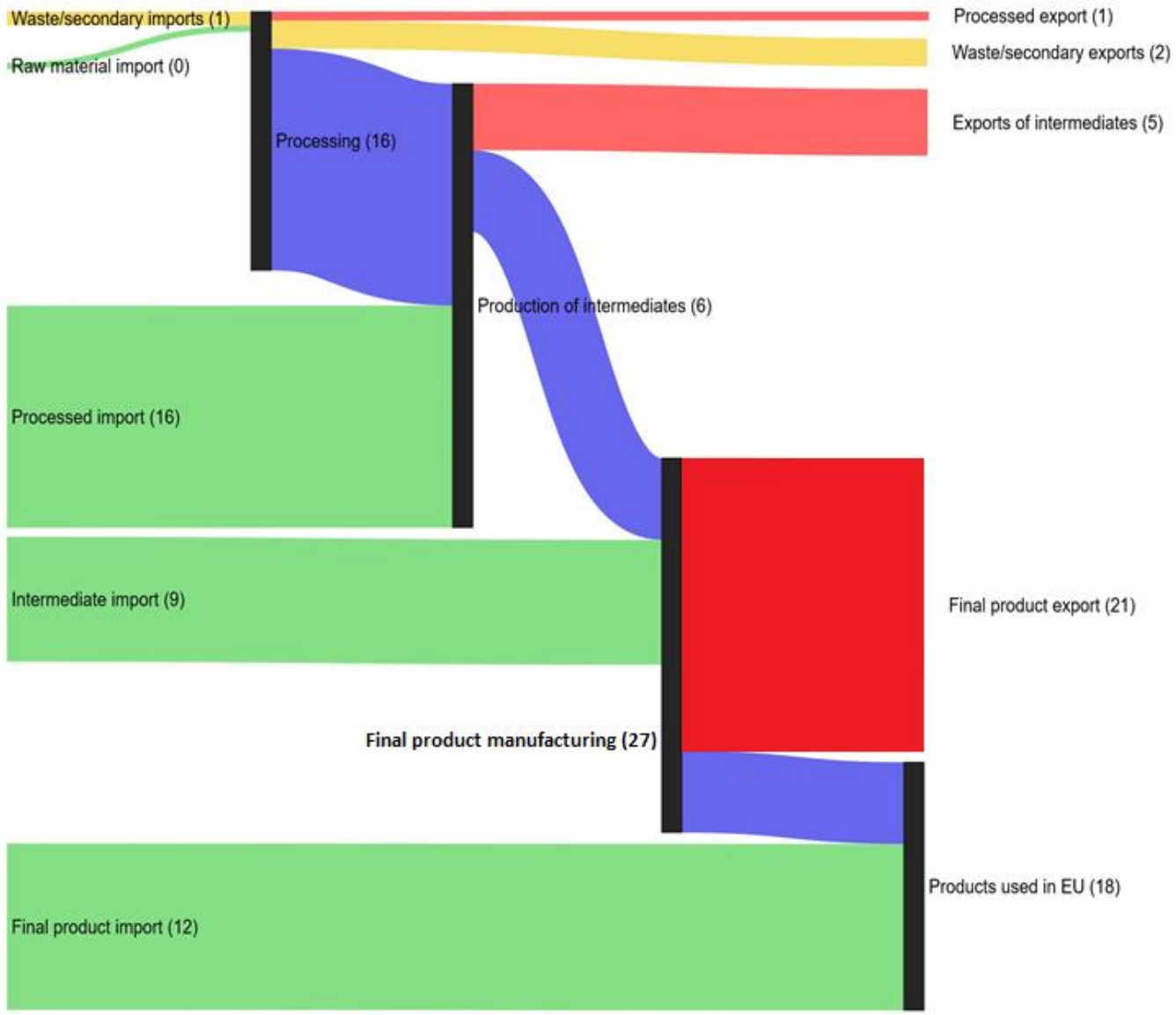

Figure A4.1. Sankey diagram of antimony flows in Europe in 2012.

A4.2 CHROMIUM

Figure A4.2 depicts the flows of chromium into, within and out of the EU in 2013, where the width of each flow pictured is based on its quantity. Chromium is a very important component for a number of intermediate products such as automotive friction parts, semiconductor and integrated circuits, which are used in sectors such as vehicle manufacturing, wind turbines and flue gas treatment.

Table A4.2. European Chromium flows (kt), for 2013 based on (BIO by Deloitte 2015). Data indicated with an * are derived from the quantitative *and* qualitative information in the MSA study.

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	IN		OUT	
	Extraction/prod- in EU	Import of EU	Export of EU	Output of processing in EU
Raw/Primary	280	94	3	370
Processed/intermediate	275	700	463	*512**
Secondary		90	84	780
Waste	380	90	9	
Intermediate	936	747	23,5	
Final	*1195**	111	221	*1085**

The European demand for chromium far exceeds its domestic capacity to produce it: of the well over 1 million tonnes of chromium used in the EU, only about 280 thousand tonnes were produced domestically, leading to a large dependence on import of processed chromium to meet the requirements in intermediate sectors (Table A4.2). Europe also imports chromium contained in intermediate products such as friction parts, semiconductor and integrated circuits. A large portion of the processed chromium and intermediate products are imported from countries like China. Chromium is more important for European economies for production of chromium containing intermediate and final products and chromium was scored very high on criticality due to its economic importance in report of the European Commission's Ad hoc Working Group on defining critical raw materials (European Commission 2014). However on supply risk it was at the threshold of the criticality index. The EU criticality report also expects a moderate growth of 3–4.5% per year in demand for chromium in EU.

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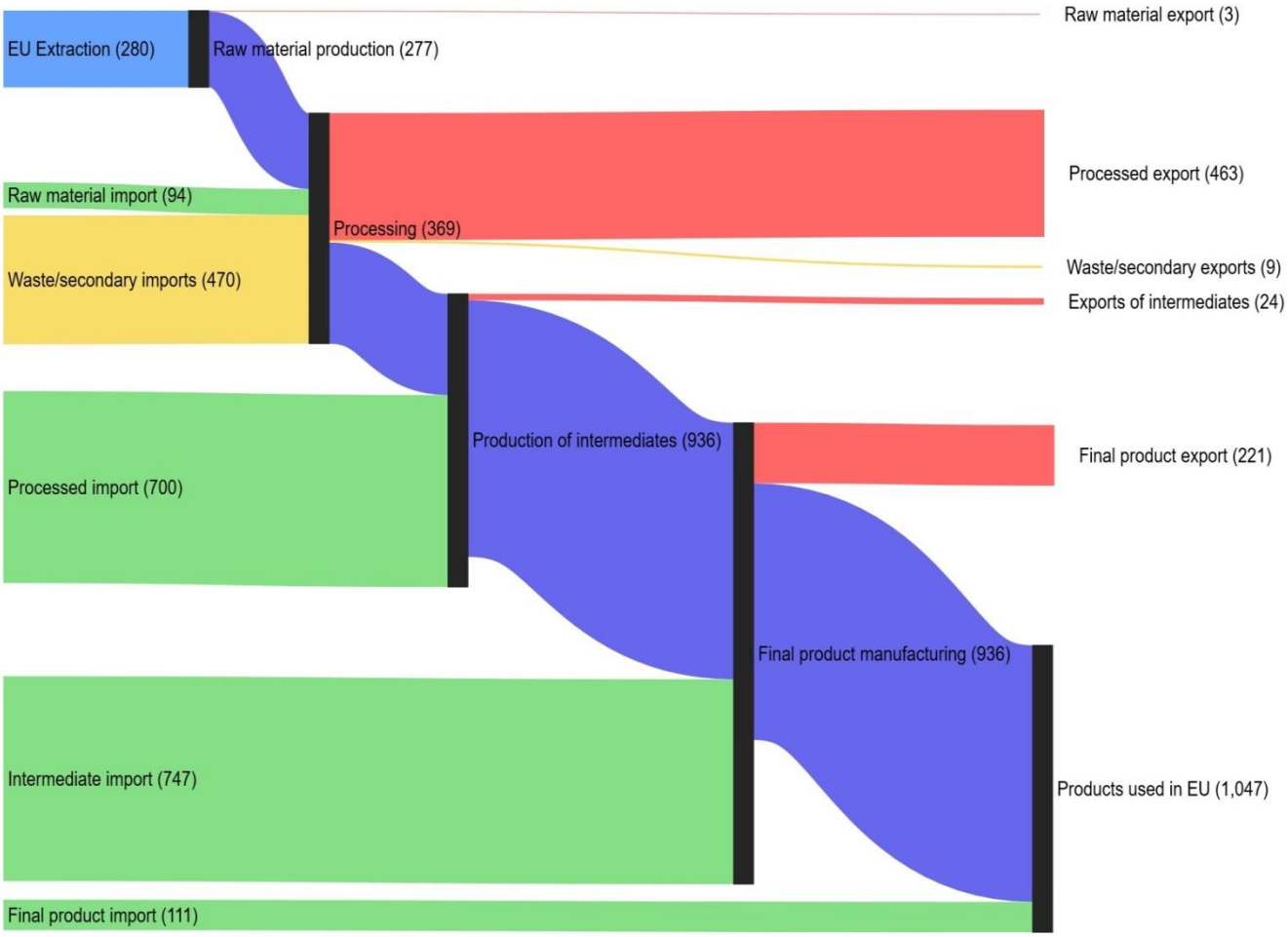

Figure A4.2. Sankey diagram of chromium flows in Europe in 2013.

A4.3 COBALT

Cobalt is getting prominent as Lithium cobalt oxide (LiCoO2) is widely used in lithium ion batteries as cathode material. The transition of the automobile sector to hybrid and electric systems in Europe has increased the demand for these batteries along with supply concentration of supply in countries like DRC, making cobalt a critical element for Europe. Other battery systems like nickel-cadmium (NiCd) and nickel metal hydride (NiMH) batteries also use cobalt to improve the oxidation of nickel in the battery. Currently applications in batteries constitute the largest cobalt usage of about 51% in Europe.

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Table A4.3. European Cobalt flows (kt), for 2012. Based on (BIO by Deloitte 2015). Data indicated with an * are derived from the quantitative *and* qualitative information in the MSA study.

	IN		OUT	
	Extraction/prod- in EU	Import of EU	Export of EU	Output of processing in EU
Raw/Primary	1,53	13	0,111	15
Processed/intermediate	15	0,6	4,76	10,84
Secondary				
Waste		0,015	1,02	
Intermediate	*11**		2,4	8,6
Final	*11**	11,4	4,79	*20**

About 18% of cobalt is used in super alloys for turbine blades for gas turbines and jet aircraft engines. Cobalt is also the major component in earlier generations of permeant magnets such as AlNiCo and SmCo, which is still have niche markets in high temperature applications in aero and space sectors. Table A4.3 shows that around 1.5 kilotons of cobalt are mined in Europe whereas the total demand across value chain as depicted in the diagram could be around 20-25 kilo tons per year. Most of the demand is met through the import of primary material, where EU processes these materials and convert to various intermediate products such as alloys. The sector is expected to grow strongly around 5.5% to 8% in EU in coming years. Cobalt is considered as less risky to supply chain disruptions and scored moderately in criticality index of 2014 CRM report. However, the recent political and policy developments, human right violations, child labor in mining areas in countries like Congo make cobalt a highly critical material from supply side as the copper belt in the Democratic Republic of the Congo, Central African Republic and Zambia have become the main producers of Cobalt. The Sankey diagram in Figure A4.3 depicts flows of Cobalt contained in kilo tons for the year 2012, where the width of each flow pictured is based on its quantity.

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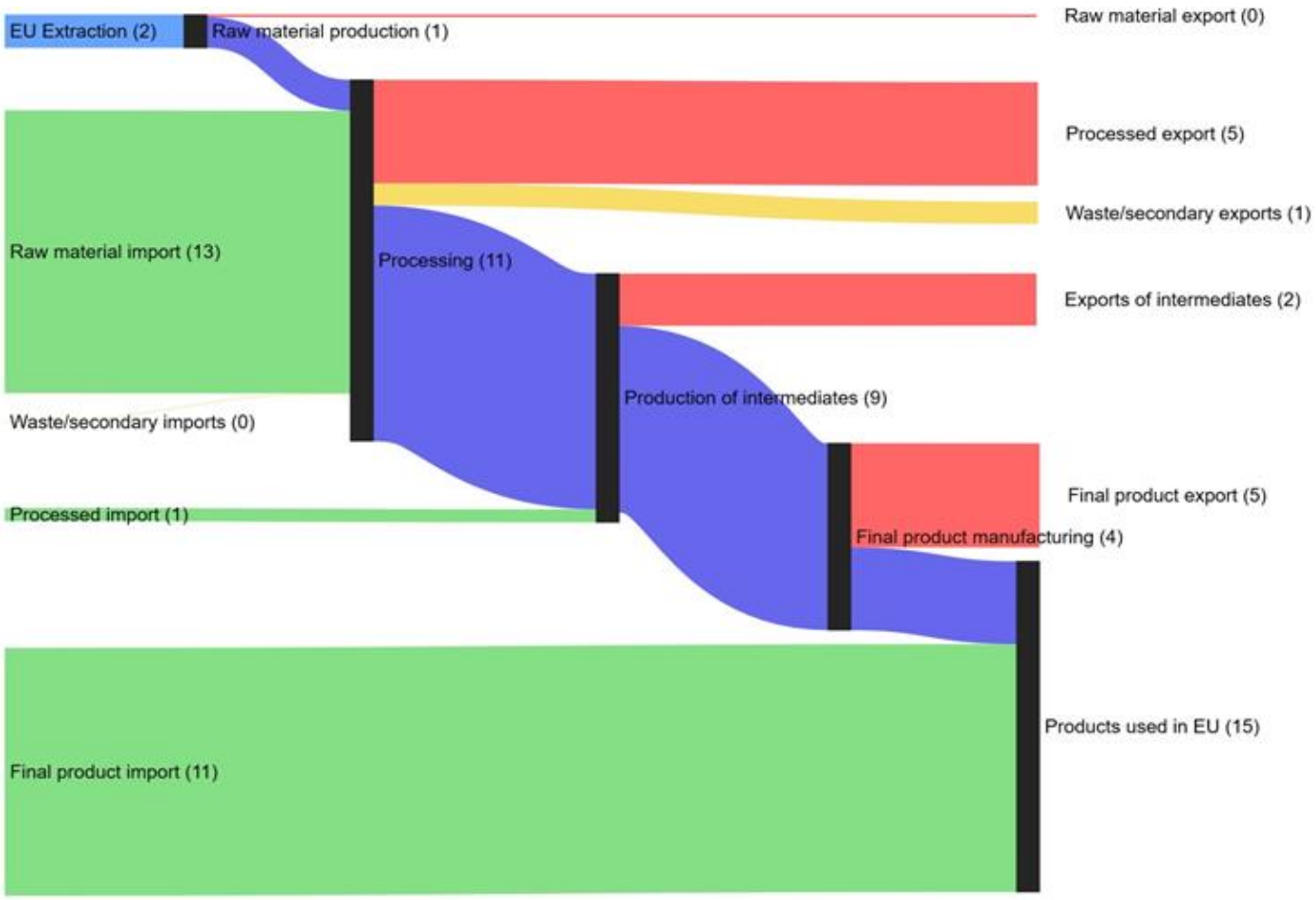

Figure A4.3 Sankey diagram of cobalt flows in Europe in 2012.

A4.4 DYSPROSIUM

Dysprosium is one of heavy rare earth elements, which has relatively few but important applications where it cannot be substituted by other chemical elements. Dysprosium is used in making laser materials and commercial lighting. It is also used in nuclear reactors as in neutron-absorbing control rods. However the main usage of dysprosium is in permanent magnets used in electric car motors and wind turbine generators. Neodymium–iron–boron magnets can have up to 6% of the neodymium substituted by dysprosium to raise the coercivity and heat resistance in drive motors for electric vehicles and generators for wind turbines.

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Table A4.4. European Dysprosium flows (t), for 2013. Based on (BIO by Deloitte 2015). Data indicated with an * are derived from the quantitative *and* qualitative information in the MSA study.

	IN		OUT	
	Extraction/prod- in EU	Import of EU	Export of EU	Output of processing in EU
Raw/Primary	0	40,2		
Processed/intermediate		31	17,2	*71,2**
Secondary			1,27	
Waste		0,8		
Intermediate	31	140	16	190
Final	*190**	56,7	63,6	200

Currently, China controls almost 100 percent of global supply and consequently dysprosium ranks very high in supply risk as depicted in EU's criticality index. Table A4.4 shows that indeed, no domestic extraction takes place in the EU. The demand for dysprosium is expected grow strongly at around 8% in EU, largely due to demand from automobile and wind energy sectors. The Sankey diagram in Figure A4.5 depicts flows of dysprosium contained in tons for the years 2013.

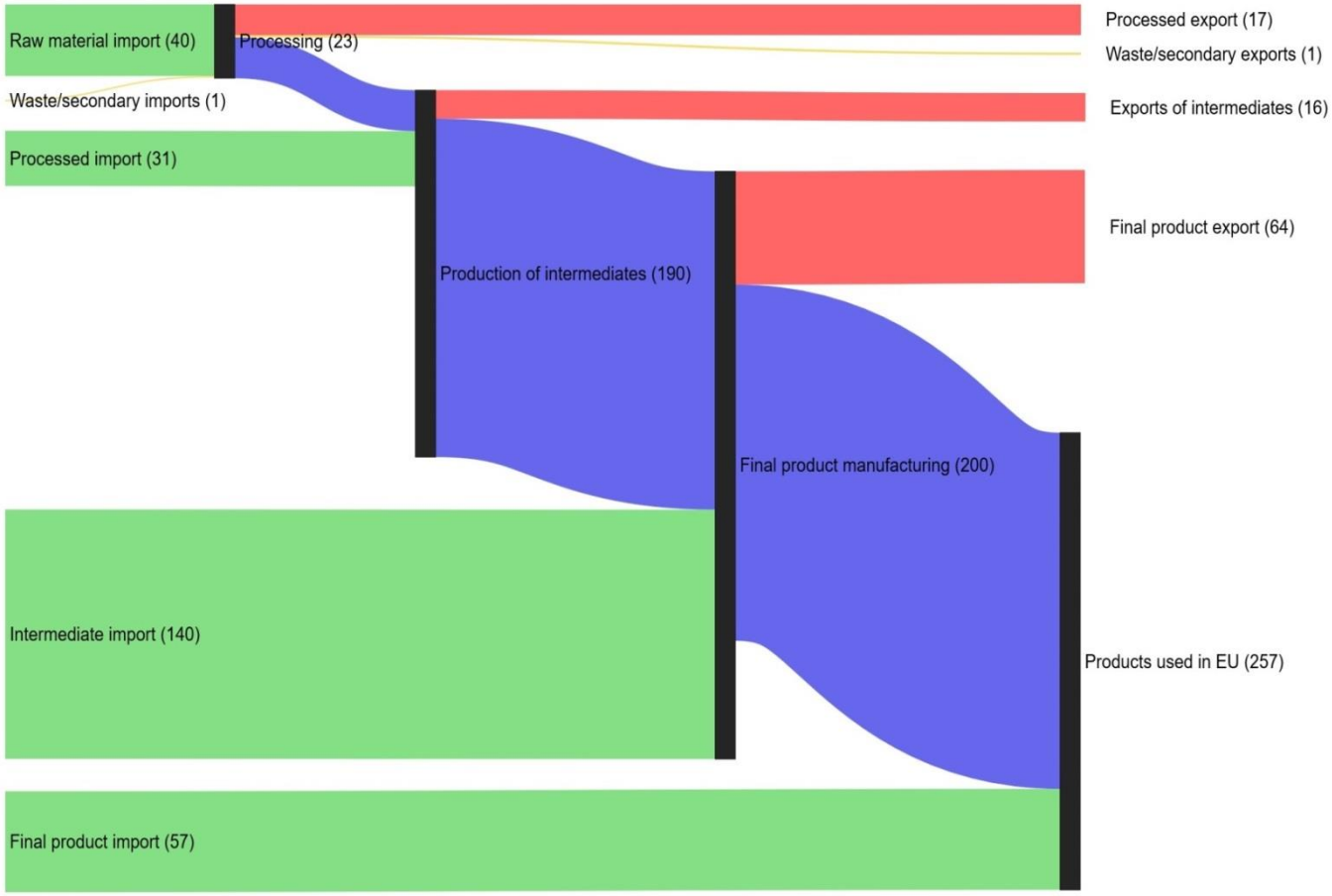

Figure A4.5 Sankey diagram of dysprosium flows in Europe in 2013.

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A4.5 INDIUM

Indium is a minor metal and extracted as a sub product from Zinc and Tin ores. About 45 metric tons of indium is recovered from Zinc production in EU and have refining facilities in Belgium, Italy, the Netherlands and Germany along with import of about 62 tons of processed material mainly from China followed by South Korea and Japan (see Table A4.5). The Indium containing main intermediate product is Indium Tin Oxide (ITO) used to produce TV monitors.

Table A4.5. European Indium flows (t), for 2012. Based on (BIO by Deloitte 2015). Data indicated with an * are derived from the quantitative *and* qualitative information in the MSA study.

	IN		OUT	
	Extraction/prod- in EU	Import of EU	Export of EU	Output of processing in EU
Raw/Primary	45	17,2	2,6	*32**
Processed/intermediate	*32**	61,3	12,5	54
Secondary		8,3		
Waste		2,9	14,5	
Intermediate	*54**	40	33	90
Final	*90**	81,4	52	*119,4**

Furthermore Indium is used in the production of intermediate materials, like semiconductors, monitors and flat panel (LCD, plasma) and indicator panels (LCD, LED). Indium is also the major constituent to produce photovoltaic modules as the semiconductor copper indium gallium selenide (CIGS), also called CIGS solar cells, a type of second-generation thin-film solar cell. Indium's high neutron-capture cross-section for thermal neutrons makes it suitable for use in control rods for nuclear reactors, typically in an alloy of 80% silver, 15% indium, and 5% cadmium. Next the intermediate materials are applied in final products, like fire alarms, vehicles, laptop PCs, desktop PCs and mobile phones. The Sankey diagram in Figure A4.5 depicts flows of Indium contained in tons for the years 2012, where the width of each flow pictured is based on its quantity.

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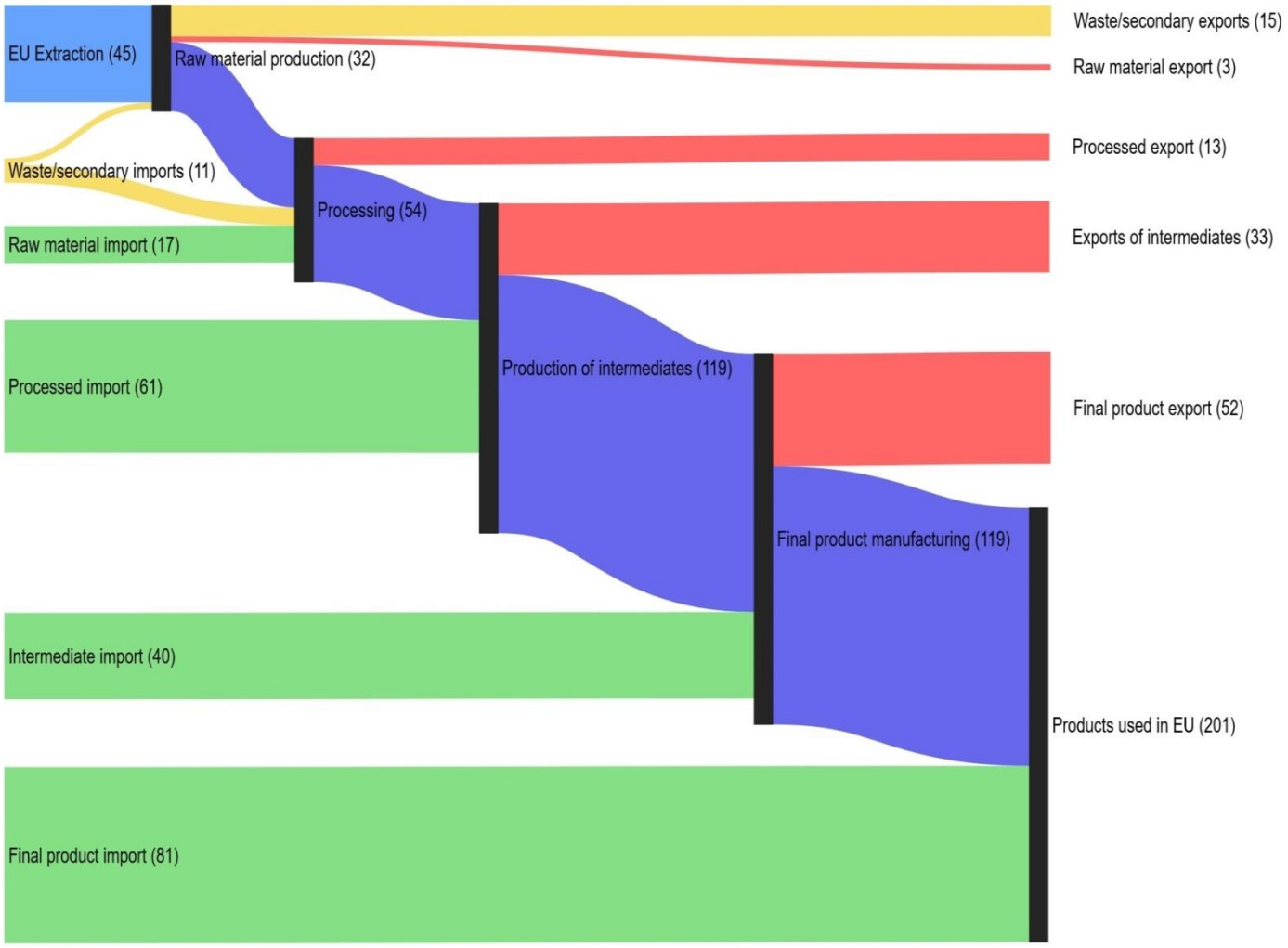

Figure A4.5 Sankey diagram of indium flows in Europe in 2012.

A4.6 PLATINUM

Though the consumption of precious metals like platinum is small in absolute quantity, they are indispensable in many applications such as auto and other catalysts and also important in sectors like IR optics and semiconductor integrated circuits. The yearly extraction of platinum in EU is less than a metric ton, while close to 100 tons of platinum is required to meet the demand in intermediate and final product stages. Most of the demand is met through the import of 52 tons of unprocessed material and 72 tons of processed platinum material. For more details, please see Table A4.6.

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Table A4.6. European Platinum flows (t), for 2012. Based on (BIO by Deloitte 2015). Data indicated with an * are derived from the quantitative *and* qualitative information in the MSA study.

	IN		OUT	
	Extraction/prod- in EU	Import of EU	Export of EU	Output of processing in EU
Raw/Primary	0,9	52	0,25	*52,7**
Processed/intermediate	*15,7**	72,3	44,8	43,2
Secondary	14	17,5		
Waste			8,3	
Intermediate	*63**	18	10	71
Final	*71**	10	20	*61**

On criticality list platinum group of metals scored moderately as value addition activities and supporting industries within EU is limited and pose no immediate risk of supply chain disturbances. The sector is expected to grow moderately around 3-4.5% per year in coming years, largely driven by demand from automobile sector and IR optic and IT related fields. The Sankey diagram in Figure A4.6 shows the contained platinum flows (in metric tons) for the year 2012, where the width of each flow pictured is based on its quantity.

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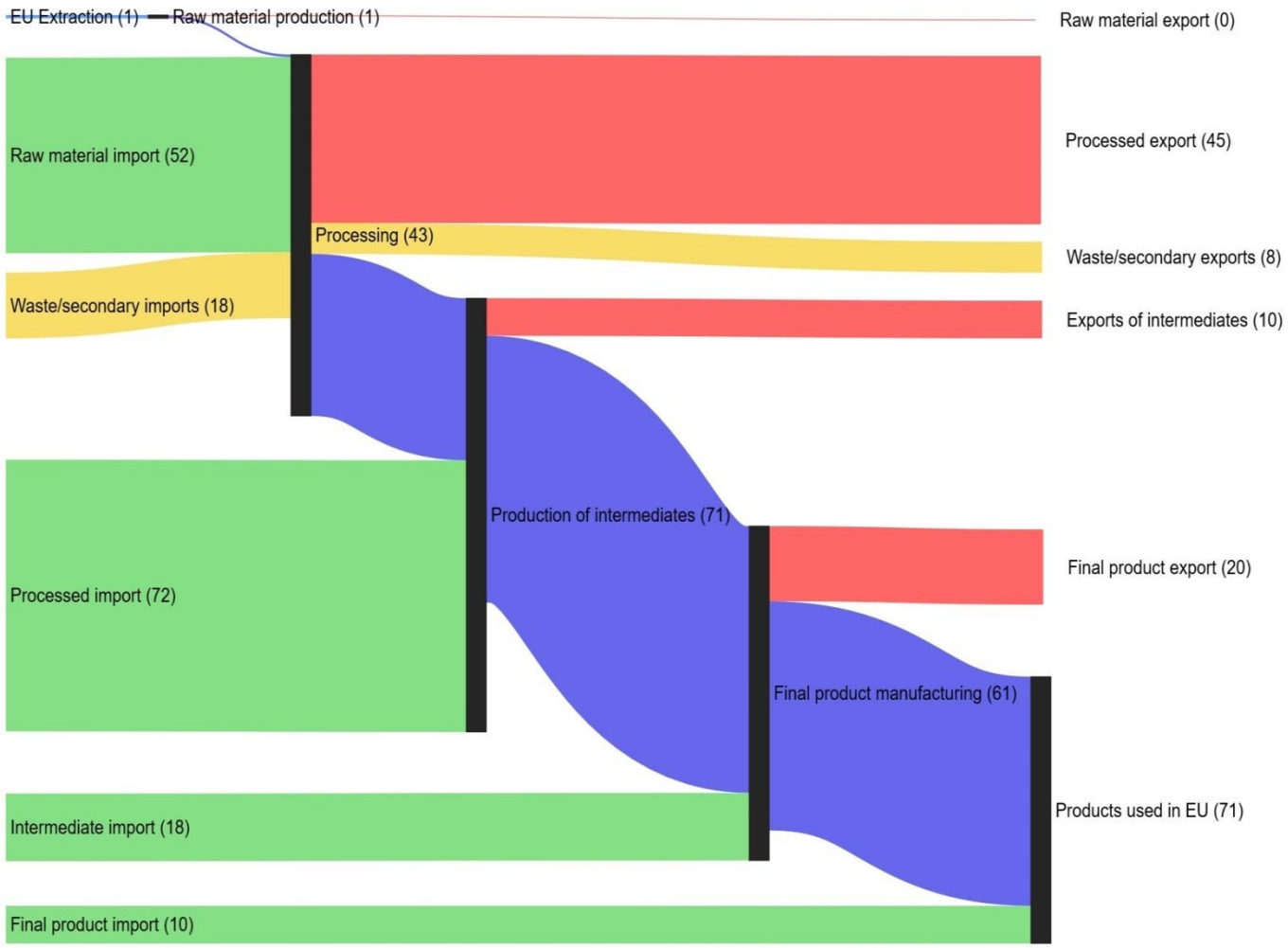

Figure A4.6. Sankey diagram of platinum flows in Europe in 2012.

A4.7 TUNGSTEN

Tungsten is one of the most critical elements featured 2014 CRM report largely due to its economic importance as well as risks related to supply stability. China and Russia dominate the global market with more than 90 percent of the global supply. About 2.7 kilotons of primary tungsten is produced in the EU, largely in UK and Portugal.

Table A4.7. European Tungsten flows (kt), for 2012. Based on (BIO by Deloitte 2015). Data indicated with an * are derived from the quantitative and qualitative information in the MSA study.

	IN		OUT	
	Extraction/prod- in EU	Import of EU	Export of EU	Output of processing in EU
Raw/Primary	2,7	2,6	1,2	*5,3**
Processed/intermediate	*5,3**	10,9	0,1	19,5
Final	*19,5**	8,1	5,4	13,8

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Table A4.7 shows that the EU imports around 11 kilotons of processed material mainly from China and Russia. The heavy import dependence on these countries is a concern as the trade practices of these countries have been discriminatory and less transparent in the past, prompting EU to file complaints in international bodies like World Trade Organization. Tungsten is also considered as a conflict material and still a considerable quantity of the ore is produced in countries like Rwanda and DRC. The processed material is used in variety of applications such as high strength and high temperature steel, milling and cutting tools, mining and construction stools, other wear tool, aircraft/defence, fluid cracking catalysts (FCC), gas turbines and electrical equipment with value adding activities in EU.

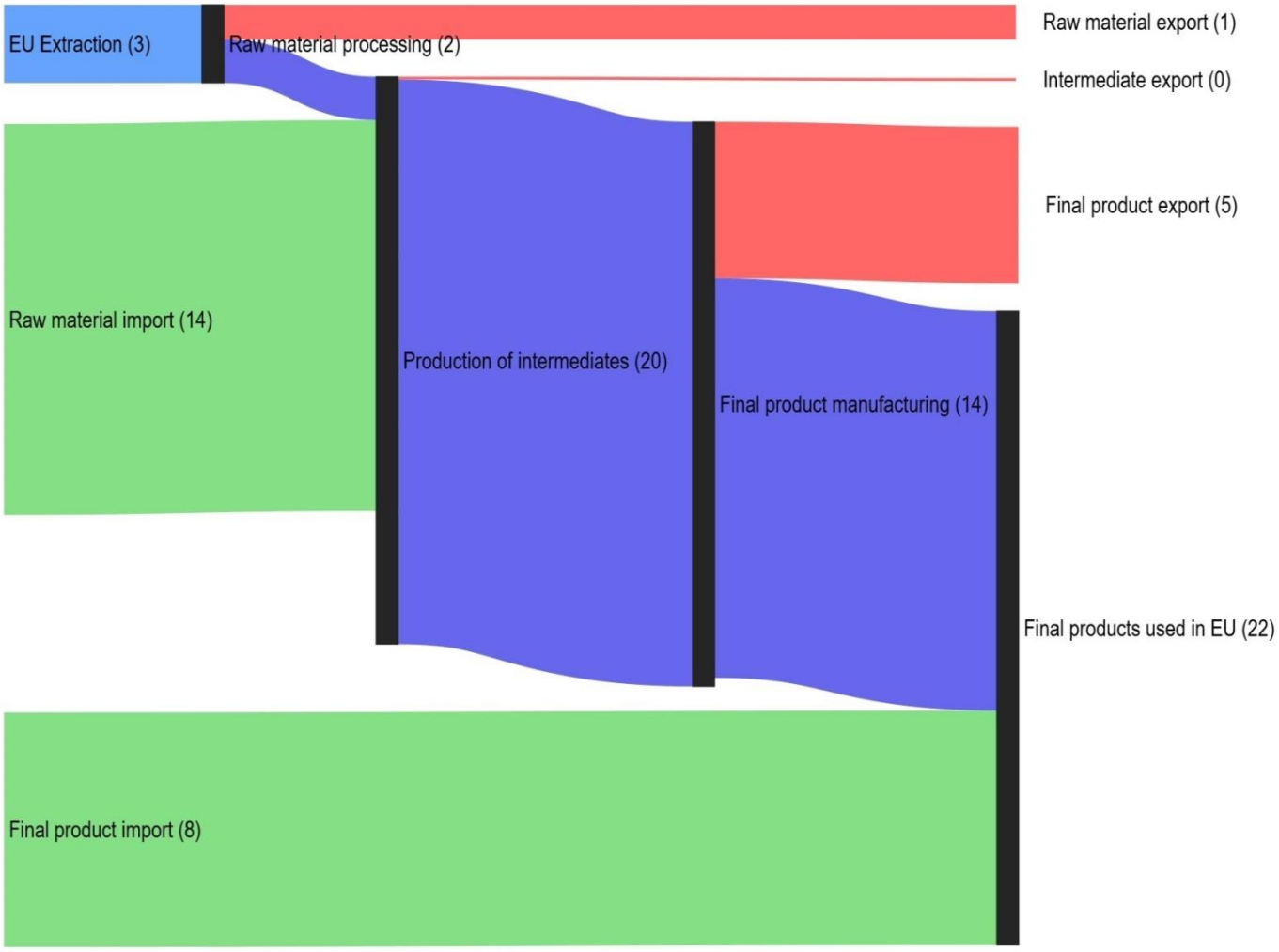

Figure A4.7 Sankey diagram of tungsten flows in Europe in 2012.

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