Study on the review of the list of Critical Raw Materials

Criticality Assessments

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Final Report

Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs
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ABBREVIATIONS AND GLOSSARY

General abbreviations

AHWG	Ad-Hoc Working Group on Defining Critical Raw Materials
BGS	British Geological Survey
CRM	Critical Raw Material
DG GROW	Directorate General Internal market, Industry, Entrepreneurship, SMEs
EC	European Commission
EI	Economic Importance
EOL-RIR	End-of-life Recycling Input Rate
ETRMA	European Tyre & Rubber Manufacturers' Association
FAO	Food and Agriculture Organization of the United Nations
FTA	Free Trade Agreements
GDP	Gross Domestic Product
GVA	Gross Value Added
HHI	Herfindahl-Hirschman-Index
HREEs	Heavy rare earth elements
IR	Import Reliance
JRC	Joint Research Centre
LREEs	Light rare earth elements
NACE	Nomenclature statistique des activités économiques dans la Communauté européenne
OECD	Organisation for Economic Co-operation and Development
PGMs	Platinum group metals
REEs	Rare earth elements
RMSG	Raw Materials Supply Group
SI	Substitution Index
SI(EI)	Substitution Index for Economic Importance
SI(SR)	Substitution Index for Supply Risk
SR	Supply Risk
USGS	US Geological Survey
VAT	Value added tax
WGI	World Governance Index
WMD	World Mining Data
WTO	World Trade Organisation

Specific abbreviations for the materials covered

Agr	Aggregates	Mn	Manganese
Al	Aluminium	Mo	Molybdenum
Sb	Antimony	NC	Natural cork
Brt	Baryte	Gr	Natural graphite
Bx	Bauxite	Nr	Natural Rubber
Bn	Bentonite	Nt	Natural Teak wood
Be	Beryllium	Nd	Neodymium
Bi	Bismuth	Ni	Nickel
Bo	Borate	Nb	Niobium
Ce	Cerium	Pd	Palladium
Cr	Chromium	Pe	Perlite
Co	Cobalt	P	Phosphorus
Cc	Coking coal	Phs	Phosphate rock
Cu	Copper	Pl	Platinum
Di	Diatomite	Po	Potash
Dy	Dysprosium	Pr	Praseodymium
Er	Erbium	Re	Rhenium
Eu	Europium	Rh	Rhodium
Fsp	Feldspar	Ru	Ruthenium
Fl	Fluorspar	Sm	Samarium
Gd	Gadolinium	Sw	Sapele wood
Ga	Gallium	Sc	Scandium
Ge	Germanium	Se	Selenium
Au	Gold	Sl	Silica sand
Gp	Gypsum	Si	Silicon metal
Hf	Hafnium	Ag	Silver
He	Helium	S	Sulphur
Ho	Holmium	Tc	Talc
In	Indium	Ta	Tantalum
Ir	Iridium	Te	Tellurium
Fe	Iron ore	Tb	Terbium
Kc	Kaolin clay	Tm	Thulium
La	Lanthanum	Sn	Tin
Pb	Lead	Ti	Titanium
Ls	Limestone	W	Tungsten
Li	Lithium	V	Vanadium
Lu	Lutetium	Yb	Ytterbium
Mgs	Magnesite	Y	Yttrium
Mg	Magnesium	Zn	Zinc

Glossary

Term	Definition in the context of this report
Abiotic	Metals (or metallic ores), industrial minerals and construction materials. These are derived from static reserves.
Biotic	Materials which are derived from renewable biological resources, not of fossil origin.
Bottleneck	A bottleneck is considered to be the point in value chain for a specific material where the supply risk is highest, i.e. the stage (either extraction/harvesting or processing/refining), that has the highest numerical criticality score for the Supply Risk.
Critical Raw Materials (CRMs)	Critical raw materials (CRMs) are raw materials of a high importance to the economy of the EU and whose supply is associated with a high risk. The main two parameters: Economic Importance (EI) and Supply Risk (SR) are used to determine the criticality of the material for the EU. The list of CRMs is established on the basis of the raw materials which reach or exceed the thresholds for both parameters.
Economic Importance (EI)	One of the two main assessment parameters (in addition to Supply Risk) of the revised EC methodology to measure the criticality of a raw material. In the EC methodology[1], the Economic Importance is calculated based on the importance of a given material in the EU end-use applications and performance of available substitutes in these applications.
End-of-life Recycling Input Rate	The end-of-life recycling input rate (EOL-RIR) in the 2017 assessment refers to the ratio of recycling of old scrap in the EU among the EU supply of raw material. In other words, EOL-RIR is production of secondary material from post-consumer functional recycling (old scrap) sent to processing and manufacturing and replacing primary material input. In the previous EC criticality assessments (EC 2011, 2014), recycling rates and EOL-RIR refer only to functional recycling i.e. the portion of EOL recycling in which the material in a discarded product is separated and sorted to obtain recyclates.
Extraction stage	Refers to the process of obtaining (extracting) raw materials from our environment and is also referred to as the mining or harvesting stage. This may involve discovering where these raw materials are located (often achieved with knowledge of geology) and developing processes to extract them from these locations (e.g. mining the ores).
Heavy rare earth elements (HREEs)	Heavy rare earth elements (HREEs) are one of the two sub-categories of the rare earth elements (REEs) group. HREEs are part of the lanthanide elements and have higher atomic weights (hence "heavier") compared to the light rare earth elements (LREEs). HREEs are currently used in a few niche applications, which are mostly related to their optical properties (Laser dopants, radiography, etc.). The HREEs (10) covered by the study include dysprosium, erbium, europium, gadolinium, holmium, lutetium, terbium, thulium, ytterbium and yttrium.
Herfindahl-Hirschman-Index (HHI)	The Herfindahl-Hirschman-Index is a commonly accepted measure of market concentration. In the context of the 2017 exercise, the Herfindahl-Hirschmann-Index (HHI_{WGI}), based on the world governance index (WGI), is used to calculate the Supply Risk as a parameter quantifying the stability and level of concentration of producing countries.
Import Reliance (IR)	Import reliance (or import dependency) is part of the Supply Risk calculation in the revised EC methodology for updating the list of critical raw materials for the EU[2]. It takes into account actual EU sourcing (net imports divided by a sum of domestic production with net imports) and the level of import dependency in the calculation of Supply Risk.
Light rare earth elements (LREEs)	Light rare earth elements (LREEs) are one of the two sub-categories of the REEs group. LREEs are part of the lanthanide elements and are characterised by lower atomic weights (hence "lighter") compared to HREEs. Generally, LREEs are more abundant in the earth's crust compared to HREEs. LREEs can be used in a wide variety of applications according to the individual REEs and regional specificities, but they are in general used in sectors such as catalysts, metallurgy, glass/polishing and magnets. The LREEs (5) covered by the study include cerium, lanthanum, neodymium, praseodymium and samarium.
Mineral	A natural concentration of material of possible economic interest in the earth's

[1] Methodology for establishing the EU List of Critical Raw Materials, 2017, ISBN 978-92-79-68051-9
[2] Methodology for establishing the EU List of Critical Raw Materials, 2017, ISBN 978-92-79-68051-9

Term	Definition in the context of this report
deposit	crust.
New scrap / Old scrap	New scrap refers to the scrap generated from processing and manufacturing processes and it is also sometimes regarded as pre-consumer scrap. It has a known composition, normally high purity, and origin, and can be often recycled within the processing facility. Old scrap, also regarded as post-consumer scrap, is the amount of material contained in products that have reached their end of life (EOL). It is often mixed with other materials such as plastics or alloys, therefore its recycling requires further detailed processing for proper recovery.
Platinum group metals (PGMs)	Five platinum group metals are covered by the assessment: ruthenium, rhodium, palladium, iridium and platinum. They have similar physical and chemical properties, tend to be found together, and are commonly associated with ores of nickel and copper. The PGMs are generally derived from the same types of ore deposit in which they occur together, commonly in the same mineral phases. For this reason they are classed as co-products, because they have to be mined together. They rarely occur in native form. The PGMs are highly resistant to wear, tarnish, chemical attack and high temperature. The PGMs are regarded as precious metals, like gold and silver. All PGMs, commonly alloyed with one another or with other metals, can act as catalysts which are exploited in a wide range of applications. Platinum and palladium are of major commercial significance, with rhodium the next most important. The main use of PGMs is in autocatalysis, but other major applications include jewellery, chemical manufacture, petroleum refining and electrical products.
Primary raw material / Secondary raw material	Primary raw materials are virgin materials, natural inorganic or organic substance, such as metallic ores, industrial minerals, construction materials or energy fuels, used for the first time. Secondary raw materials are defined as materials produced from other sources other than primary. Secondary raw materials can also be obtained from the recycling of raw (i.e. primary) materials. Examples: steel or aluminium scrap.
Processing / refining stage	Refers to a series of operations and treatments that transform raw materials from a raw-material state into substances which are then used to make semi-finished and finished products. Also referred to as the post-mining or post-harvesting stage.
PRODCOM / NACE	EUROSTAT Prodcom survey provides statistics on the production of manufactured goods. The term comes from the French "PRODuction COMmunautaire" (Community Production) for mining, quarrying and manufacturing: sections B and C of the Statistical Classification of Economy Activity in the European Union (NACE 2). The first four digits refer to the equivalent class within the Statistical classification of NACE, and the next two digits refer to subcategories within the Statistical classification of products by activity (CPA). Most PRODCOM headings correspond to one or more Combined nomenclature (CN) codes related to EU trade.
Rare earth elements (REEs)	Refers to a set of 15 elements in the Lanthanide series and two other elements: scandium and yttrium (see definitions for HREEs and LREEs). In the context of this study, yttrium is considered a rare earth element since it tends to occur in the same ore deposits as the lanthanides and exhibits similar chemical properties. However, scandium is not considered as part of the REEs in the study because its properties are not similar enough to classify it as either a heavy rare earth element or light rare earth element. The REEs are typically sub-divided into two groups, the light rare earth elements (LREEs) and heavy rare earth elements (HREEs), both for commercial reasons and their physical-chemical properties. The main uses of REEs are in automotive, telecom and electronics sectors, as well as in the aerospace, defence and renewable energy sectors. REEs find uses in a large variety of applications linked with their magnetic, catalytic and optical properties.
Raw material	Natural or processed resources which are used as an input to a production operation for subsequent transformation into semi-finished and finished good. Primary raw materials are, as opposed to semi-finished products, extracted directly from the planet and can be traded with no, or very little, further processing.

Term	Definition in the context of this report
Reserves	The term is synonymously used for "mineral reserve", "probable mineral reserve" and "proven mineral reserve". In this case, confidence in the reserve is measured by the geological knowledge and data, while at the same time the extraction would be legally, economically and technically feasible and a licensing permit is certainly available.
Resources	The term is synonymously used for "mineral resource", "inferred mineral resource", "indicated mineral resource" and "measured mineral resource". In this case, confidence in the existence of a resource is indicated by the geological knowledge and preliminary data, while at the same time the extraction would be legally, economically and technically feasible and a licensing permit is probable.
Substitution	In the revised EC methodology for updating the list of CRMs for the EU, substitution is considered to reduce the potential consequences in the case of a supply disturbance based on the rationale that the availability of substitute materials could mitigate the risk of supply disruptions. It is therefore incorporated in both the Economic Importance (EI) and Supply Risk (SR) dimension as a substitution index. Since the scope of the 2017 assessment focuses on the current situation, only proven substitutes that are readily-available today (snapshot in time) and that would subsequently alter the consequences of a disruption are considered. As a result, only substitution, and not substitutability or potential future substitution is considered in the revised EC methodology.
Supply Risk (SR)	One of the two main assessment parameters (along with Economic Importance) of the revised EC methodology to measure the criticality of a raw material. In the EC methodology, the Supply Risk is calculated based on factors that measure the risk of a disruption in supply of a specific material (e.g. global supply and EU sourcing countries mixes, import reliance, supplier countries' governance performance measured by the World Governance Indicator, trade restrictions and agreements, availability and criticality of substitutes).
Value chain	The value chain describes the full range of activities required to bring a raw material through the different phases of production, transformation, delivery to final consumers and final disposal or recovery after use.

EXECUTIVE SUMMARY

Context

Raw materials are not only essential for the production of a broad range of goods and services used in everyday life, but also for the development of emerging innovations in the EU, which are notably necessary for the development of more eco-efficient and globally competitive technologies. The accelerating technological innovation cycles and the rapid growth of emerging economies have led to increasing global demand for highly sought after metals and minerals. Securing access to a stable supply of many raw materials has become a major challenge for national and regional economies with limited production, such as the EU economy, which relies on imports of many minerals and metals needed by industry, including many critical raw materials.

To address the growing concern of securing valuable raw materials for the EU economy, the European Commission (EC) launched the European Raw Materials Initiative[3] in 2008. It is an integrated strategy that establishes targeted measures to secure and improve access to raw materials for the EU:

- Securing a fair and sustainable supply of raw materials from international markets;
- Fostering sustainable supply within the EU; and
- Boosting resource efficiency and promoting recycling.

One of the priority actions of the Initiative was to establish a list of critical non-energy raw materials at EU level. The first list was established in 2011 and it is updated every three years.

The present study addresses the third assessment of critical raw materials for the EU. The purpose of these exercises is to regularly assess the criticality of raw materials for the EU based on the methodology[4] developed by the European Commission, in cooperation with the Ad hoc Working Group on Defining Critical Raw Materials (AHWG)[5], and to update the list of critical raw materials for the EU. The first assessment, conducted in 2011, identified 14 critical raw materials out of the 41 non-energy, non-agricultural candidate raw materials assessed. In the 2014 exercise, 20 raw materials were identified as critical out of 54 non-energy, non-agricultural candidate materials. The same EC criticality methodology was used in both of the previous assessments, based on two parameters: Economic Importance (EI) and Supply Risk (SR).

Novelties of the 2017 assessment

Firstly, the 2017 assessment covers a larger number of materials (78 individual materials or 61 raw materials comprising 58 individual and 3 grouped materials) compared to the previous assessments (41 materials in 2011 and 54 materials in 2014). Nine new materials (six abiotic materials[6] and three biotic materials[7]) are assessed. Fifteen individual rare earth elements (REEs) were analysed separately, as were five platinum-group metals (PGMs), excluding osmium.

Secondly, criticality assessment results are available for the first time at both the individual material level and the group level for the rare earth elements and platinum group metals, whereas in the 2011 and 2014 assessments, the results of these material groups were presented at the group level only. The 15 rare earth elements (REEs) are split into two sub-categories based on their chemical and physical properties - 'heavy' rare earth elements (HREEs), consisting of ten individual materials[8] and 'light' rare earth elements (LREEs), comprising five individual materials[9]. The five platinum group metals

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[3] https://ec.europa.eu/growth/sectors/raw-materials/policy-strategy_en
[4] Methodology for establishing the EU List of Critical Raw Materials, 2017, ISBN 978-92-79-68051-9
[5] The AHWG on Defining Critical Raw Materials is a sub-group of the Raw Materials Supply Group expert group.
[6] New abiotic materials assessed: aggregates, bismuth, helium, lead, phosphorus, sulphur
[7] New biotic materials assessed: natural cork, natural teak wood and sapele wood
[8] HREEs: dysprosium, erbium, europium, gadolinium, holmium, lutetium, terbium, thulium, ytterbium, yttrium
[9] LREEs: cerium, lanthanum, neodymium, praseodymium, samarium

(excluding osmium)[10] (PGMs) are grouped under one group[11]. The results presented for the grouped materials (HREEs, LREEs and PGMs) are the arithmetic averages of the results of the individual materials included in these groups. It should be noted that the 2011 assessment grouped all rare earth elements, including scandium, under the rare earth elements group, while the 2014 and 2017 assessments examine scandium separately.

Finally, the 2017 assessment applies a revised version of the EC criticality methodology while ensuring comparability with the previous methodology used in 2011 and 2014. The revised methodology is based on the same two parameters – Supply Risk (SR) and Economic Importance (EI) – as the initial methodology. There are however several significant updates in the revised methodology that should be carefully considered when analysing the criticality results[12]:

- Systematic screening of the most critical points of the raw material production stages in the supply chain (mining/extracting and processing/refining).
- Inclusion of substitution in the Economic Importance calculations, while the previous assessments only addressed substitution in the SR calculations.
- More specific allocation of raw materials to the relevant end-use applications and corresponding manufacturing sectors, instead of mega sectors; moreover, the allocation is based on official statistical sectoral or product classifications.
- Refined methodology for calculating Supply Risk:
  - Inclusion of Import Reliance (IR) parameter;
  - Considering the shares of the global supply and the actual sourcing of the material to the EU (domestic production plus imports);
  - Inclusion of trade-related parameter based on export restrictions and the EU trade agreements;
  - Guidance to improve End-of-Life Recycling Input Rate (EOL-RIR) results using higher quality EU based data.
- Compared to the previous assessments, the criticality threshold in the 2017 assessment for the SR remains at 1; however, the criticality threshold for EI was moved to 2.8 due to the implementation of the revised methodology.

Results

Of the 61 candidate raw materials assessed (58 individual and 3 grouped materials), the following 26 raw materials and groups of raw materials were identified as critical:

2017 Critical Raw Materials (26)			
Antimony	Gallium	Magnesium	Scandium
Baryte	Germanium	Natural graphite	Silicon metal
Beryllium	Hafnium	Natural Rubber	Tantalum
Bismuth	Helium	Niobium	Tungsten
Borate	HREEs	PGMs	Vanadium
Cobalt	Indium	Phosphate rock	
Fluorspar	LREEs	Phosphorus	

The overall results of the 2017 criticality assessment are shown in the following figure A. Critical raw materials (CRMs) are highlighted by red dots and are located within the criticality zone (SR ≥ 1 and EI ≥ 2.8) of the graph. Blue dots represent the non-critical raw materials.

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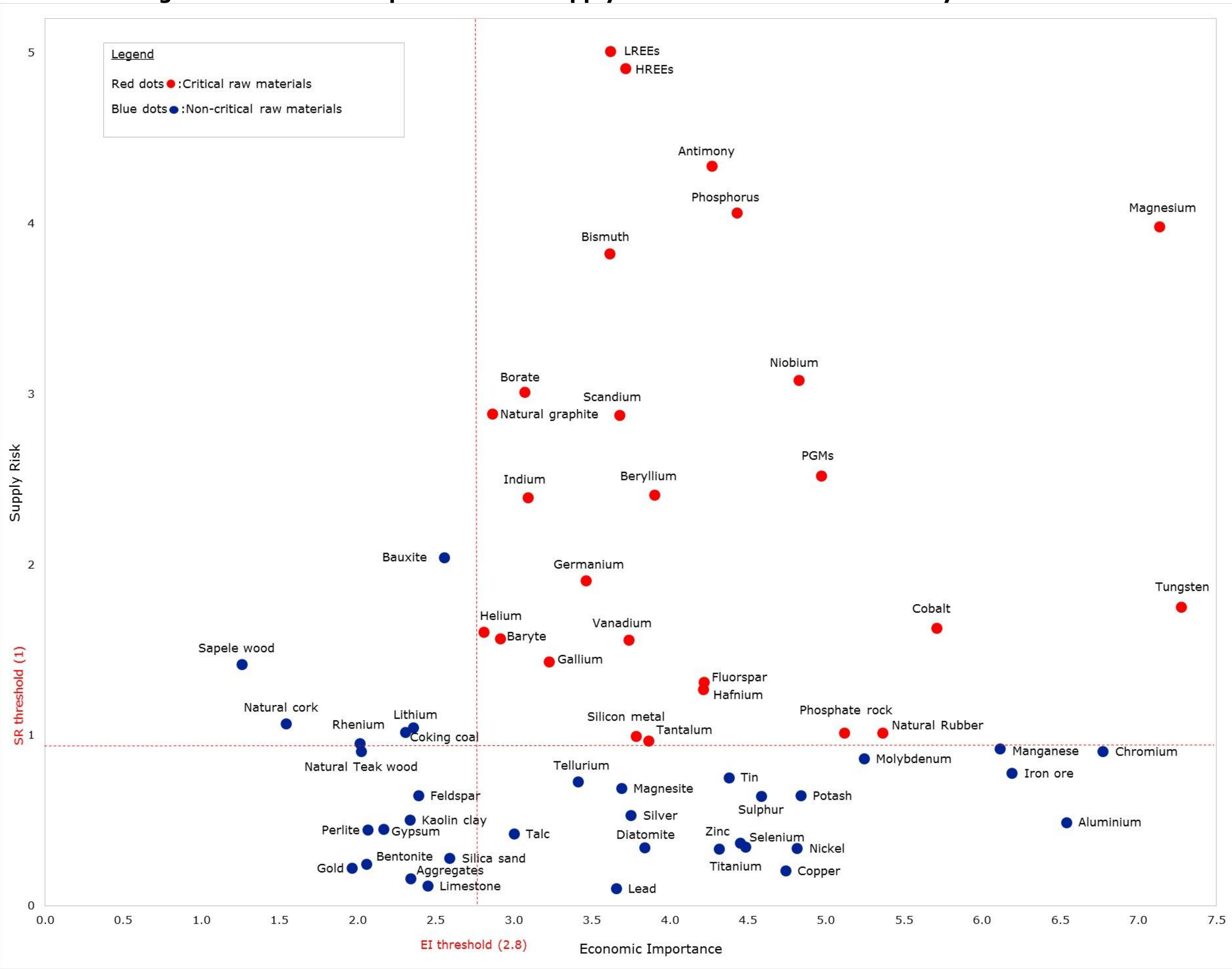
[10] Osmium was assessed in the previous assessments; however it is excluded from the 2017 exercise due to the lack of robust quantitative figures on osmium. In the 2014 criticality assessment, osmium was assessed using the data available for ruthenium and iridium. In the 2017 assessment, complementary information on osmium is provided in the PGMs factsheet, where relevant.

[11] PGMs: iridium, platinum, palladium, rhodium, ruthenium

[12] Further details in Methodology for establishing the EU List of Critical Raw Materials, 2017, ISBN 978-92-79-68051-9

Figure A: Economic importance and supply risk results of 2017 criticality assessment



The 2017 CRMs list includes 17 out of the 20 CRMs identified in 2014. The three CRMs from 2014 that are not included in the 2017 CRMs list are: chromium, coking coal and magnesite. Compared to the 2014 CRMs list, nine additional raw materials have been identified as critical and enter the 2017 CRMs list: baryte, natural rubber, scandium, tantalum, vanadium, hafnium, bismuth, helium and phosphorus. The first six materials listed were considered non-critical in 2014, whereas the latter three materials are entirely new to the 2017 CRMs list since they were not assessed in either of the previous assessments. Contrary to 2011 and 2014, natural rubber, one of the biotic materials, is classified as critical in 2017. The following table summarises the key changes in the 2017 CRMs list compared to the 2014 CRMs list.

2017 CRMs vs. 2014 CRMs			
Antimony	LREEs	Bismuth	~~*Chromium*~~
Beryllium	Magnesium	Helium	~~*Coking coal*~~
Borate	Natural graphite	Phosphorus	~~*Magnesite*~~
Cobalt	Niobium	Baryte	
Fluorspar	PGMs	Hafnium	
Gallium	Phosphate rock	Natural Rubber	
Germanium	Silicon metal	Scandium	
HREEs	Tungsten	Tantalum	
Indium		Vanadium	

Legend:

Black: CRMs in 2017 and 2014
Red: CRMs in 2017, non-CRMs in 2014
Green: CRMs assessed in 2017, not assessed in 2014
~~*Strike:*~~ Non-CRMs in 2017 (critical in 2014)

The 2017 assessment identifies all 14 of the 2011 CRMs as critical. Compared to the 2011 CRMs list, the 2017 CRMs list includes ten additional critical raw materials: baryte, borate, vanadium, bismuth, hafnium, helium, natural rubber, phosphate rock, phosphorus and silicon metal. The first three materials listed previously were considered non-critical in 2011 and the last seven materials listed were not assessed in 2011. The table below summarises the key changes in the 2017 CRMs list compared to the 2011 CRMs list.

2017 CRMs vs. 2011 CRMs			
Antimony	*LREEs*	Baryte	Bismuth
Beryllium	Magnesium	Borate	Hafnium
Cobalt	Natural graphite	Vanadium	Helium
Fluorspar	Niobium		Natural Rubber
Gallium	PGMs		Phosphate rock
Germanium	Tungsten		Phosphorus
HREEs	*Scandium*		Silicon metal
Indium	Tantalum		

Legend

Black: CRMs in 2017 and 2011

Italics: Materials grouped under the REEs group in 2011

Red: CRMs in 2017, non-CRMs in 2011

Green: CRMs assessed in 2017, not assessed in 2011

The results of the analysis of the global primary supply of the critical raw materials are presented in the two following tables. Table A presents the results for 43 raw materials, out of which 23 are individual critical raw materials and 20 belong to the three critical raw material groups: HREEs (10), LREEs (5) and PGMs (5). Table A includes the individual results of the grouped materials to allow for a more in-depth look into the global supply of the material groups. The second table B presents the averaged figures on global primary supply for the 3 material groups: HREEs, LREEs, and PGMs. It should be noted however, that in this table, calculating the average for the largest global supplier for all the PGMs is not possible because the major producing country is not the same for each of the five PGMs. For iridium, platinum, rhodium and ruthenium, the major global supplier is South Africa, whereas for palladium the major global supplier is Russia. Finally, figure B presents a world map representing the main producers of critical raw materials for the EU.

Table A: Global supply of the CRMs – individual materials

Material		Stage[13]	Main global supplier	Share	Material		Stage	Main global supplier	Share
1	Antimony	P	China	87%	23	Natural graphite	E	China	69%
2	Baryte	E	China	44%	24	Natural Rubber	E	Thailand	32%
3	Beryllium	E	USA	90%	25	*Neodymium*	E	China	95%
4	Bismuth	P	China	82%	26	Niobium	P	Brazil	90%
5	Borate	E	Turkey	38%	27	*Palladium*	P	Russia	46%
6	*Cerium*	E	China	95%	28	Phosphate rock	E	China	44%
7	Cobalt	E	DRC	64%	29	Phosphorus	P	China	58%
8	*Dysprosium*	E	China	95%	30	*Platinum*	P	S. Africa	70%
9	*Erbium*	E	China	95%	31	*Praseodymium*	E	China	95%
10	*Europium*	E	China	95%	32	*Rhodium*	P	S. Africa	83%
11	Fluorspar	E	China	64%	33	*Ruthenium*	P	S. Africa	93%
12	*Gadolinium*	E	China	95%	34	*Samarium*	E	China	95%
13	Gallium*	P	China	73%	35	Scandium	P	China	66%
14	Germanium	P	China	67%	36	Silicon metal	P	China	61%
15	Hafnium	P	France	43%	37	Tantalum	E	Rwanda	31%
16	Helium	P	USA	73%	38	*Terbium*	E	China	95%
17	*Holmium*	E	China	95%	39	*Thulium*	E	China	95%
18	Indium	P	China	56%	40	Tungsten	E	China	84%
19	*Iridium*	P	S. Africa	85%	41	Vanadium	P	China	53%
20	*Lanthanum*	E	China	95%	42	*Ytterbium*	E	China	95%
21	*Lutetium*	E	China	95%	43	*Yttrium*	E	China	95%
22	Magnesium	P	China	87%					

Legend	
Stage	E = Extraction stage P = Processing stage
HREEs	Dysprosium, erbium, europium, gadolinium, holmium, lutetium, terbium, thulium, ytterbium, yttrium
LREEs	Cerium, lanthanum, neodymium, praseodymium and samarium
PGMs	Iridium, palladium, platinum, rhodium, ruthenium

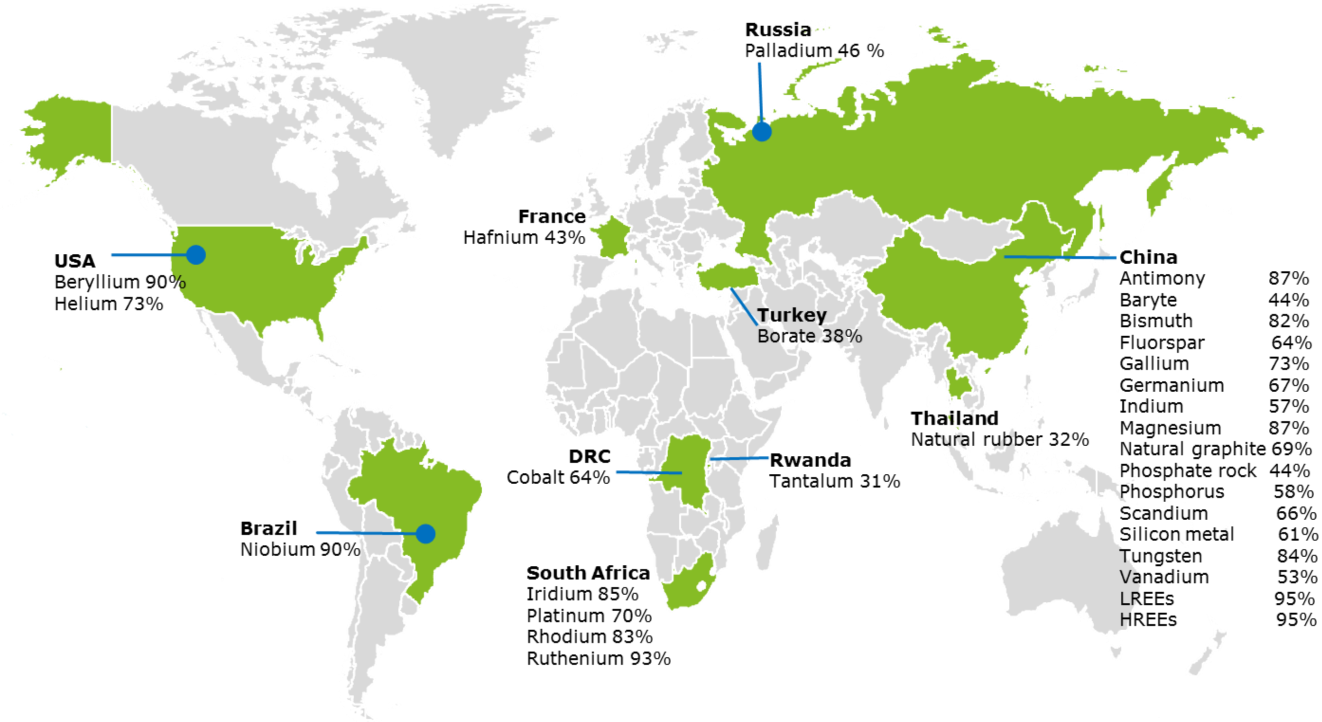
*Global supply calculation based on production capacity.

Table B: Global supply of the CRMs – grouped materials (average)

Material	Stage[13]	Main global supplier	Share
HREEs	E	China	95%
LREEs	E	China	95%
PGMs (iridium, platinum, rhodium, ruthenium)	P	South Africa	83%
PGMs (palladium)	P	Russia	46%

[13] Stage refers to the life-cycle stage of the material that the criticality assessment was carried out on: extraction (E) or processing (P).

Figure B: Countries accounting for largest share of global supply of CRMs



The analysis of the global supply results indicates that China is the largest global supplier of the identified critical raw materials. Several other countries are also important global suppliers of specific materials. For instance, Russia and South Africa are the largest global suppliers for platinum group metals, the USA for beryllium and helium and Brazil for niobium (see map in figure B).

In terms of the total number of CRMs, China is the major global supplier of 30 out of the 43 individual critical raw materials or 70% (see the following figure C[14]). This includes all of the REEs and other critical raw materials such as magnesium, tungsten, antimony, gallium and germanium among others. It is important to note as well that China is also a major consumer of several of these critical raw materials e.g. antimony, HREEs, LREEs, PGMs, magnesium, natural graphite, tungsten, etc. and, therefore, Europe competes with China and other emerging economies for supplies.

Furthermore, despite China being the largest global supplier for the majority of the critical raw materials, the analysis of the primary EU sourcing (i.e. domestic production plus imports) paints a different picture (see the figure D below[15]). The analysis of the EU sourcing includes only 37 out of the 43 individual critical raw materials since the five PGMs and beryllium are excluded from the analysis due to little or no EU sourcing activity. Although China is the major EU supplier for 15 out of 38 individual materials (or 39%), several other countries represent main shares of the EU supply for specific critical raw materials, such as the USA (beryllium and helium), Russia (tungsten and scandium) and Mexico (fluorspar).

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[14] The figure should not be interpreted in terms of tonnage of CRM that originate from these countries, but in terms of the number of CRMs, for which the country is the main global supplier or producer of the CRM.

[15] The figure should not be interpreted in terms of tonnage of CRM that originate from the countries, but in terms of the number of CRMs, for which the country is the main supplier for the EU.

Figure C: Main global suppliers of CRMs (based on number of CRMs supplied out of 43), average from 2010-2014

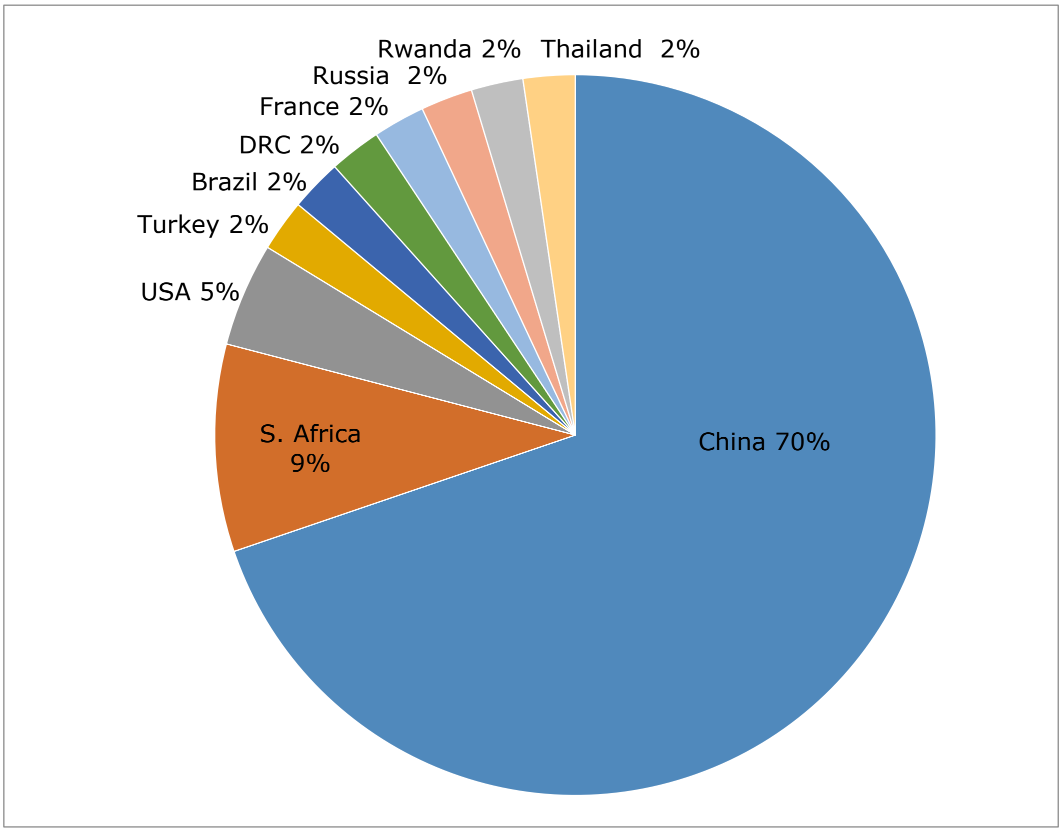
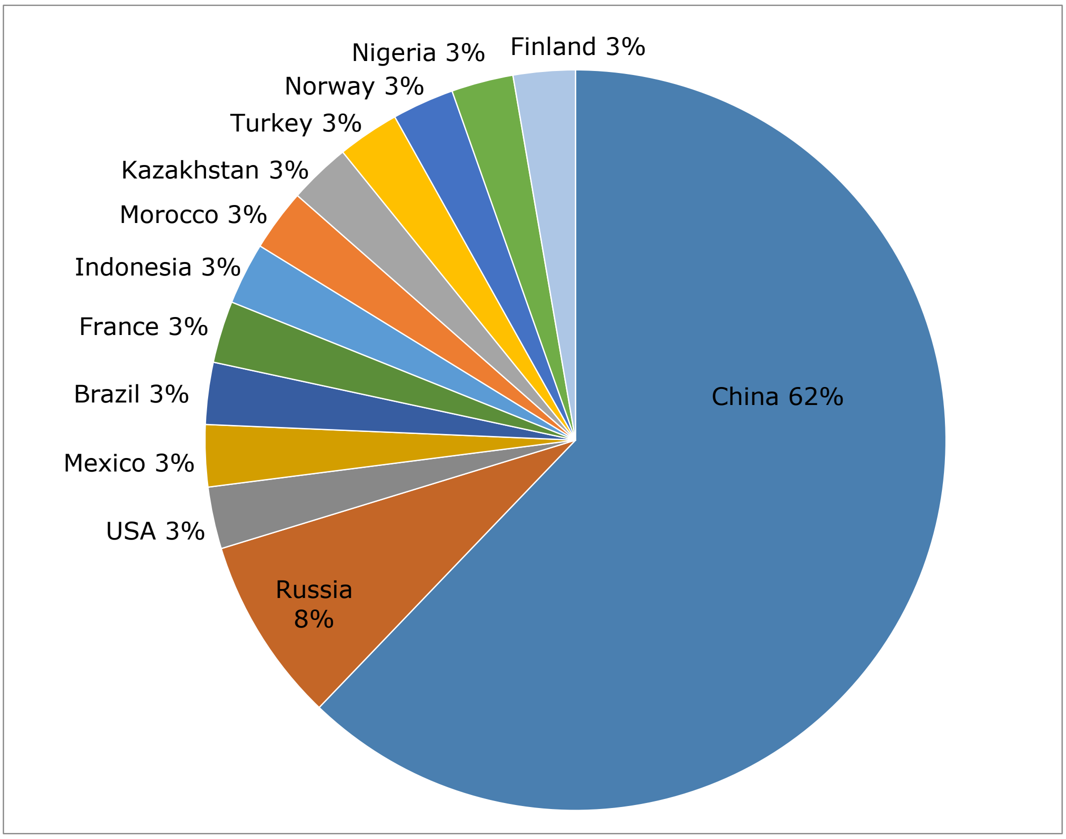


Figure D: Main EU suppliers of CRMs (based on number of CRMs supplied out of 37), average from 2010-2014



Finally, another significant finding is that for certain CRMs, despite China being the largest global supplier, other countries represent the main share in EU sourcing and not China (see following table C). The revised methodology incorporates actual sourcing to the EU, therefore allows for a more realistic picture of Europe's supply of the raw materials assessed.

Table C: CRMs with China as the largest global supplier but not as largest EU supplier

CRM	Main EU supplier	Share of EU sourcing
Fluorspar	Mexico	27%
Phosphate rock	Morocco	27%
Phosphorus	Kazakhstan	77%
Scandium	Russia	67%
Silicon metal	Norway	23%
Tungsten	Russia	50%
Vanadium	Russia	60%

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1. INTRODUCTION

1.1. CONTENT AND PURPOSE OF THE REPORT

This report serves as the revised draft final report of the study, entitled 'Study on the review of the list of Critical Raw Materials' (contract SI2.716279). This report includes information on the criticality assessments carried out on the materials covered by the 2017 exercise. The materials factsheets[16] for both critical and non-critical materials are provided in separate reports.

The present report is divided into the following chapters and annexes:

- Chapter 1 – Introduction to the report: objectives and context of critical raw materials in Europe;
- Chapter 2 – Criticality assessment approach: scope of the criticality assessments, application of the revised EC methodology to establish the list of critical raw materials for the EU, data sources used and stakeholder consultation;
- Chapter 3 – Criticality assessment outcome: results and key findings of the criticality assessments, comparison with previous assessments and limitations of the assessment results, conclusions and recommendations for further improving data quality and robustness of future exercises; and
- Annexes – Additional supporting information:
  - Annex 1: Overview of EU and international initiatives on raw materials
  - Annex 2: Overview of criticality methodologies
  - Annex 3: Stages assessed and rationale
  - Annex 4: Data sources used in the assessments
  - Annex 5: Additional details on the criticality assessment results
  - Annex 6: Summary report of the stakeholder validation workshops

1.2. OBJECTIVES OF THE REPORT

The purpose of the report is to present updated information on the list of critical raw materials for Europe, which builds upon the work carried out in the previous assessments (2011[17] and 2014[18]). The report takes into account feedback gathered from the previous and 2017 exercises, and in doing so, establishes an updated list of critical raw materials for the EU.

The objective of the criticality assessments is to assess the criticality of 78 raw materials for the EU based on the revised methodology developed by the European Commission (DG GROW and DG JRC)[19]. The operational objectives of this study were to:

- Assess the criticality of a selection of raw materials based on the revised criticality methodology.

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[16] The factsheets for critical and non-critical materials are provided in a dedicated separate report. A total of 75 factsheets (dedicated factsheets for the 26 critical raw materials, including both individual materials and groups, and remaining factsheets for the 35 non-critical raw materials) are included, covering the 78 individual candidate materials. The breakdown of the 75 factsheets are as follows:
• 70 individual material factsheets
• 1 individual factsheet for Aluminium (metal and bauxite)
• 1 individual factsheet for Phosphorus (phosphorus and phosphate rock)
• 1 individual factsheet for four heavy rare earth elements (holmium, thulium, ytterbium and lutetium)
• 1 global factsheet for the REEs group
• 1 global factsheet for the PGMs group

[17] 2011 assessment refers to the study on Critical Raw Materials for the EU published in 2010 and the Commission's Communication COM(2011)25 adopted in 2011. See: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_pl

[18] 2014 assessment refers to the study on Critical Raw Materials at EU level published in 2013 and the Commission's Communication COM(2014)297 adopted in 2014. See: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_pl

[19] Methodology for establishing the EU List of Critical Raw Materials, 2017, ISBN 978-92-79-68051-9

- Analyse the current production, key trends, trade flows and barriers of the raw materials with the aim to identify potential bottlenecks[20] and supply risks throughout the value chain. To the extent possible, data and projections are based on the reference period of the last 5 years in terms of data availability.
- Produce qualitative factsheets for all the raw materials assessed.
- Produce full datasets, calculation sheets and comprehensive list of data sources in an excel-compatible format.
- Develop proposals on how to improve the quality and availability of data sources.
- Cooperate with both EU and non-EU experts (where relevant) to improve the findings of the study.
- Collaborate with the expert group 'Ad hoc Working Group on Defining Critical Raw Materials'[21].

In particular, the 2017 assessment incorporates the following aspects:

- Analysis of a wider range of abiotic raw materials, including individual REEs and PGMs;
- Extension of the assessment to a selection of biotic raw materials;
- Updated factsheets for each of the materials assessed to include information on the supply chain, the criticality assessment and future trends; and
- Optimise data quality and transparency in the assessments and factsheets.

The present report is the result of intense cooperation between the European Commission (EC) (the Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW), the Directorate-General Joint Research Center (DG JRC)), the Ad hoc Working Group on Defining Critical Raw Materials (AHWG) [22], key industry and scientific experts and consultants from Deloitte Sustainability, the British Geological Survey (BGS), Bureau de Recherches Géologiques et Minières (BRGM) and the Netherlands Organisation for Applied Scientific Research (TNO) as partners. The Ad hoc Working Group is an expert sub-group of the Raw Materials Supply Group, comprising representatives from the Member States, from the extractive industries, intermediate users (e.g. steel), from downstream industries, from the recycling industry, from academia and from geological survey(s).

The purpose of the list of critical raw materials for the EU is to contribute to the implementation of the EU industrial policy and to ensure that European industrial competitiveness is strengthened through actions in other policy areas. This should increase the overall competitiveness of the EU economy, in line with the Commission´s aspiration of raising industry's contribution to GDP to as much as 20% by 2020. It should also help incentivise the European production of critical raw materials and facilitate the launching of new mining and recycling activities. The list is also being used to help prioritise needs and actions. For example, it serves as a supporting element when negotiating trade agreements, challenging trade distortion measures or promoting research and innovation actions. It is also worth emphasising that all raw materials, even if not classed as critical, are important for the European economy and that a given raw material and its availability to the European economy should therefore not be neglected just because it is not classed as critical.

The results of the assessment are intended to help the EC identify where supply risks of important materials for the EU economy occur, where the materials' supply to the European industry should be supported, and what the main leverages are to ensure security of supply and the performance and competitiveness of the EU economy industry.

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[20] A bottleneck is considered to be any constraint along the physical value chain that could hinder EU industrial operations dependent on the raw materials covered by this project.

[21] The consultants have provided scientific and technical support to the Commission throughout the course of the study, incorporated relevant comments and feedback, provided updates on the advancement of the work, and presented the findings of the assessment in the final report of the study on "Critical Raw Materials for the EU" and the publication of the new list of Critical Raw Materials.

[22] The AHWG on Defining Critical Raw Materials is a sub-group of the Raw Materials Supply Group expert group. The list of its members and observers is available here: http://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupDetail&groupID=1353

1.3. THE IMPORTANCE OF RAW MATERIALS IN EUROPE

Whereas the supply security of crude oil and gas has raised concerns among politicians and economic actors for many years, it is only in the last decade that the growing challenge of securing access to metals and minerals needed for economic production has received the same public attention. Raw materials are not only essential for the production of a broad range of goods and services used in everyday life, but also for the development of emerging innovations, which are notably necessary for the development of more eco-efficient technologies and globally competitive products.

This dependence on metals and minerals to sustain businesses and the economy is particularly true for the EU, where about 30 million jobs[23] are directly reliant on access to raw materials.

The importance of critical raw materials for the EU:

- ***Link to industry*** *- non-energy raw materials are linked to all industries across all supply chain stages.*
- ***Modern technology*** *- technological progress and quality of life are reliant on access to a growing number of raw materials. For example, a smartphone might contain up to 50 different kinds of metals, all of which contribute to its small size, light weight and functionality.*
- ***Environment*** *– raw materials are closely linked to clean technologies. They are irreplaceable in solar panels, wind turbines, electric vehicles, and energy efficient lighting.*[24]

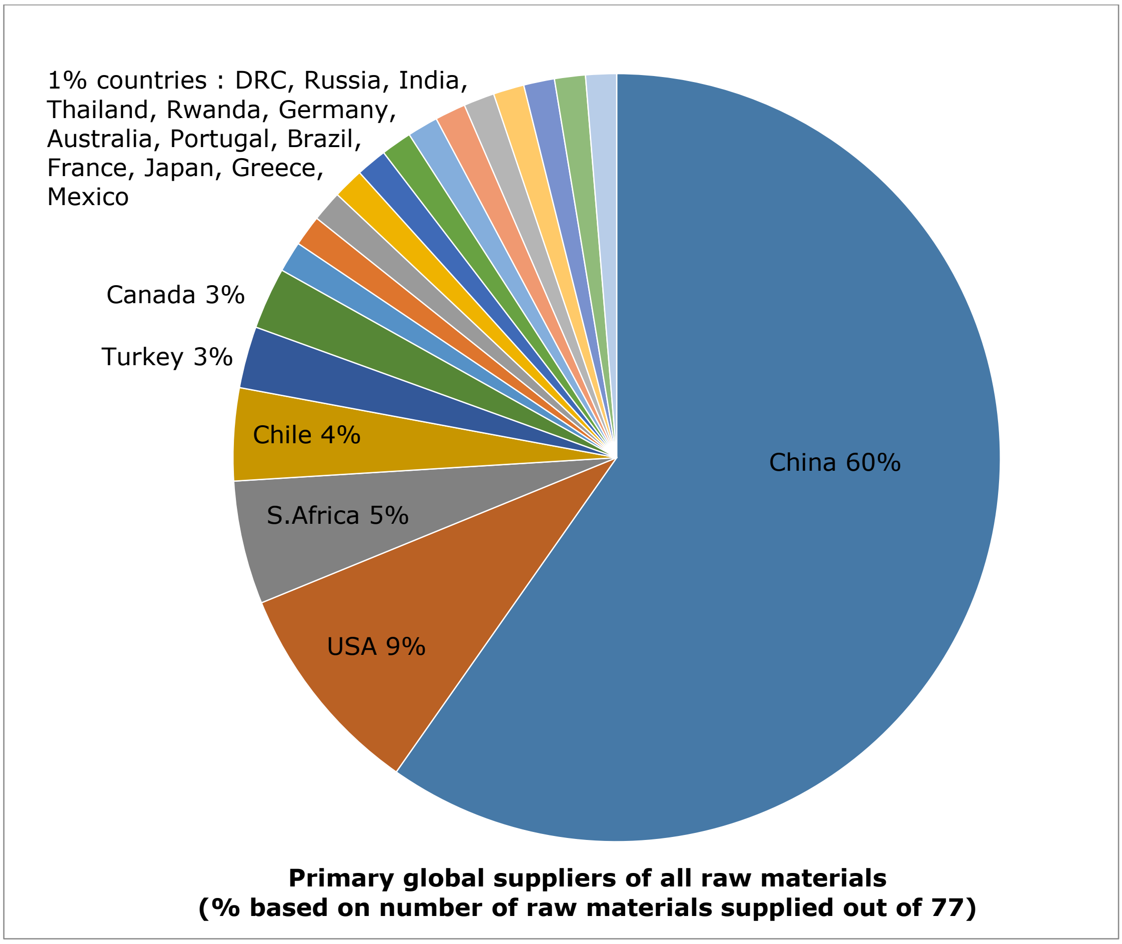
In Europe, the manufacturing industry (i.e. the manufacture of end products and applications) and the refining industry (metallurgy, etc.), are more important than the extractive industry (e.g. mining activities). The value chain of raw materials is not fully and homogeneously covered by the European industry, with a pronounced imbalance between the upstream steps (extraction / harvesting) and the downstream steps (manufacturing and use). The need for primary materials, such as ores and concentrates, and also for processed and refined materials is huge and crucial for the wealth -even the survival- of the European industries and their associated jobs and economy.

However, actually, very little extraction of non-energy raw materials occurs within European Member States, with the majority of ore and concentrates or refined materials of metals and minerals being produced and supplied from non-European countries.

The figure below represents the main global producers of raw materials (in terms of number of raw materials for which the country is the main producer, not in terms of tonnage). China clearly dominates, with 46 raw materials (of 77 assessed[25]) being mainly extracted in China. The USA is also an important player with domination for the production of 9% of raw materials assessed.

[23] https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_pl
[24] https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_pl
[25] Figures are based on the assessment results of 77 individual materials, rather than 78 due to the exclusion of sapele wood. Sapele wood was excluded from the analysis of primary global supply because it was not clear from available public EU trade data, which country(s) is the major global supplier. Several producing countries of sapele wood were identified such as Cameroon, Democratic Republic of Congo (Kinshasa), the Republic of Congo (Brazzaville), the Central African Republic, Ivory coast and Gabon, however without a clear indication of the overall shares coming from these producing countries.

Figure 1: Main global suppliers of materials assessed, (based on number of raw materials supplied out of 77), average from 2010-2014[26]



For many raw materials, the EU is absent from the upstream steps of the value chain, with no extraction of antimony, beryllium, borates, gold, magnesium, molybdenum, niobium, PGMs, phosphorus, rare earths, scandium, tantalum, titanium and vanadium. This may be due either to the limited knowledge of the availability of those materials in the EU, or to economic and societal factors that negatively affect exploration (for deposit discovery and characterisation, estimation of resources and reserves) or extraction, (closure of existing mines, reluctance to open new mines, etc.). In addition to abiotic raw materials, some biotic materials such as natural rubber, sapele wood and natural teak wood are also grown and harvested entirely outside the EU. To access these raw materials, the European Member States have no other choice than to import the ores and concentrates or the refined materials from other countries to feed their industries and markets.

The only raw materials for which an EU Member State is the main global producer are hafnium (France), natural cork (Portugal) and perlite (Greece). For some raw materials such as aggregates, feldspar, gypsum, hafnium, indium, kaolin clay, limestone (high purity), magnesite, natural cork, perlite, silica sand, sulphur and tellurium, the Member States produce enough primary materials to avoid significant extra-European imports. However, this situation is fairly uncommon, with the EU being dependent on foreign imports for more than 80% of the raw materials needed for its industry and economy.

[26] Figures are based on the assessment results of 77 individual materials, rather than 78 due to the exclusion of sapele wood. Sapele wood was excluded from the analysis of primary global supply because it was not clear from available public EU trade data, which country(s) is the major global supplier. Several producing countries of sapele wood were identified such as Cameroon, Democratic Republic of Congo (Kinshasa), the Republic of Congo (Brazzaville), the Central African Republic, Ivory Coast and Gabon, however without a clear indication of the overall shares coming from these producing countries.

1.4. THE CHALLENGE OF CRITICAL RAW MATERIALS IN EUROPE

The accelerating technological innovation cycles and the rapid growth of emerging economies have led to a steadily increasing demand for these highly sought after metals and minerals. Securing access to a stable supply of such critical raw materials has become a major challenge for national and regional economies with limited indigenous natural resources, such as the EU economy, which is heavily dependent on imported supplies of many minerals and metals needed by industry.

The fact that many of these materials are currently only extracted in a few countries, with China being the leading supplier as well as consumer of several important raw materials e.g. antimony, bismuth, magnesium, REEs, etc. increases the risk of supply shortages and supply vulnerability along the value chain. For example, the production of unwrought antimony metal is heavily concentrated, with China and Vietnam accounting for about 98 per cent of global production.

The likelihood of supply disruption is further increased by the fact that the processing, smelting and refining of many metals are also restricted to a small number of countries. Some producing countries strictly control and limit the export of raw materials in order to safeguard them for their national industries. For example, in May 2015, China ended its rare-earth export quotas, removed export tariffs, but began to impose resource taxes on rare earths based on sales value instead of production quantity. Similarly, China applies export taxes and quotas for antimony. During the 2010–2014 period, the EU imported just over 1,600 tonnes of antimony ores and concentrates; however, during the same period the EU imported almost three times as much antimony trioxide (ca. 5,900 tonnes) and more than ten times as much unwrought antimony metal (ca. 18,500 tonnes). The trade of antimony trioxide and unwrought antimony metal is dominated by China, which accounts for almost 65 per cent of European antimony trioxide imports and almost 90 per cent of European unwrought antimony metal imports. Since 2010 imports of unwrought antimony have generally decreased from a high of ca. 23,000 tonnes in 2010 to ca. 17,000 tonnes in 2014. This decrease in import volumes is likely due to restriction of Chinese supply in 2010 and 2011, due to mine closures and export quotas.

In addition, supply restrictions are not only due to source countries, but all the actors of the supply chain have an influence on the supply conditions and price volatility. Moreover, mine production of minerals and metals relies on large scale investment projects, which can take many years to implement, and, therefore, cannot react quickly to short term changes in demand, or are vulnerable to market manipulations by established suppliers trying to hamper emergent mining operations.

These factors together lead to a risk of supply shortages for various metals and minerals in the EU. The resources known to exist in the EU are not capable of providing adequate and timely supplies of these materials to meet domestic demand. The impact of raw materials supply disruption could therefore be loss of competitive economic activity in the EU and in some specific cases reduced availability of certain (strategic) final products. Moreover, market prices and investment costs compel businesses to be prudent or protective when it comes to guaranteeing a stable price level for European manufacturing. For example, REEs prices varied greatly in recent years. In 2010-2011 a 12-fold increase was observed, mainly triggered by a strong reduction of Chinese export quotas in a period of high demand. However, by early 2012, prices had fallen by about half and continued on a downward trend until 2016[27].

1.5. ADDRESSING CRITICAL RAW MATERIAL CHALLENGES

The Raw Materials Initiative and the Identification of Critical Raw Materials

To address the growing concern of securing valuable raw materials for the EU economy, the European Commission launched the European Raw Materials Initiative[28] in 2008. It is

[27] Dera (2016) Preismonitor November 2016
[28] https://ec.europa.eu/growth/sectors/raw-materials/policy-strategy_en

an integrated strategy that establishes targeted measures to secure and improve access to raw materials for the EU:

- Fair and sustainable supply of raw materials from international markets;
- Fostering sustainable supply within the EU; and
- Boosting resource efficiency and promoting recycling.

For the successful implementation of EU policies in the field of raw materials, there is a need to:

- Identify the raw materials that are key for the European economy; and
- Have accurate information on the flows of these materials in the EU.

As such, one of the priority actions of the European Raw Materials Initiative was to establish a list of critical non-energy raw materials (CRMs) at EU level.

CRMs combine **a high economic importance** to the EU with **a high risk associated with their supply**. In this context, the European Commission established an Ad Hoc Working Group on Defining Critical Raw Materials (AHWG) in 2009 as support and advisory group in identifying the non-energy raw materials considered as critical for the EU, based on their economic importance and their risk of supply interruption. The first report of this group, published in 2010, 'Critical raw materials for the EU', among its many valuable conclusions, suggested that the list of critical raw materials should be updated every three years. Accordingly, in its Communication 'Tackling the challenges in commodity markets and on raw materials' (COM(2011)25), the Commission committed to undertake a regular update of the list at least every three years. A revision of the first assessment was carried out in 2013 under the Competitiveness and Innovation Framework Programme (CIP Programme) and resulted in a publication of the report of the study on 'Critical Raw Materials at EU level'[29]. The 2017 assessment addresses the third assessment of critical raw materials for the EU.

The methodology to identify CRMs

The identification of critical raw materials for the EU is based on the updated methodology developed by the European Commission, in cooperation with the Ad hoc Working Group on Defining Critical Raw Materials (AHWG). Based on the methodology used in the previous assessments carried out in 2011 and 2014 DG GROW commissioned the DG Joint Research Centre (DG JRC) in 2015 to undertake a study on improving the assessment methodology used to define critical raw materials for the EU. This study resulted in a refined methodology for assessing the criticality of raw materials, which is applied in the present assessment. The revised EC methodology introduced methodological improvements while keeping maximum possible comparability of the results with the previous assessments. The two main high-level components of criticality are retained:

- **Economic Importance (EI)** - calculated based on the importance of a given material in the EU end-use applications and performance of its substitutes in these applications.
- **Supply Risk (SR)** - calculated based on factors that measure the risk of a disruption in supply of a given material (e.g. supply mix and import reliance, governance performance measured by the World Governance Indicators, trade restrictions and agreements, existence and criticality of substitutes)

[29] http://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical/index_en.htm

2. CRITICALITY ASSESSMENT APPROACH

2.1 SCOPE & MATERIALS COVERED

The scope of the criticality assessments includes 78 individual materials as listed in Table 1. To ensure coherence with the previous assessments carried out in 2011 and 2014, the same materials were assessed (with the exception of osmium[30]). This allows for the identification of any key materials that may move from the non-critical to critical status or vice versa.

Table 1: List of materials/groupings covered in the 2017 assessment

Legend:	
Green boxes =	Materials covered in 2014 but not in the 2011 assessments
Orange boxes =	New materials covered in the 2017 assessment

Individual abiotic materials		
Aggregates	Hafnium	Rhenium
Aluminium	Helium	Scandium
Antimony	Indium	Selenium
Baryte	Iron Ore	Sulphur
Bauxite	Lead	Potash
Bentonite	Limestone	Silica Sand
Beryllium	Gold	Silicon Metal
Bismuth	Gypsum	Silver
Boron (Borates)	Lithium	Talc
Chromium	Magnesite	Tantalum
Kaolin clay	Magnesium	Tellurium
Cobalt	Manganese	Tin
Coking coal	Molybdenum	Titanium
Copper	Natural Graphite	Tungsten
Diatomite	Nickel	Vanadium
Feldspar	Niobium	Zinc
Fluorspar	Perlite	
Gallium	Phosphorus	
Germanium	Phosphate rock	
Platinum group metals (PGMs)		
Iridium	Platinum	Ruthenium
Palladium	Rhodium	
Rare earth elements (REEs)		
LREEs	HREEs	
Cerium	Dysprosium	Lutetium
Lanthanum	Erbium	Terbium
Neodymium	Europium	Thulium
Praseodymium	Gadolinium	Ytterbium
Samarium	Holmium	Yttrium
Biotic materials		
Natural Rubber	Natural cork	
Sapele wood	Natural Teak wood	

[30] Osmium was nominally assessed in the previous assessments as part of the PGM group; however it cannot be assessed in its own right because of the lack of data specific to osmium. It was, therefore, excluded from the 2017 exercise. In the 2017 assessment, complementary information on osmium is provided in the PGMs factsheet, where relevant.

In addition to covering the same materials as the previous assessments, the candidate materials assessed in the 2017 exercise also include nine new materials (six new abiotic and three new biotic materials[31]) with the aim of widening the scope of the materials covered. The final selection of candidate materials assessed was based on expertise from and several exchanges between the consultant's expertise and feedback from the European Commission (DG GROW and DG JRC), the AHWG and industry experts[32].

In Table 1, materials highlighted in green were assessed in 2014 but not in 2011. The materials highlighted in orange are the "new" materials assessed in 2017 (9 new materials, not assessed in the 2011 or 2014 assessments). The materials are grouped into five main categories as shown in order to ensure consistency with the previous assessments. As such, the rare earth elements (REEs) and platinum group metals (PGMs) are further divided into the following categories:

- Light rare earth elements (LREEs): cerium, lanthanum, neodymium, praseodymium and samarium;
- Heavy rare earth elements (HREEs): dysprosium, erbium, europium, gadolinium, holmium, lutetium, terbium, thulium, ytterbium yttrium;
- Platinum group metals (PGMs): iridium, platinum, palladium, rhodium, ruthenium (excluding osmium).

2.1.1 Bottleneck screening

The initial bottleneck screening exercises were applied to all of the candidate raw materials.

In principle, the mining/harvesting stage of a candidate raw material should be considered as the bottleneck, unless there are duly documented arguments to perform the assessment at the processing/refining stage, e.g. lack of quality data (to be reported and described in the raw materials factsheets).

Provided that data is available for both stages, if there is a significant difference in the country distribution of mining/harvesting versus processing/refining, the calculation of the Supply Risk should be performed at both stages. The stage with higher SR score should be selected.

Data on global supply and on imports and exports to and from EU28 are to be used.

In addition to identifying the stage with the highest Supply Risk, the bottleneck selection must also take into account the availability of data i.e. whether data exists on both global supply and EU sourcing of the material in question. For the majority of the materials (50 out of 78 individual raw materials), the criticality assessments are carried out on the ores and concentrates (referred to as the extraction stage). The assessments for the remaining materials (28 out of 78 individual raw materials) were carried out at the processing/refining stage. In the case of aluminium, phosphorus and magnesium, however, a different approach was taken as the criticality assessments were carried out on both stages for these materials due to the strong possibility of significant bottlenecks at both stages of the materials' value chain. Annex 3 provides further information on which stage is assessed for each material and the rationale.

2.1.2 Time coverage

The reference period for the data used in the criticality assessments is based on the most recent 5-year average (i.e. 2010-2014, where possible). Exceptions to this are clearly stated and justified.

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[31] Aggregates, Bismuth, Helium, Lead, Phosphorus, Sulphur, Natural cork, Natural Teak wood and Sapele wood.
[32] The proposed list of materials to be assessed was presented to AHWG members meeting on 8 June 2016.

2.2 APPLICATION OF THE REVISED EC CRITICALITY METHODOLOGY

The purpose of the criticality assessments is to assess the criticality of the materials based on the revised European Commission's criticality methodology[33] (Figure 2). For comparability and coherence, the approach used for the analyses carried out in the 2017 assessment aims to be as closely comparable to the previous two assessments as possible. The first and second criticality assessments carried out in 2011 and 2014 used the same methodology including the same indicators and thresholds. However, several important modifications are included in the revised methodology.

As in the previous version of the EC criticality methodology, two main parameters form the basis of the updated methodology: Economic Importance (EI) and Supply Risk (SR), which are used to determine the criticality of the material. However, there are several new elements of the revised criticality methodology that are important to consider when comparing the results across the three assessments. The key aspects that have been changed in the revised EC criticality methodology include:

- Refined and more detailed economic allocation of raw materials to economic sectors based on the material-specific end-use applications and their corresponding NACE Rev. 2 2-digit level sectors.
- Assessment of substitution in the Economic Importance parameter in addition to the Supply Risk and refinement of the methodology to calculate substitution, considering only proven and readily available substitutes: in the previous criticality assessments, substitution was estimated as substitutability and only addressed within the analysis of the Supply Risk.
- Adoption of a systematic supply chain bottleneck approach, including initial bottleneck screening to determine which stage of the material (extraction or processing) presents the highest Supply Risks for the EU, taking into account the availability and quality of data.
- Inclusion of both the share of global supplier countries of the material and the actual share of supply to the EU in the Supply Risk parameter: the previous criticality assessments estimated the Supply Risk based on the mix of global supplier countries only.
- Inclusion of import reliance i.e. import dependency – a parameter used to balance the risks linked to the global supply mix and the actual EU sourcing mix (domestic production plus imports).
- Incorporation of export restrictions and trade agreements in the Supply Risk parameter.
- Refined methodology and data priority to calculate End-of-Life Recycling Input Rate (EOL-RIR).

Figure 2 shows the structure of the revised criticality methodology and the different indicators used to calculate Economic Importance and Supply Risk. Further details of the revised EC methodology for assessing criticality is provided in the report, "Assessment of the Methodology on the List of Critical Raw Materials" (EC, 2017).[34]

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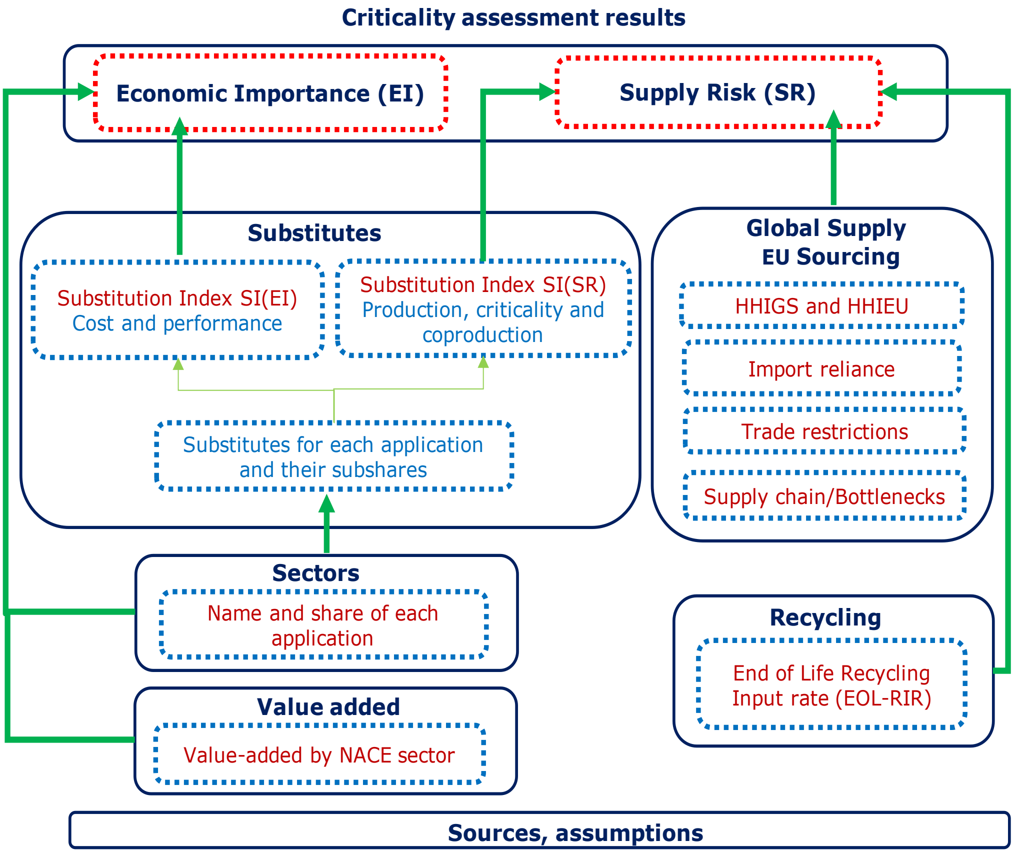
[33] Methodology for establishing the EU List of Critical Raw Materials, 2017, ISBN 978-92-79-68051-9
[34] Methodology for establishing the EU List of Critical Raw Materials, 2017, ISBN 978-92-79-68051-9

Figure 2: Overall structure of the revised criticality methodology



2.2.1 Coherence of criticality assessment results

The criticality assessments were split and carried out by the four organisations that make up the team of consultants (Deloitte, BRGM, BGS and TNO).Cross-checks were carried out to verify that the revised methodology was implemented in a consistent way across all of the assessments to ensure the coherence of the assessment results. The following cross-check actions were taken:

- Development of guidance notes on how to use the assessment tools, including regular updates concerning key decisions made on approaches used;
- Regular conference calls and email exchanges; and
- Internal cross-checking review of the assessments.

2.3 DATA COLLECTION AND SOURCES

The availability and quality of the data required to complete the criticality assessments for the materials covered by this study are essential to ensure the robustness and comparability of the results and maximise the quality of the outputs of the study. As such, a detailed literature review and stakeholder consultation were carried out.

An initial detailed list of data sources for the materials was provided by the JRC. The consultants carried out a first screening of the literature and complemented it with additional literature, where relevant. A detailed list of the sources used in the criticality assessments are provided in each of the material factsheets.

The revised criticality methodology proposes a data hierarchy that prioritises, first, official EU data over that from trade/industry associations and other special interest groups. Where possible, it also prioritises the use of data for Europe over datasets that relate to the whole world e.g. global data. In other words, European data shall receive priority over non-EU data. Data from organisations such as the United States Geological Survey (USGS) are used in the cases where no other comparable sources exist or where the alternatives are not of acceptable quality. Data from trade associations may also be considered in the absence of other data, under the pretext that such data can be shared and published.

Regarding the overall availability and quality of the data sources, in general, there is good public data availability for global supply (EU trade data and data from EU geological surveys such as BGS) and applications for the majority of materials. However, there are some materials that are more difficult to deal with because of material inconsistencies between world production and EU sourcing data. In addition, there is a general difficulty obtaining public data on the shares of applications of materials, as well as their substitutes. In many cases, stakeholders were consulted to validate or provide additional inputs regarding the data used for the assessments.

During the early stages of the project, the European Commission provided guidance on assessing the quality of the data used in the assessments. Table 2 below presents the scoring matrix used based on the recommendations of the Commission to assess the data quality of the information on EU Supply Risk. The scoring matrix defines three main criteria using a scoring scale of 1 to 3 (from lowest to highest in terms of data quality). The overall score of the data quality used for the calculation of Supply Risk was characterised as: limited, satisfactory or very strong coverage based on the individual scores of the three main criteria. Annex 4 lists the data sources used in each of the material criticality assessments. Sources used in the factsheets are provided at the end of each material or group factsheet (see separate dedicated report on critical and non-critical materials factsheets). Additional details on the quality of the data sources are provided in the individual material factsheets and in the EC's Background Report on the Assessment of the Methodology on the list of Critical Raw Materials[35].

Table 2: Scoring matrix to evaluate quality of EU supply data

Criteria	Limited coverage	Satisfactory coverage	Very strong coverage
	1	2	3
Geographic coverage	Data is not available at EU level	Data is partly available at EU level	Data is available at EU level
Time coverage	Data available only for a few years	Data with no meaningful time series due to poor regularity of updates	Data available for time series and updated at regular intervals
Source type	Private/corporate data	Public source of data (except from several justified sources)	Public source

2.4 STAKEHOLDER CONSULTATION

In addition to the use of data sources described in the previous section, the involvement of stakeholders was also of utmost importance in order to maximise the quality of the outputs of the study and ensuring transparency. By involving, directly after the approval of the inception report, all relevant industry stakeholders and members of the AHWG, the assessment results reflect the body of knowledge readily available in throughout the EU on the topic of raw materials.

The aim of the stakeholder consultation was to ensure that industrial and scientific stakeholders are given the opportunity to provide their expert feedback on specific materials and eventually improve the results of Work package 1 (Data Inventory and Criticality Assessment). Secondly, consultation with stakeholders ensures that the outcomes of this study, especially the conclusions, are optimally validated and subsequently disseminated and applied, where relevant.

In addition to bilateral exchanges during the data collection for the criticality assessment, a key aspect of the overall stakeholder consultation approach includes also the

[35] JRC technical report (2017): ASSESSMENT OF THE METHODOLOGY FOR ESTABLISHING THE EU LIST OF CRITICAL RAW MATERIALS: «Background Report», ISBN 978-92-79-69612-1, available at the JRC Science Hub: https://ec.europa.eu/jrc

stakeholder validation workshops. These meetings were aimed to review the data used for the purpose of criticality calculations and information used in the factsheets. The stakeholder validation workshops also provided the consultants with the opportunity to present the data sources used and contributions delivered by stakeholders as well as discuss any recommendations to improve results, where relevant.

Three stakeholder validation workshops took place on 25, 28 October and 7 November 2016 at the TNO conference centre located in Brussels. The aim of these stakeholder validation workshops was not to discuss the revised criticality methodology, which had been validated by the AHWG and the Commission, but to discuss in detail the criticality calculations for each of the materials covered during each workshop and to review and validate the data used in criticality assessments.

Several follow-up actions were carried out after the validation workshops, which included a summary of key stakeholder feedback received from the validation workshops and follow-up with individual stakeholders who indicated willingness and capability to contribute relevant data and input for the criticality assessments. Based on this feedback, some of the criticality assessments were validated while others were updated with more accurate data. A summary report of the stakeholder validation workshops is provided in Annex 6 and includes details of the preparation and organisation of the workshops as well as the list of participants.

3. CRITICALITY ASSESSMENT OUTCOME

3.1 CRITICALITY ASSESSMENT RESULTS

The criticality assessment results for the 78 individual candidate materials covered by the assessment are summarised in Table 3. The findings presented reflect relevant feedback received from the Commission, the AHWG and expert input from the stakeholder validation workshops. Analysis of the results is provided in the following sections.

Table 3 provides the scaled results of the Supply Risk (SR), Economic Importance (EI), Import Reliance (IR) and End-of-life Recycling Input Rate (EOL-RIR) for each of the candidate materials as well as the life cycle stage assessed. Results are rounded to one decimal point to enhance clarity of the analysis. The table also indicates the supply data that was used (e.g. global supply and / or EU sourcing) in the calculations for Supply Risk This aspect is further discussed in section 3.4. Regarding the materials with zero percent import reliance results, it should be noted that the actual figure for some materials reflects a negative import reliance result. However, to facilitate the analysis of the results, all negative import reliance figures have been changed to 0% in the table below. Further details of negative import reliance results are provided in Table 13 (see section 3.4.4). Annex 5 provides additional details of the assessment results, including substitution indexes and $HHI_{(WGI)}$ parameters.

Table 3: Criticality assessment results (78 individual materials, scaled results)

Legend:

PGMs	Iridium, palladium, platinum, rhodium, ruthenium
LREEs	Cerium, lanthanum, neodymium, praseodymium and samarium
HREEs	Dysprosium, erbium, europium, gadolinium, holmium, lutetium, terbium, thulium, ytterbium, yttrium
EOL-RIR	End-of-life Recycling Input Rate
Supply data used	Indicates whether the Supply Risk calculation uses EU sourcing (EU only), global supply only (GS) or both (GS + EU)[36]

Material	Stage assessed	Supply Risk	Economic Importance	Import reliance (%)	EoL-RIR (%)	Supply used in SR calc.
Aggregates	Extraction	0.2	2.3	0	8	EUS only
Aluminium	Processing	0.5	6.5	64	12	GS + EUS
Antimony	Processing	4.3	4.3	100	28	GS + EUS
Baryte	Extraction	1.6	2.9	80	1	GS + EUS
Bauxite	Extraction	2.0	2.6	85	0	GS + EUS
Bentonite	Extraction	0.2	2.1	14	50	GS + EUS
Beryllium	Extraction	2.4	3.9	N/A	0	GS only
Bismuth	Processing	3.8	3.6	100	1	GS + EUS
Borate	Extraction	3.0	3.1	100	0	GS + EUS
Cerium	Extraction	5.7	3.2	100	1	GS + EUS
Chromium	Processing	0.9	6.8	75	21	GS + EUS
Cobalt	Extraction	1.6	5.7	32	0	GS + EUS
Coking coal	Processing	1.0	2.3	63	0	GS + EUS
Copper	Extraction	0.2	4.7	82	55	GS + EUS
Diatomite	Extraction	0.3	3.8	16	0	GS + EUS

[36] By default, both EU and global sources are used in the calculation. In case only either EU or global supply was used, data availability prevented to use both sourcing types.

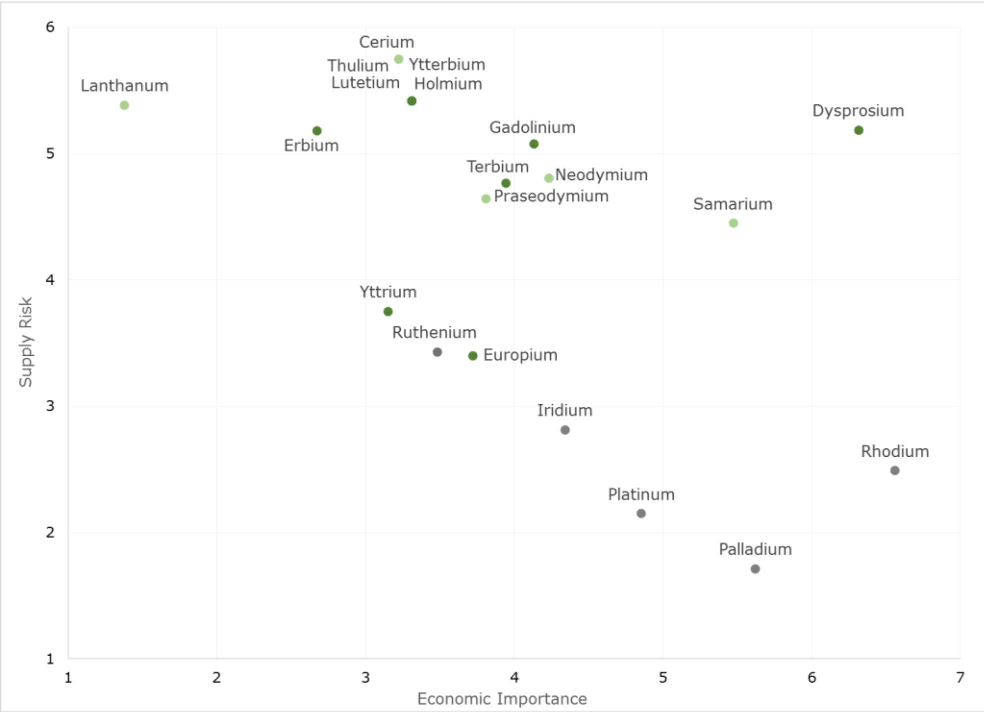
Material	Stage assessed	Supply Risk	Economic Importance	Import reliance (%)	EoL-RIR (%)	Supply used in SR calc.
Dysprosium	Extraction	5.2	6.3	100	0	GS + EUS
Erbium	Extraction	5.2	2.7	100	1	GS + EUS
Europium	Extraction	3.4	3.7	100	38	GS + EUS
Feldspar	Extraction	0.6	2.4	0	10	GS + EUS
Fluorspar	Extraction	1.3	4.2	70	1	GS + EUS
Gadolinium	Extraction	5.1	4.1	100	1	GS + EUS
Gallium	Processing	1.4	3.2	34	0	GS + EUS
Germanium	Processing	1.9	3.5	64	2	GS + EUS
Gold	Extraction	0.2	2.0	100	20	GS only
Gypsum	Extraction	0.5	2.2	0	1	GS + EUS
Hafnium	Processing	1.3	4.2	9	1	GS + EUS
Helium	Processing	1.6	2.8	96	1	GS only
Holmium	Extraction	5.4	3.3	100	1	GS + EUS
Indium	Processing	2.4	3.1	0	0	GS only
Iridium	Processing	2.8	4.3	100	14	GS only
Iron ore	Extraction	0.8	6.2	74	24	GS + EUS
Kaolin clay	Extraction	0.5	2.3	5	0	GS + EUS
Lanthanum	Extraction	5.4	1.4	100	1	GS + EUS
Lead	Extraction	0.1	3.7	18	75	GS + EUS
Limestone	Extraction	0.1	2.5	3	58	GS + EUS
Lithium	Processing	1.0	2.4	86	0	GS + EUS
Lutetium	Extraction	5.4	3.3	100	1	GS + EUS
Magnesite	Extraction	0.7	3.7	1	2	GS + EUS
Magnesium	Processing	4.0	7.1	100	9	GS + EUS
Manganese	Extraction	0.9	6.1	89	12	GS + EUS
Molybdenum	Extraction	0.9	5.2	100	30	GS + EUS
Natural cork	Extraction	1.1	1.5	0	8	EUS only
Natural graphite	Extraction	2.9	2.9	99	3	GS + EUS
Natural Rubber	Extraction	1.0	5.4	100	1	GS + EUS
Natural Teak wood	Extraction	0.9	2.0	100	0	GS only
Neodymium	Extraction	4.8	4.2	100	1	GS + EUS
Nickel	Processing	0.3	4.8	59	34	GS + EUS
Niobium	Processing	3.1	4.8	100	0	GS + EUS
Palladium	Processing	1.7	5.6	100	10	GS only
Perlite	Extraction	0.4	2.1	0	42	GS only
Phosphate rock	Extraction	1.0	5.1	88	17	GS + EUS
Phosphorus	Processing	4.1	4.4	100	0	EUS only
Platinum	Processing	2.1	4.9	98	11	GS only
Potash	Extraction	0.6	4.8	23	0	GS only
Praseodymium	Extraction	4.6	3.8	100	10	GS + EUS
Rhenium	Processing	1.0	2.0	18	50	GS + EUS
Rhodium	Processing	2.5	6.6	100	24	GS only
Ruthenium	Processing	3.4	3.5	100	11	GS only
Samarium	Extraction	4.5	5.5	100	1	GS + EUS
Sapele wood	Extraction	1.4	1.3	100	15	EUS only
Scandium	Processing	2.9	3.7	100	0	GS only
Selenium	Processing	0.4	4.5	17	1	GS + EUS
Silica sand	Extraction	0.3	2.6	0	0	EUS only
Silicon metal	Processing	1.0	3.8	64	0	GS + EUS
Silver	Extraction	0.5	3.8	80	55	GS + EUS

Material	Stage assessed	Supply Risk	Economic Importance	Import reliance (%)	EoL-RIR (%)	Supply used in SR calc.
Sulphur	Processing	0.6	4.6	0	5	GS + EUS
Talc	Extraction	0.4	3.0	13	5	GS + EUS
Tantalum	Extraction	1.0	3.9	100	1	GS only
Tellurium	Processing	0.7	3.4	100	1	GS + EUS
Terbium	Extraction	4.8	3.9	100	6	GS + EUS
Thulium	Extraction	5.4	3.3	100	1	GS + EUS
Tin	Processing	0.8	4.4	78	32	GS + EUS
Titanium	Extraction	0.3	4.3	100	19	GS + EUS
Tungsten	Extraction	1.8	7.3	44	42	GS + EUS
Vanadium	Processing	1.6	3.7	84	44	GS + EUS
Ytterbium	Extraction	5.4	3.3	100	1	GS + EUS
Yttrium	Extraction	3.8	3.2	100	31	GS + EUS
Zinc	Extraction	0.3	4.5	61	31	GS + EUS

Group averages	Stage assessed	Supply Risk	Economic Importance	Import reliance (%)	EOL-RIR (%)	Supply data in SR
LREEs	Extraction	5.0	3.6	100	3	GS + EUS
HREEs	Extraction	4.9	3.7	100	8	
PGMs	Processing	2.5	5.0	99.6	14	GS only

Figure 3 shows the individual results for the grouped materials (see also Table 21 in Annex 5).

Figure 3: SR and EI results for the grouped materials: PGMs, LREEs and HREEs



The Supply Risk and Economic Importance results for all the 78 individual raw materials are presented graphically in Figure 4. Figure 5 presents the individual results for all non-grouped materials as well as the average SR and EI scores for the PGMs, LREEs and HREEs groups. In Figure 5, the grey dot represents the average scores for the platinum group metals (PGMs), the light green dot indicates the average result for the light rare earth metals (LREEs) and the dark green dot presents the heavy rare earth metals (HREEs).

Figure 4: SR and EI results, 78 individual materials

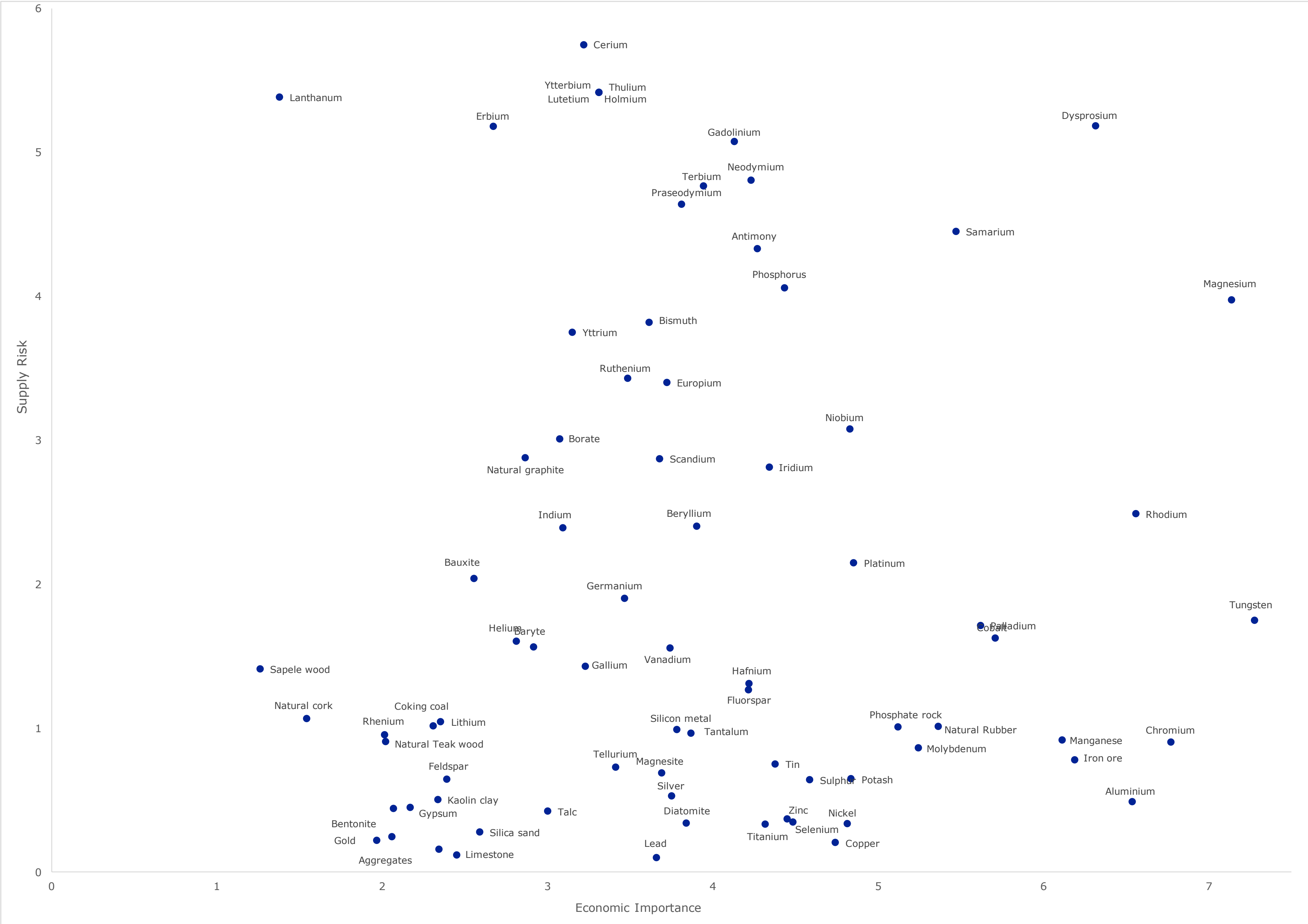
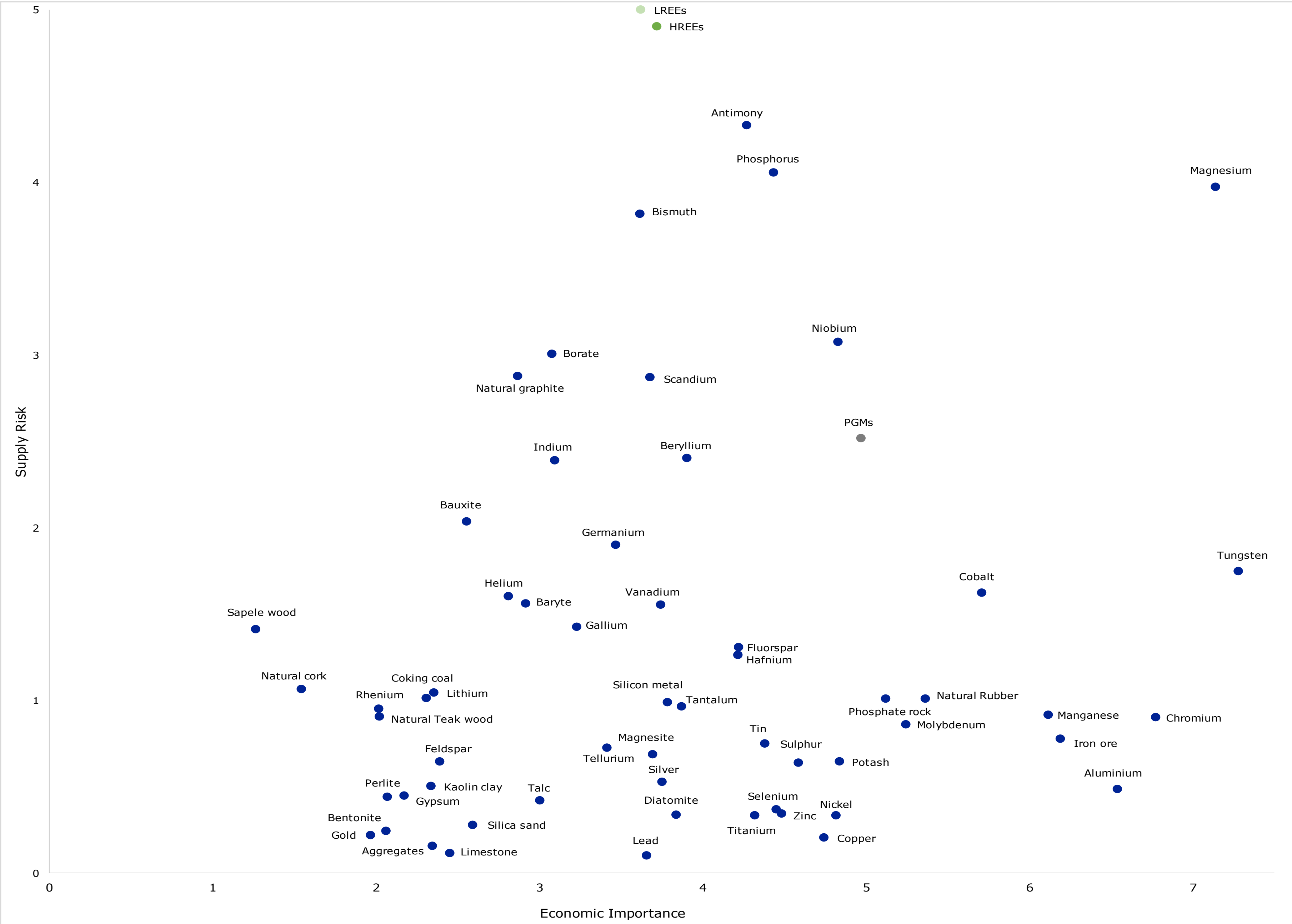


Figure 5: SR and EI results for individual non-grouped and grouped materials (HREEs, LREEs and PGMs)



3.2 LIST OF 2017 CRITICAL RAW MATERIALS (CRMs)

Of the 61 candidate raw materials assessed (58 individual and 3 grouped materials), the following 26 raw materials and groups of raw materials were identified as critical.

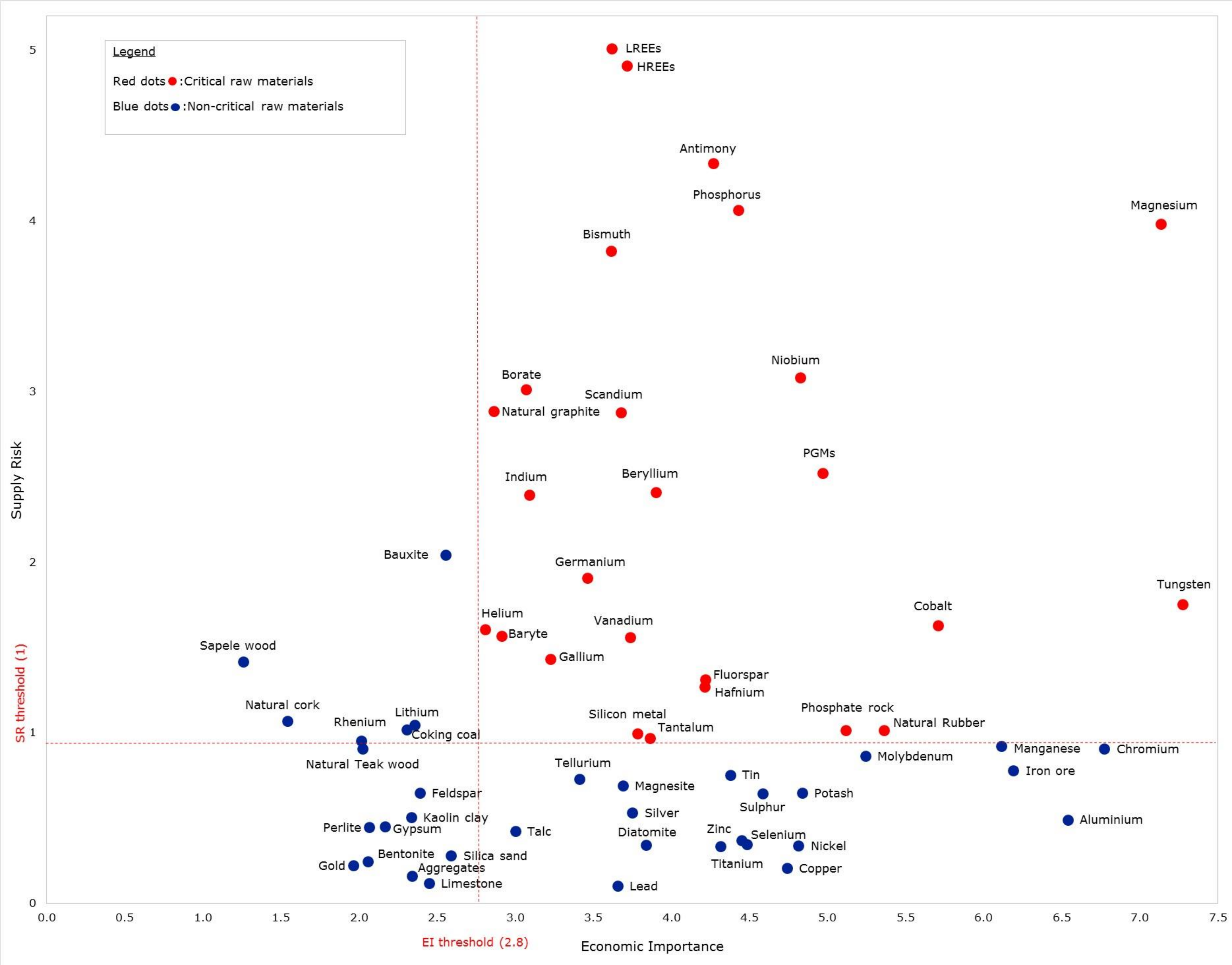
Table 4: 2017 Critical raw materials for the EU

2017 CRMs (26)			
Antimony	Gallium	Magnesium	Scandium
Baryte	Germanium	Natural graphite	Silicon metal
Beryllium	Hafnium	Natural Rubber	Tantalum
Bismuth	Helium	Niobium	Tungsten
Borate	HREEs	PGMs	Vanadium
Cobalt	Indium	Phosphate rock	
Fluorspar	LREEs	Phosphorus	

The criticality of a raw material is determined by comparing the Economic Importance (EI) and Supply Risk (SR) values with established criticality threshold values, based on the scaled results of the criticality assessments. The list of critical raw materials (CRM) is established on the basis of the raw materials which reach or exceed the thresholds for both parameters. There is no ranking order of the raw materials in terms of criticality.

The overall results of the criticality assessments are mapped against the criticality thresholds as shown in Figure 6 below. Critical raw materials are highlighted by red dots and are located within the shaded criticality zone ($SR \geq 1$ and $EI \geq 2.8$) of the graph. Blue dots represent the non-critical raw materials.

Figure 6: Criticality assessment results (78 individual materials, scaled)



3.3 COMPARISON WITH PREVIOUS CRITICALITY ASSESSMENT RESULTS

It is important that the criticality results of the 2017 assessment ensure a good level of backwards compatibility and consistency with the previous criticality assessments. Nonetheless, it is also important to keep in mind that the revised criticality methodology includes several significant updates that were not considered by the previous assessments, as described in Section 2.2: Application of the revised EC criticality methodology. Therefore, some limitations are expected in terms of the extent that full comparisons can be made between the results of the 2017 assessment and the previous criticality assessments. Limitations of the criticality assessment results are described in Section 3.5.

In the two previous assessments, the threshold values were set at 1 for SR and 5 for EI. However, several updated elements included in the revised EC methodology impact the calculations. Particularly, in the EI calculation a more precise allocation of the material's end-uses to the corresponding manufacturing sectors (2-digit NACE sectors instead of mega sectors) and the inclusion of substitution caused a decrease in the EI values. Therefore scaled thresholds in 2017 assessment are set at 1 for SR (no change) and at 2.8 for EI (based on the average shift of the results for the materials subject to all three assessments).

The 2017 CRMs list includes 17 out of the 20 CRMs identified in 2014. The three CRMs from 2014 that are not included in the 2017 CRMs list are: chromium, coking coal and magnesite. Compared to the 2014 CRM list, 9 additional raw materials are identified as critical and enter the 2017 CRMs list: baryte, natural rubber, scandium, tantalum, vanadium, hafnium, bismuth, helium and phosphorus. The first six materials listed were considered non-critical in 2014, whereas the latter three materials are entirely new to the 2017 CRMs list since they were not assessed in either of the previous assessments. Contrary to 2011 and 2014, natural rubber, one of the biotic materials, is classified as critical in 2017. Table 5 summarises the key changes in the 2017 CRMs list compared to the 2014 CRMs list.

Table 5: Key changes to the 2017 list of CRMs compared to the 2014 CRMs list

2017 CRMs vs. 2014 CRMs			Legend:
Antimony	Magnesium	Baryte	Black: CRMs in 2017 and 2014
Beryllium	Natural graphite	Hafnium	Red: CRMs in 2017, non-CRMs in 2014
Borate	Niobium	Natural Rubber	Green: CRMs assessed in 2017, not assessed in 2014
Cobalt	PGMs	Scandium	~~Strike out:~~ Non-CRMs in 2017, critical in 2014
Fluorspar	Phosphate rock	Tantalum	
Gallium	Silicon metal	Vanadium	
Germanium	Tungsten		
HREEs	Bismuth	~~*Chromium*~~	
Indium	Helium	~~*Coking coal*~~	
LREEs	Phosphorus	~~*Magnesite*~~	

The 2017 assessment identifies all 14 of the 2011 CRMs as critical. Compared to the 2011 CRMs list, the 2017 CRMs list includes ten additional critical raw materials: baryte, borate, vanadium, bismuth, hafnium, helium, natural rubber, phosphate rock, phosphorus and silicon metal. The first three materials listed previously were considered non-critical in 2011 and the last seven materials listed were not assessed in 2011. Table 6 summarises the key changes in the 2017 CRMs list compared to the 2011 CRM list.

Table 6: Key changes to the 2017 list of CRMs compared to the 2011 CRMs list

2017 CRMs vs. 2011 CRMs			Legend:
Antimony	Natural graphite	Bismuth	Black: CRMs in 2017 and 2011
Beryllium	Niobium	Hafnium	*Italics*: Materials grouped under the REEs group in 2011
Cobalt	PGMs	Helium	Red: CRMs in 2017, non-CRMs in 2011
Fluorspar	Tungsten	Natural Rubber	Green: CRMs assessed in 2017, not assessed in 2011
Gallium	*Scandium*	Phosphate rock	
Germanium	Tantalum	Phosphorus	
HREEs	Baryte	Silicon metal	
Indium	Borate		
LREEs	Vanadium		
Magnesium			

Finally, the materials that have remained critical in all three assessments are listed in Table 7. Other key differences in the assessments across the three exercises are further discussed in the following section.

Table 7: Materials identified as critical in 2011, 2014 and 2017 assessments

Critical raw materials in 2011, 2014 and 2017		
Antimony	Germanium	Natural graphite
Beryllium	Heavy rare earth elements	Niobium
Cobalt	Indium	Platinum group metals
Fluorspar	Light rare earth elements	Tungsten
Gallium	Magnesium	

3.4 KEY FINDINGS OF THE CRITICALITY ASSESSMENTS

This section highlights the key findings of the criticality assessment results. Additional details are also provided in the Annexes. Finally, more detailed analysis of each of the materials assessed is also provided in the individual material factsheets.

3.4.1 Summary of overall criticality results for the 2017 CRMs

The application of the updated EI formula in the criticality assessments has resulted in an overall decrease in the EI results for a majority of the materials assessed (with a few exceptions, see Table 14 in section 3.4.4). The reduction in the overall values of EI is due to a more precise allocation of the material's end-uses to the corresponding manufacturing sectors (2-digit NACE sectors instead of mega sectors) as well as the inclusion of the substitution parameter in the revised EI calculation.

The materials that account for the highest Economic Importance score is tungsten (EI = 7.3) and magnesium metal (EI=7.1). The materials with the highest Supply Risk scores is the REEs group, which comprises HREEs and LREEs (average SR=4.8 and 4.9, respectively). Additional insights regarding the assessment results related to Economic Importance are provided in Table 14 and Table 15 in section 3.4.4. More information is also provided on the Supply Risk results in section 3.4.3 as well as in the individual material factsheets.

Six materials were identified as non-critical in the 2014 assessment but critical in the 2017 assessment: baryte, hafnium, natural rubber, scandium, tantalum and vanadium. For baryte and scandium, the EI and SR are relatively similar to the results of the 2014 assessment. Both materials have a SR score of at least 1; however the decrease in the EI criticality threshold to 2.8 in the 2017 assessment results in the criticality of these materials. The EI results of hafnium, natural rubber, tantalum and vanadium meet the minimum EI threshold level, however, contrary to the results of the 2014 assessment, the Supply Risk results for these materials also exceed the SR threshold for criticality, thereby qualifying them as critical raw materials. Three of these materials (vanadium, natural rubber and hafnium) apply the revised SR calculation, which incorporates actual sourcing to the EU. This is the preferred calculation according to the Commission's guidelines. The assessment for tantalum however uses global supply data only in the SR calculation. More specific explanations (see also the material factsheets) are provided in the following bullet points (see also section 3.4.4) explaining how the approach used in the assessment or the revised methodology impacted the SR result i.e. in general, higher SR values for these materials:

- In the case of tantalum, the SR score is higher in 2017 than in the 2014 assessment (tantalum SR=1.0 in 2017; SR=0.6 in 2014). This is partly due to the revised methodology, which takes into account the concentration of global production (Global HHI), the diversity of EU supply sources and geopolitical risks. Tantalum's SR result is also based on global supply data only (robust data on EU supply was not available). In the 2014 assessment, the major global suppliers in 2010 were Brazil (26%), Mozambique (18%) and Rwanda (16%). In terms of EU supply, China (29%), the US (28%) and Japan (18%) represented the largest shares. In the 2017 assessment, the major global producers of tantalum are Rwanda (31%), the Democratic Republic of Congo (19%) and Brazil (14%). Findings of the 2017 criticality assessment of tantalum indicate that EU imports of Ta ores and concentrates for the period 2010-2014 were primarily from Nigeria (81%), Rwanda (14%) and China (5%). These shares were estimated based on expert interpretation of the figures provided for customs code 261590, which mixes niobium, tantalum and vanadium concentrates. The SR result for tantalum is therefore not surprising considering the fact that the SR calculation for tantalum takes into account the share that Nigeria (81%) represents in the EU supply. Nigeria's scaled WGI value (6.92) and the EU Supply Risk ((HHI_{WGI}-t) EU28=4.6) are very high. The level of confidence concerning Ta trade in Central Africa is therefore a key parameter affecting the material's criticality[37].
- For vanadium, the SR result is based on trade data for vanadium ore using both the global HHI and the EU28 HHI as prescribed in the revised criticality methodology. In the 2014 assessment, the major global producers were South Africa (37%), China (36%) and Russia (24%). The 2017 assessment also identifies these countries as the major global producers, however with slightly different shares: China 53%, which ranks as first producer, South Africa 25% and Russia 20%. Contrary to the 2014 assessment, the 2017 assessment incorporates trade data on actual EU sourcing, which takes into account the EU supply shares from Russia (60%), China (11%) and South Africa (10%) to estimate the Supply Risk. The dependency of Russia and China for almost 85% of the European imports explains the high SR result.
- For natural rubber, the allocation of applications and the supply data are similar in the 2017 assessment compared to the 2014 assessment. The main reason for the difference in results is explained by the changes in the revised methodology regarding the calculation of the supply risk, recycling and substitution options. For example, the calculation of the SR for natural rubber in the 2017 assessment notably takes into account actual EU sourcing from Indonesia (35%), Malaysia (22%), Thailand (19%) and the Ivory Coast (13%), with no known production in Europe. Therefore, natural rubber is characterised by an import dependency of 100%. The 2017 assessment reports a final SR score of 1.0 (SR=0.8 in 2014), which is influenced by the lack of readily available substitutes for all identified end-use applications and the low EOL-RIR (1%).
- The results for hafnium are significantly different in the 2017 criticality assessment compared to the 2014 assessment. In addition to the influence of the revised methodology on the overall decrease in economic importance and increase in supply risk scores compared to previous assessments, the economic importance is also influenced (i.e. reduced) by the fact that the energy sector is not

[37] Tantalum is covered by the Conflict Minerals Regulation (Regulation (EU) 2017/821) establishing a Union system for supply chain due diligence to curtail opportunities for armed groups and security forces to trade in tin, tantalum and tungsten, and their ores, and gold.

considered to be dependent on hafnium. The Supply Risk indicator is particularly influenced by the limited number and amount of reported suppliers of hafnium. It must be noted that the supply risk is dependent on monopoly or quasi-monopoly situations, independent from the fact that the monopoly is in a European or an extra-European country. Furthermore, the actual SR score is based on the inclusion of actual EU sourcing, which takes into account the EU supply shares from France (71%), Canada (19%) and China (10%). Indeed, in the previous (2014) assessment, the SR was calculated using a share of 50% for France and for the US. In the 2017 assessment, the higher share of France in the EU supply also drives up the SR score.

Three materials that were identified as critical in 2014 are no longer considered critical in the 2017 assessment. The principal reasons explaining the change in the criticality are summarised below, with additional details provided in each of the material's factsheets:

- *Coking coal* – Coking coal's SR result (SR=1.0) meets the minimum SR threshold, however its EI result does not meet the minimum threshold for criticality (EI=2.3). The decrease in EI (compared to the 2014 assessment) is explained by the application of the revised EI formula which proposes a more precise and disaggregated allocation of major end-uses to manufacturing sectors rather than mega sectors, which has a lower overall GVA, and thereby impacting its Economic Importance score. In the case of coking coal, a direct result in EI is observed because base metal is isolated from metal products on NACE-2 digit level, thereby discarding the mega sector approach. This results in a lower overall GVA, impacting the overall Economic Importance score for coking coal. The change in supply risk results is small and mainly due to minor changes in supplier countries. The recycling rate or substitution options have not changed compared to the 2014 assessment. See also Table 15 in section 3.4.4 and the coking coal factsheet for further details.
- *Chromium* – the EI for chromium (6.8) meets the minimum EI threshold, however its SR result (SR=0.9) does not. The decrease in SR compared to 2014 is due to several aspects. Firstly, it is important to note that the stage assessed in the 2017 assessment is the refining stage due to unavailability of high quality global supply data at the extraction stage. The main primary material assessed is metallurgical-grade chromium ore, which is processed into ferrochromium and used, along with scrap, to produce stainless steel and alloy steel. The 2017 assessment incorporates the EU sourcing data in the 2017 SR estimation, which results in a lower SR result (SR=1.0 in 2010, SR=0.9 in 2017). In the 2014 assessment, the primary global supply of chromium (ores and concentrates) in 2010 was attributed to South Africa (43%) and Kazakhstan (20%). China was not identified as a major global supplier of chromium ores and concentrates. In the 2017 assessment, 86% of the primary global supply of ferrochromium comes from four main countries China (33%), South Africa (31%), Kazakhstan (13%) and India (9%)[38]. However, in terms of the share of EU supply, South Africa accounts for 46% and Finland accounts for 19%.
- *Magnesite* – the EI for magnesite (4.0) meets the minimum EI threshold, however the SR result (SR=0.7) does not. The economic importance of magnesite/magnesia decreased between 2014 and 2017, due to the change in methodology as well as a better representativeness of end-use applications covered by refractories. In the 2014 study, refractory applications represented 83% of magnesite applications, the rest being split between caustic calcined end-use applications. In the present study, the project team was able to distribute refractories between specific end-use applications, thanks to various stakeholders' feedback. The supply risk indicator is lower than in the previous years, which is due to the methodological modification, i.e. the inclusion of the EU supply and global supply in the calculation of the supply risk, rather than to an evolution in the global supply of magnesite.

[38] Based on the average for 2010-2014.

The stage assessed for each of the critical raw materials is listed in Table 8. Almost half of the CRMs were assessed at the extraction stage (12) and a bit more than half at the processing stage (14). See Annex 3 for full details on the rationale for the selection of the stage assessed for each material.

Table 8: Stages assessed for the critical raw materials (26)

Mining/extraction (12)	Processing/refining (14)
Baryte	Antimony
Beryllium	Bismuth
Borate	Gallium
Cobalt	Germanium
Fluorspar	Hafnium
HREEs	Helium
LREEs	Indium
Natural graphite	Magnesium
Natural Rubber	Niobium
Phosphate rock	PGMs
Tantalum	Phosphorus
Tungsten	Scandium
	Silicon metal
	Vanadium

The results of the analysis of the global primary supply of the critical raw materials are presented in Table 9 and Table 10.

Table 9 presents the results for 43 raw materials, out of which 23 are individual critical raw materials and 20 belong to the three critical raw materials' groups: HREEs (10), LREEs (5) and PGMs (5). The table includes the individual results of the grouped materials to allow for a more in-depth look into the global supply of the material groups. Table 10 presents the averaged figures on global primary supply for the 3 material groups: HREEs, LREEs, and PGMs. It should be noted however, that in Table 10, it is not possible to calculate the average for the largest global supplier of all the PGMs because the major producing country is not the same for the five PGMs. For iridium, platinum, rhodium and ruthenium, the major global supplier is South Africa, whereas for palladium the major global supplier is Russia.

Table 9: Global supply of the CRMs, individual materials

Material		Stage[39]	Main global supplier	Share	Material		Stage	Main global supplier	Share
1	Antimony	P	China	87%	23	Natural graphite	E	China	69%
2	Baryte	E	China	44%	24	Natural Rubber	E	Thailand	32%
3	Beryllium	E	USA	90%	25	*Neodymium*	E	China	95%
4	Bismuth	P	China	82%	26	Niobium	P	Brazil	90%
5	Borate	E	Turkey	38%	27	*Palladium*	P	Russia	46%
6	*Cerium*	E	China	95%	28	Phosphate rock	E	China	44%
7	Cobalt	E	DRC	64%	29	Phosphorus	P	China	58%
8	*Dysprosium*	E	China	95%	30	*Platinum*	P	S. Africa	70%
9	*Erbium*	E	China	95%	31	*Praseodymium*	E	China	95%
10	*Europium*	E	China	95%	32	*Rhodium*	P	S. Africa	83%
11	Fluorspar	E	China	64%	33	*Ruthenium*	P	S. Africa	93%
12	*Gadolinium*	E	China	95%	34	*Samarium*	E	China	95%

[39] Stage refers to the life-cycle stage of the material that the criticality assessment was carried out on: extraction (E) or processing (P).

Material		Stage[39]	Main global supplier	Share	Material		Stage	Main global supplier	Share
13	Gallium*	P	China	73%	35	Scandium	P	China	66%
14	Germanium	P	China	67%	36	Silicon metal	P	China	61%
15	Hafnium	P	France	43%	37	Tantalum	E	Rwanda	31%
16	Helium	P	USA	73%	38	*Terbium*	E	China	95%
17	*Holmium*	E	China	95%	39	*Thulium*	E	China	95%
18	Indium	P	China	56%	40	Tungsten	E	China	84%
19	*Iridium*	P	S. Africa	85%	41	Vanadium	P	China	53%
20	*Lanthanum*	E	China	95%	42	*Ytterbium*	E	China	95%
21	*Lutetium*	E	China	95%	43	*Yttrium*	E	China	95%
22	Magnesium	P	China	87%					

Legend	
Stage	E = Extraction stage P = Processing stage
HREEs	Dysprosium, erbium, europium, gadolinium, holmium, lutetium, terbium, thulium, ytterbium, yttrium
LREEs	Cerium, lanthanum, neodymium, praseodymium and samarium
PGMs	Iridium, palladium, platinum, rhodium, ruthenium

*Global supply calculation based on production capacity.

Table 10: Global supply of grouped CRMs, arithmetic average

Global supply or production capacity of the CRMs – grouped materials (average)			
Material	Stage[13]	Main global supplier	Share
HREEs	E	China	95%
LREEs	E	China	95%
PGMs (iridium, platinum, rhodium, ruthenium)	P	South Africa	83%
PGMs (palladium)	P	Russia	46%

The analysis of the global supply results indicates that China is the largest global supplier of the critical raw materials. In terms of the total number of CRMs, China is the major supplier of 30 out of the 43 individual raw materials or 70% (see Figure 7[40]). This includes all of the REEs and other critical raw materials including magnesium, tungsten, antimony, gallium and germanium, among others. It is important to also note that China is also a major consumer of several of these critical raw materials e.g. antimony HREEs, LREEs, PGMs, magnesium, natural graphite, tungsten, etc. and, therefore, Europe competes with China and other emerging economies for supplies. In addition to China, several other countries are also important global suppliers of specific materials. For instance, Russia and South Africa are the largest global suppliers of platinum group metals, the USA of beryllium and helium and Brazil for niobium.

Furthermore, despite China being the largest global supplier for the majority of the critical raw materials, the analysis of the primary EU sourcing (i.e. domestic production plus imports) paints a different picture (see Figure 8[41]). The analysis of the EU sourcing includes only 37 out of the 43 individual critical raw materials since the five PGMs and beryllium are excluded from the analysis due to little or no EU sourcing activity. Although China is the major EU supplier for 15 out of 38 individual materials (or 39%), several other countries represent main shares of the EU supply for specific critical raw materials, such as the USA (beryllium and helium), Russia (tungsten and scandium) and Mexico (fluorspar).

Figure 7: Main global suppliers of CRMs (based on number of CRMs supplied out of 43), average from 2010- 2014

[40] The figure should not be interpreted in terms of tonnage of CRM that originate from these countries, but in terms of the number of CRMs, for which the country is the main global supplier or producer of the CRM.

[41] The figure should not be interpreted in terms of tonnage of CRM that originate from the countries, but in terms of the number of CRMs, for which the country is the main supplier for the EU.

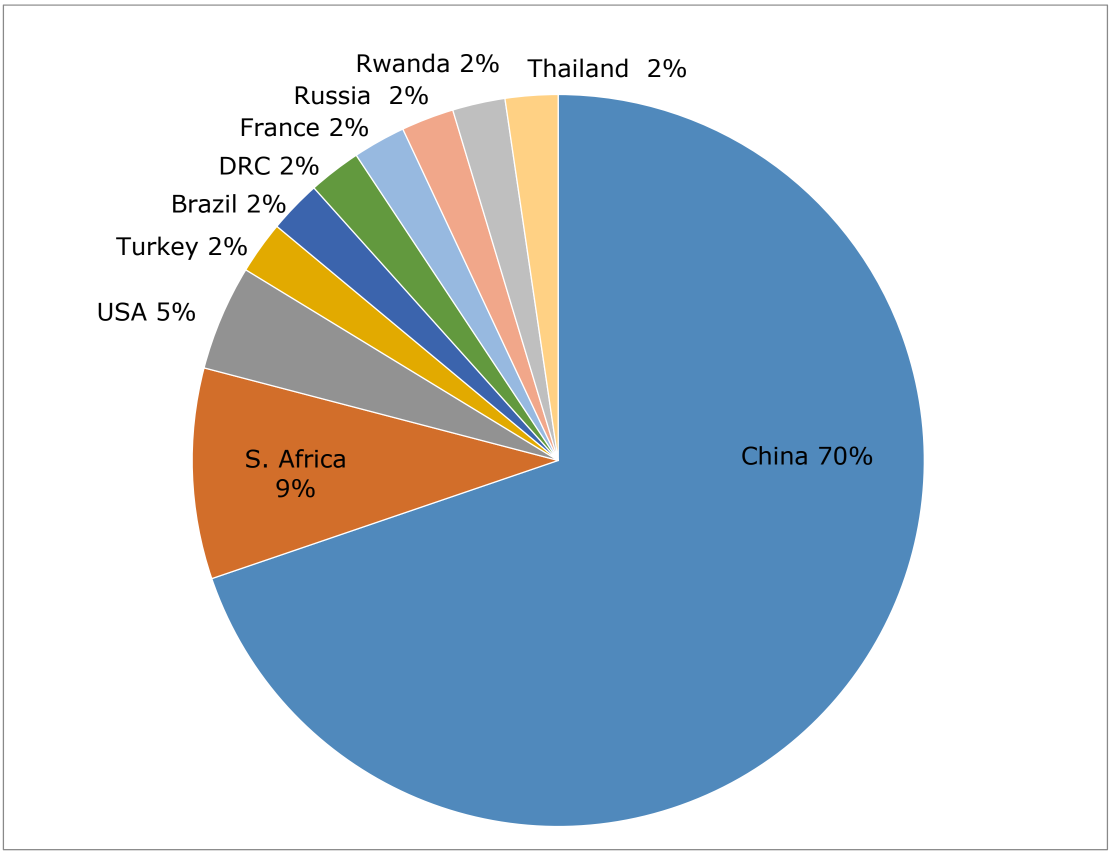
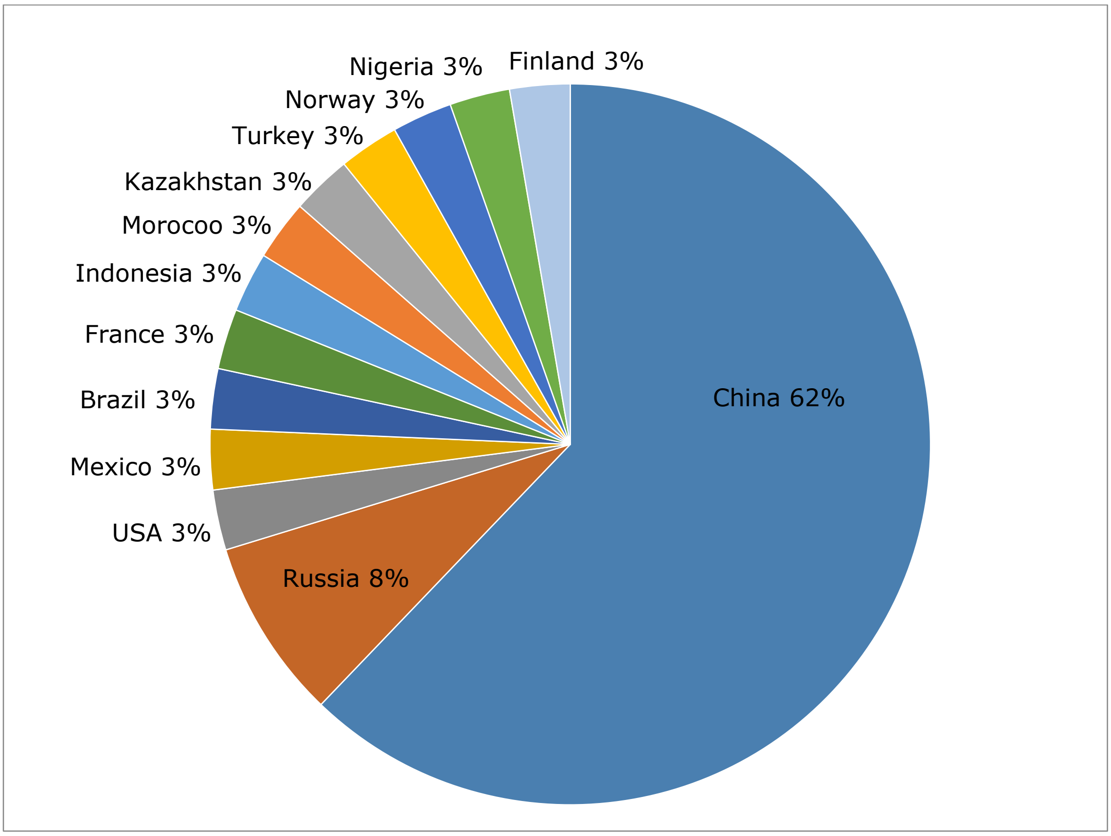


Figure 8: Main EU suppliers of CRMs (based on number of CRMs supplied out of 37), average from 2010- 2014



Finally, another significant finding is that for certain CRMs, despite China being the largest global supplier, other countries represent the main share in EU sourcing (see Table 11). The revised methodology incorporates actual sourcing to the EU, therefore allows for a more realistic picture of Europe's supply of the raw materials to be assessed.

Table 11: CRMs with China as the largest global supplier but not as largest EU supplier

CRM	Main EU supplier	Share of EU sourcing
Fluorspar	Mexico	27%
Phosphate rock	Morocco	27%
Phosphorus	Kazakhstan	77%
Scandium	Russia	67%
Silicon metal	Norway	23%
Tungsten	Russia	50%
Vanadium	Russia	60%

3.4.2 Summary of criticality results for newly assessed materials

Nine new materials were assessed in the 2017 exercise. These materials were not assessed in either of the previous assessments: aggregates, bismuth, helium, lead, phosphorus, sulphur, natural cork and natural teak wood. Three of the nine new materials are considered critical (bismuth, helium and phosphorus) as highlighted in bold in Table 12. In addition, both phosphate rock (extraction stage) and phosphorus (refining stage) were selected to be assessed due to possibility of a bottleneck at both stages. The results indicate that both stages are critical. The assessment results indicate that these materials should continue to be assessed in future exercises to monitor evolution of their criticality.

Table 12: Criticality assessment results for new materials

Material	Stage assessed	Supply Risk	Economic Importance	Import Reliance (%)	EOL-RIR (%)
Aggregates	E	0.2	2.3	0	8
Bismuth	P	3.8	3.6	100	1
Helium	P	1.6	2.8	96	1
Lead	E	0.1	3.7	18	75
Natural cork	E	1.1	1.5	0	8
Natural Teak wood	E	0.9	2.0	100	0
Phosphorus	P	4.1	4.4	100	0
Sapele wood	E	1.4	1.3	100	15
Sulphur	P	0.6	4.6	0	5

3.4.3 Summary of criticality assessment results for the material groups

Platinum group metals

In the previous assessments, the PGMs were not assessed separately but were treated as a single group, although the major influence on the measured criticality of the group were platinum, palladium, and, to a lesser extent, rhodium because these metals have much greater economic importance than the other PGMs and more data are available to assess their Supply Risk. The global assessment results were then averaged based on each of the material's production, i.e. each of PGMs. In the 2017 assessment, the criticality of the five PGMs was assessed individually using the revised methodology. These assessments are discussed in the factsheets that cover the individual PGMs. Osmium was not assessed because of the very small size of its market and the lack of any quantitative data on its supply and demand. The SR and EI score for the PGMs were calculated through an arithmetic average of the individual SR and EI scores of platinum, palladium, iridium, rhodium and ruthenium.

In the 2014 assessment of the PGM group the EI value was 6.6 and the SR was 1.2. In the 2017 assessment, based on the arithmetic average of the values for the five individual PGM, the EI and SR values are 5.0 and 2.5, respectively. These differences cannot be readily explained because of the recent methodological changes that have been introduced. Another notable difference between the two assessments relates to the life cycle stage assessed. In the 2014 study the supply risk was calculated on the basis of the global supply of ores and concentrates. However, given that there is actually very little trade in PGM ores and concentrates, the 2017 assessment was based on the processing stage (i.e. refined metal). Furthermore, in the 2017 assessment, considerable attention was paid to elucidating the detailed supply chain of the individual PGMs and their end uses. Accordingly the EI and SR values derived for the group as a whole in this study are considered to be more reliable than those calculated in the 2014 assessment.

The detailed assessment results are not identical for each PGM. Nevertheless, when looking at each of the assessment results of the five PGMs (see Table 21 in Annex 5), all the PGMs would be considered critical.

Rare earth elements

As with the PGMs group, the REEs were not assessed separately in the previous assessments. The individual assessment results of each of the 15 REEs (see Table 21 in Annex 5) indicate that each one should be considered critical, with the exception of erbium (EI=2.7) and lanthanum (EI=1.4) with EI results below the EI criticality threshold of 2.8. The revised methodology introduced in the 2017 assessment of critical raw materials as well as other factors have impacted the differences in the results observed across the three assessments.

The main driver for the Supply Risk result for the overall REEs group is explained by important EU reliance on Chinese production, which is influenced by the quotas / export taxes from China enacted during the 2010 – 2014 period. The three main suppliers of REEs to the EU are China (40%), the United States (34%) and Russia (25%). These three countries represent approximately 99% of EU imports of REEs (about 8 000 tonnes). Generally speaking, there is no significant REEs transformation and manufacturing activity in the EU; a large proportion of EU consumption / imports of REEs comes from finished products to the EU (e.g. magnets, alloys, hard drives, laptops, electric or hybrid vehicles, etc.). Further, in most of their applications, REEs cannot be substituted without loss in performance. However, for economic reasons, many R&D strategies have focused on reducing the amount of REEs used in their different applications.

3.4.4 Summary of other criticality assessment results

Supply risk results

Certain elements of the updated formula for estimating the Supply Risk (SR) in the revised methodology should be considered in order to provide the necessary context for a clearer understanding of the Supply Risk results, particularly when comparing the results of the same materials across the three assessments.

In the previous criticality methodology, the SR was estimated based on the mix of global supplier countries only. The revised methodology used an updated Supply Risk formula, which incorporates both global supply and EU sourcing. EU sourcing refers to actual sourcing of the supply to the 28 EU Member States. In the revised methodology, the actual supply to the EU (EU sourcing) is used in combination with the global supply in order to calculate a more representative measure of the risk. As such, the revised methodology uses the Import Reliance (IR) indicator to take into account the two measures of Supply Risk, i.e. the one based on global supply and the one based on actual EU sourcing:

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

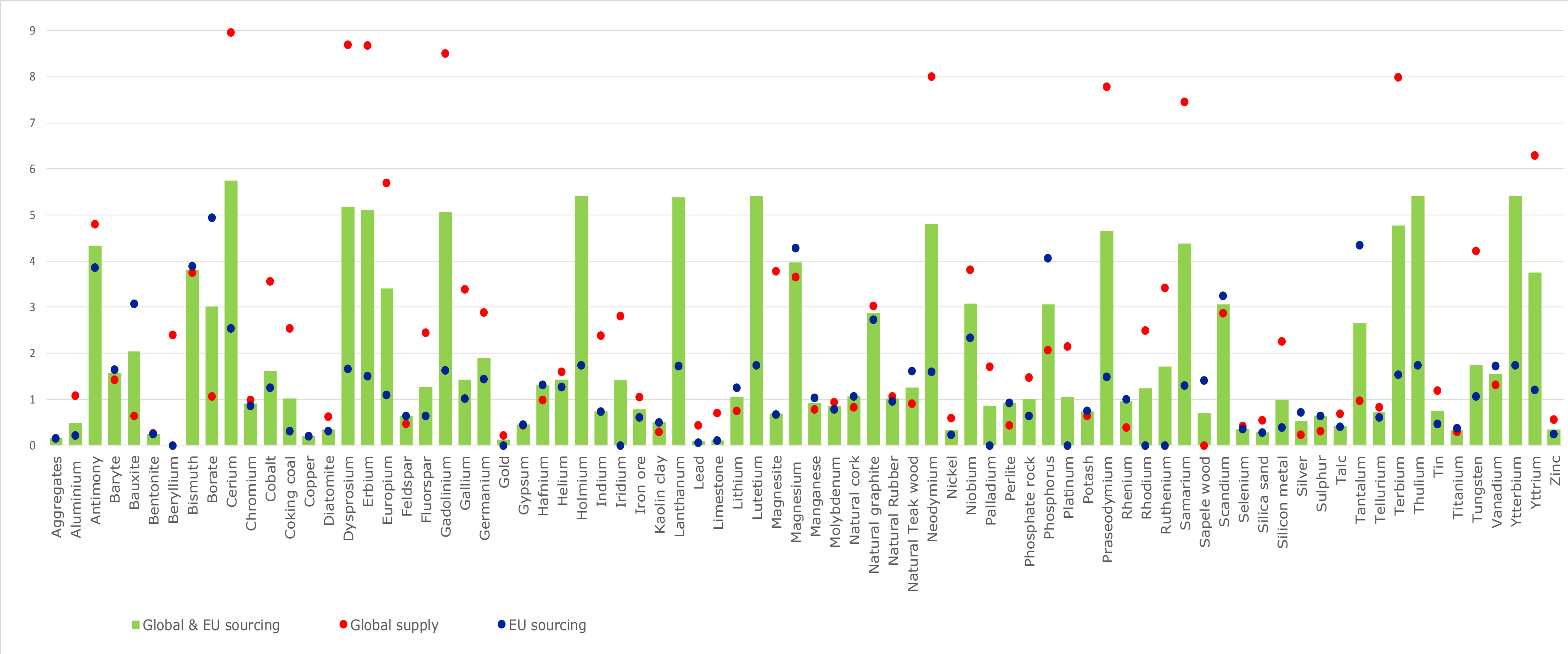
Due to concerns over sufficiently available high-quality data, the revised methodology recommends that in the case of data unavailability and/or low quality, the SR should be estimated based on global supply only (as stipulated in the previous methodology). This is based on the rationale that although it is not a true measure of the risk specific to the EU, the risk calculated using global supply is a more stable calculation and more reliable in terms of data quality. Moreover, the mix of global suppliers is generally more stable in time, whereas the exporters to the EU might change more rapidly. The guidelines for applying the revised SR formula based on both global supply and EU sourcing is summarised as follows:

- Use of both global supply and EU sourcing data, which is the preferred method when the data quality is of sufficient high quality for both indicators;
- Use of global supply data only when the data on EU sourcing is of very poor quality or not available;
- Use of EU sourcing data only, which is to be used only in specific cases when it is correct to assume that import dependency is negative or at zero percent.

Figure 9 presents a graphical comparison of the difference in SR scores based on the supply data used in the SR calculation. Table 19 in Annex 5 provides the detailed SR figures for each of the materials assessed. Analysis of the different possible SR results indicates that the SR score, when based on global supply only is in general much higher compared to when EU sourcing data only. These findings should however be carefully considered since it was not possible to apply the revised SR formula (using both global supply and EU sourcing data in the calculations) for all the materials assessed due to the unavailability of sufficiently high quality data or due to other aspects specific to certain materials.

For example, in the case of aggregates, the SR result is calculated based on EU sourcing data only because there is currently no international market for aggregates (therefore it is assumed that there is no global supply for aggregates). The SR calculation for natural cork, phosphorus, sapele wood and silica sand also uses EU sourcing data only, which correlates to the third point listed above i.e. use of EU sourcing only when the import dependency is zero. In specific cases where the EU is independent from imports (or almost), the global supply mix is disregarded and the risk is entirely calculated based on the actual sourcing of the material to the EU. Finally, for phosphorus and sapele wood, only EU sourcing data is used to estimate the Supply Risk due to the unavailability of robust global supply data on the bottleneck/stage assessed (refining and extraction stage respectively).

Figure 9: Comparison of SR results based on scope of supply data used[42]



[42] Global supply data and/'or EU sourcing supply data i.e. refers to actual sourcing (imports) of the material into the EU

Import reliance results for specific materials

Another key finding indicates that for a few materials, the import reliance is negative or zero, which means that exports from the EU are higher than imports to the EU (see Table 13). As stipulated in the revised methodology, when IR is 100%, the Supply Risk calculation should take the average of the two indicators, i.e. 50% based on global supply and 50% based on actual EU sourcing. In the few cases where the EU is independent, or almost independent, of imports, the global supply mix is disregarded and the risk is entirely calculated based on the actual sourcing of the material to the EU.

For the materials where the SR is calculated using EU sourcing and global supply (e.g. gypsum, natural cork and sulphur), a negative or zero IR percentage can reduce the SR score, leading to potential underestimation of the risk associated with the material's supply. As explained in the previous section, only five out of the 78 individual materials assessed calculates SR based on EU sourcing only. After a thorough review and consultations with the Commission and the members of the AHWG, it was decided to change the negative IR result to 0%. A 0% IR means that the SR result is calculated based on EU sourcing data only.

Table 13: Materials with negative or zero Import reliance

Material	Harmonised Import reliance result	Actual import reliance result
Aggregates	0%	-12%
Feldspar	0%	-25%
Gypsum	0%	-21%
Indium	0%	-15%
Natural cork	0%	-1%
Perlite	0%	-2%
Silica sand	0%	0%
Sulphur	0%	-13%

Economic importance results

As discussed previously, the application of the revised criticality methodology has resulted in a general reduction in the derived Economic Importance values. As such, a new EI threshold (2.8) was established to maintain coherence and consistency across the three assessments.

The revised methodology refined the EI calculation assuming more detailed and precise allocation of the raw material's primary uses to the relevant manufacturing sectors based on the material-specific end-use applications and their corresponding NACE Rev. 2 sectors. In other words, in the previous version of the methodology, EI is based on the allocation of the raw material's end uses to mega sectors, which are defined as "a collection of related NACE sectors" e.g. at NACE 3- and 4-digit level. The revised methodology bases the EI evaluation on the allocation of the material's primary end uses to the corresponding manufacturing sector at the NACE Rev. 2 2-digit level, which allows for a more precise and disaggregated allocation of the material's end uses.

Consequently, the scope of the materials' use applications considered in the 2017 exercise differs from the ones covered in the previous assessments. As such, the application of the revised formula for calculating EI resulted in an overall decrease in EI values for the majority of the candidate materials assessed due to a more disaggregated allocation of the end uses to manufacturing sectors, different scope of end use applications considered and incorporation of the substitution parameter in the EI formula (see Table 18 in Annex 5 for detailed results on the substitution index values).

Of the 78 individual candidate materials assessed, diatomite and magnesium metal are the only two materials that have higher EI results compared to the previous assessments[43]. This is further discussed in Table 14.

Table 14: Materials with higher EI compared to 2011 and 2014 assessments

Assessments	2011	2014	2017	Discussion of 2017 assessment results
Material	Economic importance			
Diatomite	3.7	3.0	3.8	The overall EI results of the 2017 assessment are consistent with the previous two assessments. However, the increase in the Economic Importance result for diatomite in the 2017 assessment compared to 2014 is due to the difference in the allocation of the end-use applications to manufacturing sectors. In the 2014 assessment, a large share of the identified end uses were allocated to the beverages mega sector, whereas in the 2017 assessment, a larger share of the end-use applications is allocated to the manufacture of chemicals and chemical products, which has a higher value added compared to the sectors considered in the 2014 assessment, resulting in a higher overall EI result.
Magnesium	6.5	5.5	7.1	Similar to diatomite, the increase in the 2017 Economic Importance result for magnesium compared to 2014 is due to the scope of the end-use applications considered and the allocation to different manufacturing sectors. In the 2014 assessment, a large share of end uses were allocated to the beverages and transport-road mega sectors, whereas the 2017 assessment allocates a larger share of the end-use applications to magnesium metal applications sectors e.g. NACE 2, C29 - manufacture of motor vehicles, trailers and semi-trailers, C25 - manufacture of fabricated metal products, except machinery and equipment, C24 - Manufacture of basic metals, etc. resulting in a higher overall EI result. This allocation reflects better representativeness of end-use applications based on magnesium alloys and aluminium alloys by using the associated sectors (transportation, packaging, construction) instead of intermediate applications ("aluminium based alloys", "magnesium die casting").

Table 15 provides further explanations of how the revised methodology impacts the EI results compared to previous assessments. The table includes only a few examples to help clarify understanding of the EI results. More in-depth discussion of the analysis of these materials is provided in the individual factsheets.

[43] Also the EI score for baryte noted a slight increase from 2.8 to 2.9, which was influenced by using end-use applications on the EU market in the current assessment. More detailed information is included in the baryte factsheet.

Table 15: Factors impacting lower EI of a few materials compared to previous assessments

Assessments	2011	2014	2017	Discussion of 2017 assessment results
Material	Economic importance			
Coking coal	N/A	9.0	2.3	The sharp decline in Economic Importance is the direct result of isolating base metals from metal products at NACE-2 digit level and discarding the mega sector approach i.e. inclusion of sectors C24 - Manufacture of basic metals and C23 - Manufacture of other non-metallic mineral products, rather than the metals mega sector, which was used in the 2014 assessment. This results in a lower overall GVA, and thereby impacting the Economic Importance score for coking coal. Coking coal was not assessed in 2011.
Lithium	5.6	5.5	2.4	In previous assessments, the end uses for lithium were allocated to several mega sectors, including plastics and electronics whereas in the 2017 assessment, a more disaggregated allocation of the major end uses at NACE 2 level is applied e.g., C23 - manufacture of other non-metallic mineral products, C19 - manufacture of coke and refined petroleum products, C24 - manufacture of basic metals, C27 - manufacture of electrical equipment, etc. This results in a significantly lower EI result compared to the results from the previous exercises due to the scope of the end use applications considered and the lower added values of the manufacturing sectors compared to mega sectors.
Natural graphite	8.7	7.4	2.9	The significant decrease in EI is due to the revised EI calculation used in the 2017 assessment. The 2017 assessment considers natural graphite applications only, whereas in the 2014 assessment, the calculation of the economic importance was based on natural graphite and synthetic graphite applications e.g. electrodes for the steel industry accounted for 34% of the global demand in the 2010 assessment; however these are not made out of natural graphite but of synthetic graphite. The economic importance indicator is therefore lower and the supply risk indicator is higher in 2017.
PGMs	6.7	6.6	5.0	PGMs are assessed individually in the 2017 assessment as opposed to previous assessments where they were assessed as a group. As such, the EI of the PGM group is based on the arithmetic average of the individual PGM results based on allocation of the end uses and the corresponding manufacturing sectors of each of the major end uses of the individual PGMs rather than the allocation of end uses for the overall PGM group to mega sectors, which was the approach used in previous assessments. This results in a lower overall EI score compared to the previous assessments.
Silicon metal	N/A	7.1	3.8	As is the case for the EI results of other materials – particularly for steel alloying elements,[44] the allocation of major end uses at NACE 2 manufacturing sectors rather than industrial mega sectors results in a decrease of the EI result for silicon metal. The EI value is significantly reduced given the difference in the scope of end use applications considered and the lower value added of the NACE-2 level sectors e.g. C20 – manufacture of chemicals and chemical products, C24 - Manufacture of basic metals and C26 - Manufacture of computer, electronic and optical products compared to the mega sector values used in the previous assessment e.g. chemicals, metals and electronics. Silicon metal was not assessed in 2011.
Silica sand	5.8	5.8	2.6	The allocation of major end uses at NACE 2 manufacturing sectors rather than industrial mega sectors results in a decrease of the EI result for silicon sands. The EI value is significantly reduced given the lower value added of the manufacturing sectors of the end use applications considered e.g. NACE-2 sector: C23 - Manufacture of other non-metallic mineral products and C24 - Manufacture of basic metals products compared to the mega sector values used in the previous assessments e.g. plastic, construction and metals.
Tantalum	7.4	7.4	3.9	In previous assessments, the end uses for tantalum were allocated to the electronics mega sector, whereas in the 2017 assessment, a more disaggregated allocation of the major end uses at NACE 2 level is applied e.g., C26 - manufacture of computer, electronic and optical products, C30 - manufacture of other transport equipment and C25 - manufacture of fabricated metal products, except machinery and equipment. This results in a significantly lower EI result compared to the results from the previous exercises due to lower added values of the manufacturing sectors compared to mega sectors.
Vanadium	9.7	9.1	3.7	Similar to the EI results of other materials assessed, particularly steel alloying elements, the decrease in EI is due to the allocation of end uses to NACE-2 sectors rather than the mega sectors. In the previous assessments, vanadium end uses were allocated to base metal and advanced metal mega sectors, which reflects a much higher value added than that used in the 2017 assessment e.g. NACE-2 sectors for machinery and transport equipment.

[44] Alloy steels refer to steels that are composed of other alloying elements, which are added to improve the mechanical properties of alloy steels and determine the property profile of a certain steel grade. Steel alloying elements include for example materials such as chromium, cobalt, manganese, molybdenum, nickel, niobium, tungsten and vanadium.

3.5 LIMITATIONS OF THE CRITICALITY ASSESSMENTS AND REVISED METHODOLOGY

Certain limitations of the criticality assessment are important to take into account when interpreting the results. These key limitations address in particular the following main areas: the robustness of the 2017 assessment results and the comparability of the results across the three assessments.

3.5.1 Robustness of the results

Regarding the robustness of the analysis and corresponding results, despite the use of updated data of optimised quality, the following **limitations on data** should be highlighted:

- **Data on EU market shares**: For several materials EU market shares were not available, therefore hypotheses and assumptions were used based on available global shares instead. Moreover, there were some issues with the use of NACE 2-digit codes since a single code had to be selected per application; however, in some cases more than one code was applicable to a specific application.
- **Cases with issues on data to assess the EU supply**: As stipulated in the revised methodology, the 2017 assessment integrates data on EU sourcing (when available and of high quality) to calculate the Supply Risk. Taking into account actual sourcing to the EU provides a more realistic picture of the situation for each material. Previous assessments considered the global supplier mix only to calculate SR. In general, there was good public data availability for global supply (EU trade and production data) for the majority of the materials assessed, however, data on EU sourcing were not always available or were of poor quality for some materials. Further, for some materials, there were also challenges related to inconsistencies in the type of data reported (for the REEs and PGMs for example) e.g. units, % of the material contained, time period covered, life-cycle stage covered, etc. between world production and EU sourcing data. In these cases, only reliable global supply data was used or stakeholders were consulted to validate or provide additional inputs to develop possible justified assumptions and hypothesis, where relevant.
- **Data on substitution and shares of material applications**: In general, it was difficult to identify or obtain public data on the shares of material applications, as well as their substitutes. The reason for the lack of available and reliable data on the sub-share of substitutes for a given application is that there are very few cases where substitutes are actually already being used in practice. As a result, in many cases, the consultants sought feedback from industry experts to develop acceptable assumptions and hypotheses for potential substitutes and sub-shares, where it was possible. An example of an issue regarding substitution is the definition of "readily available". Specific and realistic thresholds in time (e.g. two weeks) and value (e.g. substitute should be no more than XX% more expensive than the material in question) would need to be ascertained.
- **Data on End-of-life Recycling Input Rates (EOL-RIR):** In the revised methodology, the role of recycling as a risk-reducing filter of Supply Risk remains unchanged compared to the previous EC criticality exercises. Instead, in the 2017 assessment, efforts were focused on integrating available high quality EU based data. As such, priority was given to EU sources of data such as the Raw Material System Analysis (MSA) study (BIO by Deloitte, 2015) and data published in the report 'Recycling Rates of Metals' by the International Resource Panel of the United Nations Environment Programme (UNEP) to maintain the highest possible comparability with previous EC criticality reports. For many materials, data on EOL-RIR was available through the previously mentioned references, however this was not the case for all the materials assessed (particularly for those that were not assessed in the previous

exercises). In the cases where MSA and UNEP data were not available, data or assumptions were used based on information provided in other sources e.g. sectorial reports, expert judgement and stakeholder inputs. The EOL-RIR is an important component of the SR estimation, therefore the SR result of the materials which use an EOL-RIR figure that does not stem from the preferred reference studies should be considered carefully. There were also some challenges related to the definition of EOL-RIR and identifying the data for EOL-RIR for those materials where data sources were not available (e.g. UNEP rates).

3.5.2 Comparability of the results across the three assessments

In addition to the robustness of the assessment and the data considerations discussed above, several limitations regarding the **comparability of the results across the three criticality assessments** were also identified. These limitations can be categorised in relation to the scope of the criticality assessments and the implementation of revised criticality methodology.

Scope of the 2017 assessment

Firstly, the 2017 assessment covers a larger number of materials (78 individual materials or 61 candidate raw materials comprising 58 individual and 3 grouped materials) compared to the previous assessments (41 materials in 2011 and 54 materials in 2014). The scope of the 2017 assessment includes nine new materials (six abiotic materials[45] and three biotic materials[46]) and individual rare earth elements and platinum group metals. The larger number of the materials assessed affects the overall results as they are scaled and weighted based on the number and results of each of the individual materials assessed.

Secondly, criticality assessment results are available for the first time at both the individual material level and the group level for the rare earth elements and platinum group metals. In the 2014 assessment, the results of these material groups were presented at the group level only. The 15 rare earth elements (REEs) are split into two sub-categories based on their chemical and physical properties - 'heavy' rare earth elements (HREEs), comprising ten individual materials[47] and 'light' rare earth materials (LREEs), comprising five individual materials[48]. The five platinum group metals[49] (PGMs) also constitute one group[50]. The results presented for the grouped materials (HREEs, LREEs and PGMs) are the averages of the results of the individual materials included in these groups. It should be also noted that the 2011 assessment grouped all rare earth elements, including scandium under the rare earth elements group, while the 2014 and 2017 assessments examine scandium separately.

Finally, the 2017 assessment implements a preliminary screening to identify the life cycle stage to be assessed i.e. bottleneck screening. In the previous exercises, the extraction stage was the default stage that was assessed for criticality for the majority of materials. In the 2017 assessment, the bottleneck screening approach was applied to determine whether the extraction and/or refining stage represents the highest Supply Risk. In principle, the extraction stage is considered, unless the refining stage is proven to be most critical in the value chain. The stage deemed to reflect the highest SR is the stage

[45] New abiotic materials assessed: aggregates, bismuth, helium, lead, phosphorus, sulphur
[46] New biotic materials assessed: natural cork, natural teak wood and sapele wood
[47] HREEs: dysprosium, erbium, europium, gadolinium, holmium, lutetium, terbium, thulium, ytterbium, yttrium
[48] LREEs: cerium, lanthanum, neodymium, praseodymium, samarium
[49] PGMs: iridium, platinum, palladium, rhodium, ruthenium
[50] Osmium was assessed in the previous assessments; however is excluded from the 2017 exercise due to the lack of robust quantitative figures on osmium. In the 2014 criticality assessment, osmium was assessed using the data available for ruthenium and iridium. In the 2017 assessment, complementary information on osmium is provided in the PGMs factsheet, where relevant.

that is assessed, unless there are issues related to the availability of high quality data for the selected stage. Of the 78 individual materials assessed, 50 were assessed at the extraction/ores and concentrates stage and 28 were assessed at the processing/refining stage. Of these 28 materials assessed at the processing stage, 14 are considered critical.

Revised criticality methodology

The main reason behind the differences seen in the results of the 2017 exercise and previous exercises relates to the implementation of the revised EC methodology for assessing criticality. While the revised criticality methodology aims to ensure comparability with the previous methodology, there are several significant updates in the revised methodology, as described in Section 2.2: Application of the revised EC criticality methodology, which should be carefully considered when analysing the criticality assessment results[51].

The impact of the new aspects introduced in the revised criticality methodology on the overall assessment results are summarised below:

- Economic Importance: The 2017 exercise applies the revised formula for estimating Economic Importance, implying more detailed economic allocation of raw materials based on the material-specific end-use applications and their corresponding NACE Rev. 2 sectors. The scope of the corresponding manufacturing sectors considered are not identical to the megasectors used in the previous assessments. The use of NACE 2 codes improves the calculation used in previous studies, which was focused more on intermediate applications and corresponding mega sectors. Consequently, there was an overall decrease in the EI results for the majority of the materials assessed. Where relevant, assumptions and hypotheses were used based on expert knowledge. The magnitude of the difference in the results of certain materials therefore varies widely across the three exercises based on several aspects such as the characteristics of the end-use applications considered, the values added of the selected sectors, integration of EU sourcing data, etc.
- Supply Risk: The 2017 exercise applies the revised formula for estimating the Supply Risk. The inclusion of additional components such as EU sourcing (in addition to global supply) and adjusted trade in the HHI(WGI) (reflecting export restrictions and EU trade agreements) has resulted in varying magnitudes of differences observed for certain materials across the three exercises.
- Revised thresholds for criticality: The threshold levels were reviewed and adapted to take into account the results of the 2017 assessment, while ensuring comparability across the three assessments (SR threshold remained at 1 and EI threshold was moved from 5.0 to 2.8 due to the implementation of the revised methodology). Therefore, while the revised EI threshold allows some background comparability with the previous assessments, it is recommended to also consult the detailed results of each material (see Annex 5) as well as the material factsheets to obtain deeper insights into the analyses.
- Data sources used: The 2017 assessment uses updated data compared to the previous exercises. In the 2011 assessment, almost only USGS datasets were used and in the 2014 assessment, EU sourcing data was not considered. In the 2017 exercise, data sources such as those published by BGS (World Mineral Production 2010-2014, World Mineral Statistics Data, European Mineral Statistics 2009-2013, etc.), the Study on Data for a Raw Material System Analysis (BIO Intelligence Service, 2015), World Mining Data 2016 (Austria Federal Minister of

[51] Further details in Methodology for establishing the EU List of Critical Raw Materials, 2017, ISBN 978-92-79-68051-9.

Science, Research and Economy) and updated figures from Eurostat and the Minerals4EU databases were used, when possible.

While it is important that the results of the criticality assessment ensure a good level of backwards compatibility and consistency with the previous criticality assessments, it is also important to keep in mind that the 2017 assessment covers a wider scope of materials and applies a revised criticality methodology, which includes several significant changes that were not considered in the previous assessments. Therefore, some limitations are expected in terms of the extent to which comparisons can be made between the results of the 2017 assessment and previous assessments. With this in mind, it is also necessary to emphasize the fact that this is the first assessment to be carried out using the revised version of the methodology. Therefore, although parts of the revised methodology could be further improved or refined, this methodology addresses several weaknesses identified in the previous assessments with the aim of strengthening the accuracy of the results.

It should be also noted that the revised methodology has gone through an extensive review and feedback period involving key actors such as the European Commission and members of the AHWG, including representatives of the EU Member States, industry and scientific experts. Future exercises will strive to continue to improve the results of the assessments. For example, the background report on the revised criticality methodology includes several suggestions to consider on areas of further investigation that might improve future assessments[52].

3.6 CONCLUSIONS AND RECOMMENDATIONS

In the Communication on raw materials of 2011[53], the Commission committed to regularly update the CRM list, at least every three years. A second criticality assessment was therefore published in 2014 with the aim of updating the results based on the latest available data and other improvements to the analysis, while preserving comparability with the previous assessment. This study underpins the third, 2017 assessment of the criticality of materials for the EU economy, which is part of the process to maintain and update important information and findings on a regular basis, and was carried out based on the refined methodology. With this in mind, the following section summarises the key recommendations to be considered in order to facilitate further updates and the robustness of the exercises on criticality in the future.

The recommendations provided address two main areas: recommendations for improving the quality of the data used and recommendations for improving the reliability of future exercises.

Regarding recommendations to improve the quality of the data, although the revised methodology advises the use of high quality EU based data, certain limitations and uncertainties with data sources were identified that could be further improved in future exercises. This underlines the importance of continuing to work closely with industry experts, members of the AHWG, important data providers e.g. Eurostat, MS authorities and the European Commission to further improve the quality and reporting of European data. The following points could also be considered to increase the quality of the required data:

- Maintaining the importance of the transparency, objectivity and quality of the data used – as is recommended in the revised methodology, priority should be given to official and publically available data over other sources such as private data that cannot be publically accessed or unofficial / unpublished

[52] JRC technical report (2017): ASSESSMENT OF THE METHODOLOGY FOR ESTABLISHING THE EU LIST OF CRITICAL RAW MATERIALS: «Background Report», ISBN 978-92-79-69612-1, available at the JRC Science Hub: https://ec.europa.eu/jrc

[53] Communication *'Tackling the challenges in commodity markets and on raw materials'* (COM(2011)25)

data. In addition, future exercises should continue to strive to maximise the contributions from all stakeholders and experts to ensure transparency as well as robustness of the data used and results derived. Continuous consultation with industry stakeholders is of crucial importance as they can provide important insights and feedback that are not necessarily available through existing data sources. With this mind, adequate time should be allowed for the stakeholder consultation. This entails not only a period dedicated for the review of the criticality assessment calculations and the material factsheets but also to allow for exchanges with stakeholders and experts regarding contributions and other feedback. Similarly, distinction between stakeholder validation and expert consultation is also useful to make. This allows for more targeted stakeholder consultation. For example, it is important to distinguish between individuals who are in a position to contribute data and knowledge, and individuals who would be more relevant to comment or ask questions on findings. Most individuals involved in raw material extraction and processing in the EU could be considered "stakeholders", whereas the label "expert" implies a certain status regarding a data validation and contribution role that would need confirmation by the EC.

- Working more closely with organisations that publish or provide publically available EU-based data e.g. Eurostat, OECD, National statistics departments, geological surveys, ministries, trade organisation and others – this is important to further improve the quality and availability of EU production and trade statistics used in the criticality assessments. Regular discussions with these official data providers for example would be helpful to identify specific areas e.g. certain Member States, sectors, topics, specific data reporting challenges where greater efforts may be needed to improve and interpret the data reported. In particular, it is important to ensure that reported data are coherent and comparable. Certain challenges faced in the 2017 assessment on data availability included for example issues with existing nomenclatures, units and the years that the data covered.

- Finally, it is also essential to maintain the availability of detailed and coherent metadata information from EC public databases as well as the development of explanatory notes related to nomenclatures, which can provide important information in order to accurately interpret the data reported.

As the first exercise to implement the revised methodology, some recommendations for potential methodological improvements in future exercises are summarised in Table 16.

Table 16: Summary of conclusions and recommendations to further strengthen future criticality exercises

Topics	Conclusions and recommendations
Application of a revised methodology	Additional time and resources were needed at the beginning of the project to ensure that the revised criticality methodology was applied correctly and harmoniously across the different criticality assessments. ⇒ In the case future exercises applied additional revisions to the criticality methodology, sufficient time and resources should be considered during the pre-launch or development phase. In addition, thorough testing of any amendments to the criticality methodology should be carried out in due time before it is formally validated and applied for use in the criticality assessments of all the candidate raw materials.

Topics	Conclusions and recommendations
Materials and scope definitions	Additional resources were also needed at the early stages of the project to develop harmonised definitions and clearly define the scope the assessments. For example, it was not always straightforward on how to refer to certain materials e.g. phosphorous (phosphorous)/phosphorous (phosphate rock), aluminium (metal)/ aluminium (bauxite), etc. ⇒ Specific definitions of candidate materials should be established in advance of the assessment phase. Clear guidance on the nomenclature and terms used to define materials and other concepts would be helpful to more efficiently define the scope of the study from the outset.
Life-cycle stages accessed	A basic issue with all criticality assessments is the scope of the assessment that is made. As with most other analyses of this type, the revised EU methodology focuses on risk related to raw materials (i.e. the first step in the mineral life cycle) or related to a bottleneck further down the value chain, potentially related to the refining steps. These studies generally do not consider the steps in which the refined material is used in a multitude of applications. The assessment allowed for a wider analysis of risk across the supply chain compared to previous assessments, however the decision on where and how to define the end of the value chain for certain applications was not always straightforward and can easily lead to differences of interpretation. Further, the assessment does not consider in detail other stages of the life cycle that may also be important to consider. This is related for example to 'non-commodities' i.e. materials that are not traded on public markets, which are not within the scope of the assessment. There is a general absence of data on non-commodities since these materials are often "privately" traded. However, such factors are important to consider when looking at the complete value chain of a material. This emphasizes the importance of the material factsheets, which allow for more in-depth investigation of the materials across their life cycle and the supply chain, including aspects such as future outlook, pricing and other key trends. ⇨ The above aspects should continue to be investigated in future work to further refine and strengthen the supply chain approach. For example, the development of a standardised approach to effectively map out the value chain of raw materials building on previous work carried out by the Commission. Any potential modifications on the approach in the future should be supported by sufficient evidence.
End-of-life Recycling Input Rates (EOL-RIR)	A more harmonised approach to reporting and interpreting data on EOL-RIR is an area that could also be further strengthened. While the revised methodology provides guidelines and data sources than can be used for the EOL-RIR, the available data for all of the materials assessed is of varying quality. The Raw Material System Analysis (MSA) study (BIO by Deloitte, 2015) serves as a good basis, however certain elements could be further improved. For example, this study does not cover all materials covered by the 2017 criticality assessment and certain data is not reliable or up to date. In addition, the EOL-RIR in the revised EC methodology only considers the recycling of primary supply of the raw materials and does not take

Topics	Conclusions and recommendations
	into account potential Supply Risk associated with secondary raw materials. This links to the above topic on the scope of the material's value chain. For materials such as natural rubber for example, the recycling of secondary materials represents a significant share of recycling rates. This factor is not taken into account in the revised EC methodology. Imports of "wastes and scraps" are not considered as part of the Supply Risk parameter, even though Supply Risk may exist. This may also be the case for other materials such as PGMs and aluminium. Such information, while not included in the criticality assessments, is provided in the factsheets for the materials concerned. This supports the importance of the factsheets, which provide more in-depth discussion and analysis of the different parameters of the material's value chain. ⇨ Further work would contribute to a more consistent approach towards estimating the EOL-RIR and the data used.
Reserves and resources	Overall, there is very little up to date resource or reserve data available for mineral raw materials in Europe. Geographical coverage is highly variable and in the case of several materials, no data are available at MS level. Where such data are available, the quality is often poor, outdated and irrelevant. Also, metadata are not always available and it cannot, therefore, be used to complement the analysis. Furthermore, there is considerable variation in the reporting practices and standards used: some data has no associated reporting standards, while other data is reported according to various national or international systems. This presents a particular challenge when attempting to estimate national totals for individual materials. It is even more challenging to derive a reliable pan-EU total on reserves and resources. ⇨ Further work would contribute to a more complete, consistent and up-to-date resource and reserve data for the EU and MS. It is important to note that neither resources nor reserves are used in the criticality assessment. As such, related information should only briefly be discussed, based on reliable data and with any assumptions duly justified. Resources and reserves are dynamic economic entities that continually change according to market conditions. They are therefore not the most reliable indicator in terms of future availability or depletion. Nonetheless, this aspect contributes useful insights to consider for specific materials and overall in terms of criticality. Additional information on reserves and resources is included in the material factsheets.
Allocation of end-use per sector	It was not always straightforward to determine to what extent a specific material is used directly in a manufacturing sector or used in downstream" sectors" towards the final product. An example would be the use of a certain metal in a turbine, which could be a metal product or a piece of machinery. Evidence could also indicate that the material's end-use is the production and distribution of energy. ⇨ The selection of applications and associated sectors has a significant influence on the Economic Importance values. Therefore, future methodological improvements could offer additional guidance on the approach to be used. Clear guidance on how to deal with the evolution of volumes and values across

Topics	Conclusions and recommendations
	the value chain would be helpful. The various aggregated value chains at NACE 2-digit level taken from macro-economic data and models (resulting in between 30,000 and 50,000 different chains) could serve as a numerical basis for this guideline.
Introduce different weights per raw material	In the 2017 assessment, the overall scaled EI results are based on an equal weighting of the EI results for each of the 78 individual materials assessed. An example would be the difference in economic importance of a material with annual global production of 15Mt versus 10Kt. The guidelines of the revised criticality methodology prescribe equal weights to both these materials. ⇨ It could be worth exploring whether the substitution index for economic importance could be replaced or extended by a factor that indicates either the volume or the value of the use of a particular raw material. This would introduce a certain weight into the EI calculation that would more accurately reflect the significance of a raw material to the European economy.

To conclude, all raw materials, even if not considered critical, are important for the European economy. Therefore, the fact that a given material is classed as non-critical material does not imply that its availability and importance to the European economy be neglected. Moreover, the availability of new data and possible evolutions in EU and international markets may affect the list in the future. As such, targeted policy and initiatives should not be limited exclusively to critical raw materials, but should also be able to address the larger issue of all raw materials.

ANNEXES

Annex 1. Overview of EU and international initiatives on raw materials

EU policy initiatives related to the Raw Material Initiative

In 2000 the EU defined a strategic goal within the Lisbon strategy to become "capable of sustainable economic growth with more and better jobs and greater social cohesion, and respect for the environment". A decade later, in March 2010, the goal was reiterated in the Europe 2020 Strategy. Now more pertinent than ever, the aim for Europe is to achieve "smart, sustainable and inclusive growth".

Two flagship initiatives of the Europe 2020 Strategy are closely linked with raw materials: *Resource Efficient Europe*[54] and *An Industrial Policy for the Globalisation Era*[55]. The aim stated for the *Resource Efficient Europe* is to decouple Europe's economic growth from resource and energy use, enhance competitiveness and promote greater energy security. *An Industrial Policy for the Globalisation Era* states that "all sectors are facing the challenges of globalisation and adjusting their production processes and products to a low-carbon economy".

Under this framework, the EC has launched a number of policies in different areas that affect EU industries and raw materials supply, for example:

- European Innovation Partnership on Raw Materials, a stakeholder platform that brings together representatives from industry, public services, academia and NGOs. Its mission is to provide high-level guidance to the European Commission, Members States and private actors on innovative approaches to the challenges related to raw materials. Actions to achieve these include research and development, addressing policy framework conditions, disseminating best practices, gathering knowledge and fostering international cooperation.
- The 2011 Eco-innovation Action Plan (Eco-AP) (COM(2011) 0899final), as part of the flagship initiative 'Innovation Union of the 2020 Strategy'.
- Adoption of the Circular Economy Action Plan to support the circular economy in each step of the value chain – from production to consumption, repair and manufacturing, waste management and secondary raw materials that are fed back into the economy.
- The 2020 EU Climate and Energy Package and the recently adopted 2030 Framework for Energy and Climate Policies.
- EIT Raw Materials was designated as an EIT Knowledge and Innovation Community (KIC) by the EIT Governing Board on 9th December 2014. Its mission is to boost the competitiveness, growth and attractiveness of the European raw materials sector via innovation and entrepreneurship. TNO and BRGM are main partners of the EIT Raw Materials.

The Circular Economy Package was adopted by the Commission on 2 December 2015, which sent a clear message and established concrete measures to support the transition towards a more circular economy in the EU. This package included legislative proposals on waste, with long-term targets to reduce landfilling and increase recycling and reuse.[56] The rationale behind this comprehensive approach to resource efficiency focuses not only on waste but on other loops (beyond recycling) within the circular economy, informing a mixture of different policy measures at every step of the chain of supply of raw materials to correctly overcome each barrier. However, recycling and efficient raw material usage won't be enough to cover the actual and future EU needs in terms of raw materials. In addition to those sustainable practices, initiatives which aim to secure the primary raw materials supply from outside EU are also necessary. For example, the demand for PGMs for use in auto catalysts is increasing

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[54] http://ec.europa.eu/resource-efficient-europe/
[55] https://ec.europa.eu/growth/industry/policy/renaissance_en
[56] http://ec.europa.eu/environment/circular-economy/implementation_report.pdf

as more vehicles are built and emission control standards are tightened. Recycling of PGMs cannot meet the current demand and primary supplies will continue to be needed in greater quantities.

Ongoing and recent work on Critical Raw Materials

In addition to ongoing EU policy initiatives, a considerable body of research has either already been undertaken or is in progress in the field of Critical Raw Materials and the broader, related topic of minerals supply security, either funded by the EU or by Member States. A review of the results and work developed contribute to avoiding duplication of work and enrich the sources and approach taken. A short description of some of these pan-European activities is provided in the table below, and a detailed list of projects and literature is presented in Annex III.

Table 17: Example of on-going and recent work on Critical Raw Materials

Scope	Title	Year
EU	Study on Data for a Raw Material System Analysis: Roadmap and Test of the Fully Operational MSA for Raw Materials is a project commissioned by the European Commission, DG GROW to map the flows of Critical Raw Materials and other materials used in the EU economy. It presents a first exercise of MSA of the selected materials and recommendations to maintain and improve it. This project is the follow-up of the preliminary study "Study on Data Needs for a Full Raw Materials Flow Analysis" finished in 2012.	2015
EU	The European Raw Materials Knowledge Base (EURMKB) is a part of the European Innovation Partnership's Strategic Implementation Plan. Its aim is to be a one-stop-shop for all information on raw materials in the EU. With the help of EU countries, the service will collect, store, maintain, upgrade, analyse, and disseminate information on the raw materials. The first EU Raw Materials Information System has been launched to serve policy makers, industry and professional and general public as a valuable source of data.	Ongoing
EU	Minerals4EU is a research project funded by the EU FP7 programme to meet the recommendations of the Raw Materials Initiative and develop an EU Mineral intelligence network structure delivering a web portal, a European Minerals Yearbook and foresight studies. The network will provide data, information and knowledge on mineral resources in Europe.	2013 – 2015
FR	France: Criticality assessment of 17 metals and groups of metals used by the French manufacturing industry (2015-2017)[57]	2015 – 2017
EU	French ASTER project "Systemic analysis of flows and stocks of rare earths in the EU" is a research project funded by the French National Agency for Research (ANR), which establish a MSA for rare earths in EU. Guyonnet, D., et al., (2015) Material flow analysis applied to rare earth elements in Europe, Journal of Cleaner Production, in press	2015
EU	Study on Critical raw materials used in the EU defence sector is a project commissioned by the EC DG JRC IET to produce an inventory of critical raw materials and special materials that are used by the EU defence sector. A similar project has been launched in 2014 by the European Defence Agency.	2014
EU	Critical Metals in Strategic Energy Technologies is a project carried out by the EC DG JRC IET in 2011 to assess whether there could be any potential bottlenecks to the deployment of low-carbon energy technologies (i.e. nuclear, solar, wind, bioenergy, carbon capture and storage and the electricity grid) in the EU due to the shortage of certain metals. The study concluded that 5 metals, namely tellurium, indium, gallium, neodymium and dysprosium, are at a particularly high risk, with special relevance to the wind and photovoltaic energy generation technologies. The follow-up of this project commissioned by the EC DG JRC IET in 2013 identified 8 metals as critical in the report 'Critical metals in the path towards the decarbonisation of the EU energy sector': dysprosium, europium, terbium, yttrium, praseodymium, neodymium, gallium and tellurium.	2013
NL	Statistics Netherlands (2010) Critical materials in the Dutch economy – Preliminary results and Materials in the Dutch Economy.[58] [59]	2010

[57] 17 material reports are currently published and available online (French only): www.mineralinfo.fr/page/fiches-criticite

Scope	Title	Year
DE	German Federal Ministry of Education and Research (2013) Raw materials of strategic economic importance for high-tech made in Germany.[60]	2013
UK	BGS (2011) Risk List 2011.[61]	2011
World	Graedel et al (2015), 'Criticality of metals and metalloids' in PNAS, April 7, 2015, vol. 112, no 14, 4257-4262	2015
World	Simon Glösera, et al (2015) Raw material criticality in the context of classical risk assessment; Resources Policy, Volume 44, June 2015, Pages 35–46How to evaluate raw material supply risks—an overview	2015
World	Nansai, Ket al. (2014) Global flows of critical metals necessary for low-carbon technologies: the case of neodymium, cobalt, and platinum. Environ. Sci. Technol. 48, 1391e1400.	2014
US	National Research Council (2008): Minerals, Critical Minerals, and the U.S. Economy.[62]	2008
US	U.S: Department of Energy (2011): Critical Materials Strategy. [63]	2011
US	Critical Materials Institute – USA[64]: In 2013 the U.S. Department of Energy established a new research centre, known as the Critical Materials Institute (CMI), with funding of US$120 million over a five-year period. The mission of the CMI is to ensure security of supply for materials critical to clean energy technologies. It aims to do this through developing and deploying new technologies for diversifying and expanding supplies and for reducing waste in manufacturing and recycling. It also aims to identify substitutes for some critical raw materials in certain clean energy applications.	2013
JP	METI (2009), Announcement of "Strategy for Ensuring Stable Supplies of Rare Earth Metals[65]	2009
JP	Hiroki Hatayama & Kiyotaka Tahara (2015) Evaluating the sufficiency of Japan's mineral resource entitlements for supply risk mitigation; Resources Policy, Volume 44, June 2015, Pages 72–80	2015

[58] Available online at: www.cbs.nl/NR/rdonlyres/37ADC207-2FD4-4D34-B5DE-02A3ADBDF3B4/0/criticalmaterialsinthedutcheconomy.pdf
[59] Available online at: https://www.rijksoverheid.nl/documenten/rapporten/2015/12/11/materialen-in-de-nederlandse-economie
[60] Available online at: www.fona.de/mediathek/pdf/Strategische_Rohstoffe_EN.pdf
[61] Available online at: www.bgs.ac.uk/mineralsuk/statistics/riskList.html
[62] Available online at: www.nap.edu/catalog.php?record_id=12034
[63] Available online at: http://energy.gov/sites/prod/files/DOE_CMS2011_FINAL_Full.pdf
[64] https://cmi.ameslab.gov/
[65] http://www.meti.go.jp/english/press/data/20090728_01.html

Annex 2. Overview of criticality methodologies

Various methodological approaches to raw materials criticality assessment have been conducted in Member States and in the rest of the world, focusing on those undertaken in the last decade. The alternative approaches are compared with the EU methodology and consideration given to those aspects that may be advantageous to include in future EU assessments. Therefore, this section includes a comparative overview of:

- Raw materials covered by all assessments (including EU CRM);
- Raw materials labelled as critical and;
- Methodologies, in particular the main criteria that determine criticality.

It should be noted that the JRC technical report (2017): ASSESSMENT OF THE METHODOLOGY FOR ESTABLISHING THE EU LIST OF CRITICAL RAW MATERIALS: «Background Report» already includes a very thorough and comprehensive review of criticality assessments from recent years. The review analyses 212 communications dealing with critical raw materials, including 58 scientific publications describing different criticality methodologies and 55 publications providing specific information of the materials being investigated. A detailed inventory of the papers reviewed is provided in Annex 4 attached to this report. The papers describe in-house developed criticality methodologies on the following aspects:

- Objectives of the studies
- The organisations involved
- The basis of the methodology
- The materials subject to the referenced study and the critical raw materials identified, where relevant.

Therefore, the purpose of this section is not to re-do work that has already been undertaken in the JRC report, but rather summarise the key findings and analyse some of the basic methodologies and underlying metrics in comparison to the metrics developed by the JRC and employed in the 2017 assessment. The assessment is confined to those studies that emphasize the raw materials vulnerability at the level of countries (EU being considered a "country"). Metrics that are introduced to assess the vulnerability at company or sectorial level are interesting as such, but lead to vulnerability indicators that may be irrelevant (because not leading to action) at country and government level.

Context and background to criticality methodologies

The criticality assessment of the EC (revised by the JRC) generally follows the approach to vulnerability assessments, which has many things in common with risk assessment. Vulnerability assessments are typically performed according to the following steps:

1. Cataloguing assets and capabilities (resources) in a system
2. Assigning quantifiable value (or at least rank order) and importance to those resources
3. Identifying the vulnerabilities or potential threats to each resource
4. Mitigating or eliminating the most serious vulnerabilities for the most valuable resources

The outcome of a risk analysis takes the shape of a vulnerability diagram as depicted in Figure 10. In the revised EC methodology, the assets chosen are a multitude of (biotic and abiotic) raw materials, the probability investigated is the probability for a supply disruption if a specific raw material, and the consequences of that Supply Risk (SR) are assessed in relation to the potential damage for the European economy EI (Economic Importance). The general picture for criticality assessments is given in Figure 11.

Figure 10: Classical risk analysis plot

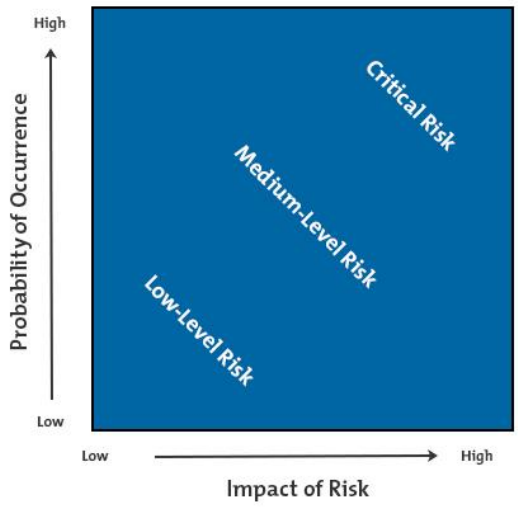
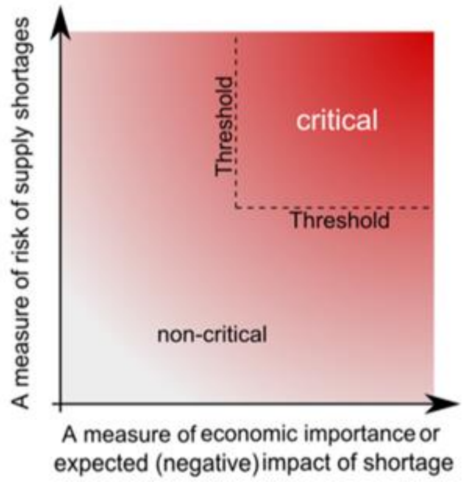


Figure 11: Vulnerability plot from 2014 EC-report on critical materials



Summary of key findings from existing criticality methodologies

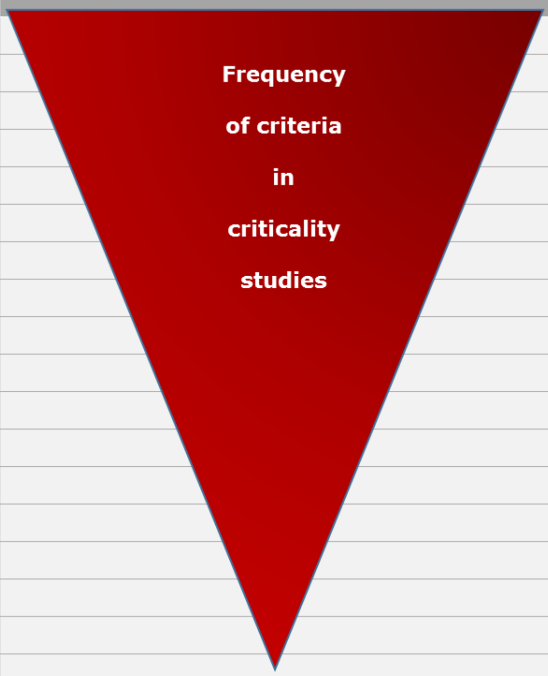
Many publications report assessments of raw materials criticality: various insightful comparisons between raw material criticality methodologies and their outcomes have been published before[66]. Though most authors develop 'proprietary' assessments, the overall approach and the nature of the indicators is remarkably similar. It is clear from the review of the criticality studies that there are many features in common. Mayer (2015) represent these common features observed between different criticality methodologies as illustrated in Figure 12.

The general approach of a risk analysis i.e. determining a probability of an event and the consequences if that event takes place) is followed by many authors. The clearer that approach, the clearer the outcome: in the EC criticality methodology, the role of indicators relating to substitutability as a factor influencing Supply Risk, can be revised, since substitutability is generally seen as a factor mitigating the impact of supply disruption (and thus a factor influencing the x-axis).

[66] Relevant reviews are: L. Erdmann, T.E. Graedel, Criticality of Non-fuel minerals: A Review of Major Approaches and analyses, Environ.Sci.RTechnol. 2011, 7620-7630; C. Helbig et al., How to evaluate raw material vulnerability – An Overview, Resources Policy, 2016, 13-24; Annex F of the Study on Critical Raw Materials at EU Level by the EC, 2014; Mayer, H. and Gleich, B. (2015) Measuring Criticality of Raw Materials: An Empirical Approach Assessing the Supply Risk Dimension of Commodity Criticality. Natural Resources, 6, 56-78.

Figure 12: Common features of criticality methodologies[67]

Indicator	Dimension	Data type
Geopolitical concentration	SR	●
Static reserve range	SR	●
Mine production	SR	●
Economic relevance	VU	○
Supply & demand trends	SR	●
Strategic relevance	VU	○
Recycling rates	SR	●
Substitutability	VU / SR	○
Production as by-product	SR	○
Political conditions	VU	○
Company concentration	SR	●
Emerging technologies	VU / SR	○
Production costs	SR	●
Functionality & Technology	VU	○
Ability to drive through price	VU	○
Damage potential	ER	○
Impact on climate change	SR / ER	○
Exploration budget & investment	SR	●



○ : Qualitative data ● : Quantitative data **VU**: Vulnerability **SR**: Supply Risk **ER**: Environmental risk

With respect to assessing the probability of supply disruption we can conclude:

- **Recycling** is used as an indicator for the Supply Risk axis in several studies. Though recyclability in itself does not impact Supply Risk, nor does it influence the impact as such (for, recycling levels are rather constant over time and a supply disruption therefore does not lead to more recycling as a reaction), it is considered relevant to include recyclability because it indicates the availability of a secondary source in (often) consumer countries. It is worthwhile devoting effort to assess production volumes and countries for secondaries, so that these data can be included in the generally accepted HHI indicator.
- **Distribution of reserves** over the globe (as opposed to distribution of current production) is already used in several papers, and may be considered for future use for long term risk analysis. The EU-28 is the proper podium to identify long term upcoming monopolies and consider action. For shorter term company actions reserve distribution is indeed les relevant.
- **The companionality** is an indicator already used in several studies and is worthwhile considering in future vulnerability assessments, though more effort should be paid to the insight in current refining capacities and the extent to which the maximum levels of companions are currently harvested.

With respect to assessing the impact of supply disruption we can conclude:

- **Substitution** is commonly employed as an element that has an impact on the vulnerability, a debate about the level at which substitution is considered (material for material, function for function) is not conclusive which renders this indicator prone to varying interpretation. Short term substitutes of high TRL that do not significantly alter production processes may be a **narrow** but workable **definition** on a company (and thus economy and added value) level.
- The relation between raw materials and the direct impact on the economy benefits from deep knowledge about the **actual application of raw materials in products**, the estimates currently employed in the EC-assessments (gross allocation of raw material use to NACE sectors) could be refined to a great extent with some existing methods.

[67] Mayer, 2015

Several papers conclude that these vulnerability assessments should pay **more attention to the dynamic aspects of the raw materials market** and should provide more data about price volatility and the future demand and supply situation. Some methods that were discussed require deep (agent-based or system dynamic) modelling and it is obvious that such methods cannot be used for the current purposes. The use of exploration investments was also shown to be non-conclusive. However, it might be considered to use trends of production and consumption over limited historic time-series in order to highlight issues for materials that have experienced high demand growth under stagnating mining capacity or unexpected high price volatilities.

Regarding the supply and value chain of raw materials, with only a few exceptions, **none of the criticality methodologies pay attention to the potential vulnerability caused by processes** in the value chain between the actual extraction process and the final consumption by a company or country. This could lead to overestimates on the risks at the mining/harvesting stage and underestimates the vulnerabilities due to production concentrations in the refining industry and the manufacturing industry further down the value chain. The emphasis in the raw materials debate may therefore in cases focus on the wrong materials and wrong players and actions. In the revised EC-methodology this is partly addressed by at least assessing whether the 'next step' in processing (i.e. refining) of materials exhibits higher country concentration than the extraction stage. Ideally, for strategic value chains, such analyses should be taken beyond the point of refining and dive deeper in the value chain.

Annex 3. Stages assessed and rationale

	Stage assessed		Overview of rationales		Detailed rationales for stage assessed	
Material	Extraction	Processing	Data quality / (un)availability	Known bottleneck	Data quality / (un)availability on EU and global supply	Known bottleneck / expert feedback
Aggregates	X		X		Yes	Global supply data was available at both stages (extraction and refining). However, there is no strong evidence for significant refining production in the EU, therefore the extraction stage was selected for the criticality assessment.
Bauxite	X	See rationale under aluminium	X	X	Yes	The criticality of aluminium is assessed for two different life cycle stages, the extraction and processing stage (see Al criticality assessment). Data on global and EU supply was available and used in the assessment. It is important to assess the extraction stage, as the import reliance in Europe is substantial.
Aluminium	See rationale under bauxite	X	X	X	Yes	The criticality of aluminium is assessed for two different life cycle stages, the extraction and refining (see bauxite criticality assessment). Data on global and EU supply was available and used in the assessment. It is important to assess the refining stage, due to the importance of Aluminium in the European manufacturing sector and the competing demand from other global regions/ countries.
Antimony		X	N/A	X	N/A	Although trade data is available for antimony ores and concentrates, the criticality assessment for antimony is based on the production and trade of unwrought antimony metal (processing stage). This is because unwrought metal is the most significant form in terms of trade volume and therefore represents the most likely bottleneck in the EU supply chain.
Baryte	X		X	N/A	Global supply data was available at the extraction stage only, therefore this stage was selected for the criticality assessment.	N/A
Bentonite	X		X	X	Yes	Global and EU supply data was available at the extraction stage. Further, there was no robust evidence indicating a bottleneck at the refining stage, therefore the extraction stage was selected. Europe is a major producer of bentonite hence the sector is important for the EU economy.
Beryllium	X		X	N/A	N/A	There is no production of beryllium ores (extraction step) or refined beryllium (processing step) in the EU, however refined materials are the main traded form imported to the EU, therefore it was assumed that the processing stage would represent the most likely bottleneck in the EU supply chain by experts. However, after further analysis, the extraction stage was selected as the bottleneck, as the SR results are higher.
Bismuth		X	X	N/A	Global supply data was available at the refining stage only, therefore this stage was selected for the criticality assessment.	N/A

	Stage assessed		Overview of rationales		Detailed rationales for stage assessed	
Material	Extraction	Processing	Data quality / (un)availability	Known bottleneck	Data quality / (un)availability on EU and global supply	Known bottleneck / expert feedback
Borate	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). There is no production activity of natural borates in the EU. However, the extraction stage was selected for the criticality assessment since ores are imported to the EU and the SR results are higher for this stage.
Cerium	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). Based on expert opinion and stakeholder feedback, the supply risk of REE concentrates is greater than the supply risk of REE metals, therefore the extraction stage was selected for the criticality assessment.
Chromium		X	X		Global supply data was available at the refining stage only, therefore this stage was selected for the criticality assessment.	N/A
Cobalt	X		X	X	Yes	The assessment was originally done on both stages (ores & concentrates, refined material). Previously it was thought that the bottleneck was at the refined stage, but actually there is a greater supply risk at the ores & concentrates stage, therefore results of the extraction phase are presented.
Coking coal		x	X	X	Global supply data was available at the refining stage only, therefore this stage was selected for the criticality assessment.	N/A
Copper	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). However, there is no strong evidence for significant refining production in the EU, therefore the extraction stage was selected for the criticality assessment.
Diatomite	X		X	X	Global supply data was available at the extraction stage only.	Global supply data was available at the extraction stage only. Further, there is no strong evidence indicating a bottleneck at the refining stage, therefore the extraction stage was selected for the criticality assessment.
Dysprosium	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). Based on expert opinion and stakeholder feedback, the supply risk of REE concentrates is greater than the supply risk of REE metals, therefore the extraction stage was selected for the criticality assessment.
Erbium	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). Based on expert opinion and stakeholder feedback, the supply risk of REE concentrates is greater than the supply risk of REE metals, therefore the extraction stage was selected for the criticality assessment.

	Stage assessed		Overview of rationales		Detailed rationales for stage assessed	
Material	Extraction	Processing	Data quality / (un)availability	Known bottleneck	Data quality / (un)availability on EU and global supply	Known bottleneck / expert feedback
Europium	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). Based on expert opinion and stakeholder feedback, the supply risk of REE concentrates is greater than the supply risk of REE metals, therefore the extraction stage was selected for the criticality assessment.
Feldspar	X		X	X	Global supply data was available at the extraction stage only.	Global supply data was available at the extraction stage only. Further, there is no strong evidence indicating that there is a bottleneck at the refining stage, therefore the extraction stage was selected for the criticality assessment.
Fluorspar	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). However, since extraction activity occurs in EU, the extraction stage was selected for the criticality assessment.
Gadolinium	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). Based on expert opinion and stakeholder feedback, the supply risk of REE concentrates is greater than the supply risk of REE metals, therefore the extraction stage was selected for the criticality assessment.
Gallium		X	X	N/A	Global supply data was available at the refining stage only, therefore this stage was selected for the criticality assessment.	N/A
Germanium		X	N/A	X	N/A	Ge is a by-product extracted from Zn ores and there are no Ge ores imports to the EU. Therefore, the processing stage was selected for the criticality assessment as it is assumed the processing stage has the highest supply risk i.e. bottleneck
Gold	X		X		Global supply data was available at the extraction stage only, therefore was selected for the criticality assessment.	N/A
Gypsum	X		X	X	Global and EU supply data was available at the extraction stage only.	Global and EU supply data was available at the extraction stage only. The rationale for the selection of the bottleneck is that for most industrial minerals the extraction stage is the bottleneck, as they are produced and sold in this form to product manufacturers.
Hafnium	-	X	N/A	X	N/A	Hafnium is only obtained as a by-product during the processing of other minerals e.g. zirconium. Therefore, data at the extraction (mine) level cannot exist. As such, the processing stage was selected as the bottleneck for the criticality assessment as the data used represents materials obtained after processing.
Helium		X	X	N/A	Global supply data was available at the refining stage only, therefore the processing stage was selected for the criticality assessment.	N/A

	Stage assessed		Overview of rationales		Detailed rationales for stage assessed	
Material	Extraction	Processing	Data quality / (un)availability	Known bottleneck	Data quality / (un)availability on EU and global supply	Known bottleneck / expert feedback
Holmium	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). Based on expert opinion and stakeholder feedback, the supply risk of REE concentrates is greater than the supply risk of REE metals, therefore the extraction stage was selected for the criticality assessment.
Indium		X	X	N/A	Global supply data was available at the refining stage only, therefore the processing stage was selected for the criticality assessment.	N/A
Iridium		X	N/A	X	N/A	Almost all iridium derived from primary source materials (i.e. mine production) is traded in the form of refined metal produced from integrated mining/metallurgical operations. There is only very limited international trade in iridium ores and concentrates, therefore the processing stage was selected for the criticality assessment.
Iron ore	X		X	X	Yes	Global and EU supply data was available at the extraction stage. The rationale for the selection of the bottleneck is the significant import reliance of iron ore to the EU.
Kaolin clay	X		X	X	Global and EU supply data was available at the extraction stage.	Global supply data was available at the extraction stage only. Further, there is no evidence indicating a bottleneck at the refining stage, therefore the extraction stage was selected for the criticality assessment.
Lanthanum	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). Based on expert opinion and stakeholder feedback, the supply risk of REE concentrates is greater than the supply risk of REE metals, therefore the extraction stage was selected for the criticality assessment.
Lead	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). Based on feedback from experts and EU trade data, the extraction stage represents a higher supply risk for the EU. Therefore, the extraction stage was selected for the criticality assessment.
Limestone	X		X	X	Global supply data for high grade limestone are not readily available.	Global supply data for high grade limestone are not readily available. Therefore, based on feedback from experts and data availability and quality, the extraction stage was selected for the criticality assessment, nevertheless data availability is very limited to undertake a detailed assessment.
Lithium		X	X	X	Yes	Global supply data was available at both stages (extraction and refining). Based on feedback from experts and EU trade data, the processing stage represents a higher supply risk for the EU. Therefore, the processing stage was selected for the criticality assessment.

	Stage assessed		Overview of rationales		Detailed rationales for stage assessed	
Material	Extraction	Processing	Data quality / (un)availability	Known bottleneck	Data quality / (un)availability on EU and global supply	Known bottleneck / expert feedback
Lutetium	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). Based on expert opinion and stakeholder feedback, the supply risk of REE concentrates is greater than the supply risk of REE metals, therefore the extraction stage was selected for the criticality assessment.
Manganese	X		N/A	X	N/A	Europe relies heavily on imports of manganese ores and concentrates, which is the primary reason for the selection of the extraction stage for the bottleneck assessed in the criticality assessment.
Magnesite	X		X	N/A	Global supply data was available at the extraction stage only, therefore the extraction stage was selected for the criticality assessment.	N/A
Magnesium		X	X	X	X	There is no production of dolomite (extraction step of magnesium value chain) or refined magnesium (processing step) in the EU, however the refined materials are significantly imported to the EU, therefore indicating that that the processing step represents the highest supply risk. As such, the processing stage was selected for the criticality assessment. It is important to assess the refining stage of magnesium, due to the importance of magnesium metal in the European manufacturing sector and the competing demand from other global regions/ countries.
Molybdenum	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). The extraction stage was selected for the criticality assessment based on data quality and the number of source countries.
Natural cork	X		X	X	Global supply data was available at the extraction stage only.	Global supply data was available at the extraction stage only. Further, there is no strong evidence for significant refining production in the EU, therefore the extraction stage was selected for the criticality assessment.
Natural graphite	X		X	N/A	Global supply data was available at the extraction stage only, therefore the extraction stage was selected for the criticality assessment.	N/A
Natural Rubber	X		X	X	Global supply data was available at the extraction stage only.	Global supply data was available at the extraction stage only. Further, there is no strong evidence for significant refining production in the EU, therefore the extraction stage was selected for the criticality assessment.

	Stage assessed		Overview of rationales		Detailed rationales for stage assessed	
Material	Extraction	Processing	Data quality / (un)availability	Known bottleneck	Data quality / (un)availability on EU and global supply	Known bottleneck / expert feedback
Natural Teak wood	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). However, there is no strong evidence for significant refining production in the EU, therefore the extraction stage was selected for the criticality assessment.
Neodymium	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). Based on expert opinion and stakeholder feedback, the supply risk of REE concentrates is greater than the supply risk of REE metals, therefore the extraction stage was selected for the criticality assessment.
Nickel		X	X	X	Yes	Global supply data was available at both stages (extraction and refining), however the criticality assessment of nickel is performed for the refined material, which is justified by the fact that the refined material is a metal with a nickel content of over 99%. Therefore this stage is most relevant life cycle stage for assessing the economic importance, substitution options and realistic recycling input rates. An additional justification for selection of the processing stage for the criticality assessment was to harmonize the economic applications of nickel with the two previous assessments.
Niobium		X	N/A	X	N/A	The processing stage was selected for the criticality assessment based on feedback received from experts indicating that the processing stage (e.g. ferroniobium) represents the most important bottleneck for the EU.
Palladium		X	N/A	X	N/A	Almost all palladium derived from primary source materials (i.e. mine production) is traded in the form of refined metal produced from integrated mining/metallurgical operations. There is only very limited international trade in palladium ores and concentrates. Therefore, the processing stage was selected for the criticality assessment.
Perlite	X		X	X	Global and EU supply data was available at the extraction stage only.	Global and EU supply data was available at the extraction stage only. Similarly to other industrial minerals, the extraction stages is mainly the bottleneck. Europe is a major producer of perlite therefore the extraction stage is of major importance to the EU.
Phosphate rock	X		X	X	Global and EU supply data was available at the extraction stage.	To highlight the difference between an extracted product and a refined product, both phosphate rock and phosphorus (P4) are assessed
Phosphorus		X	X	X	Global and EU supply data was available at the processing stage.	To highlight the difference between an extracted product and a refined product, both phosphate rock and phosphorus (P4) are assessed
Platinum		X	N/A	X	N/A	Almost all platinum derived from primary source materials (i.e. mine production) is traded in the form of refined metal produced from integrated mining/metallurgical operations. There is only very limited international trade in platinum ores and concentrates. Therefore, the processing stage was selected for the criticality assessment.

	Stage assessed		Overview of rationales		Detailed rationales for stage assessed	
Material	Extraction	Processing	Data quality / (un)availability	Known bottleneck	Data quality / (un)availability on EU and global supply	Known bottleneck / expert feedback
Potash	X		X	X	Global supply data was available at the extraction stage only.	Global supply data was available at the extraction stage only. Limitations with data availability is the primary reason for the selection of the extraction stage instead of the refining stage to undertake the assessment.
Praseodymium	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). Based on expert opinion and stakeholder feedback, the supply risk of REE concentrates is greater than the supply risk of REE metals, therefore the extraction stage was selected for the criticality assessment.
Rhenium		X	X	X	Global supply data was available at the refining stage only, therefore the processing stage was selected for the criticality assessment.	N/A
Rhodium		X	N/A	X	N/A	Almost all rhodium derived from primary source materials (i.e. mine production) is traded in the form of refined metal produced from integrated mining/metallurgical operations. There is only very limited international trade in rhodium ores and concentrates. Therefore, the processing stage was selected for the criticality assessment.
Ruthenium		X	N/A	X	N/A	Almost all ruthenium derived from primary source materials (i.e. mine production) is traded in the form of refined metal produced from integrated mining/metallurgical operations. There is only very limited international trade in ruthenium ores and concentrates. Therefore, the processing stage was selected for the criticality assessment.
Samarium	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). Based on expert opinion and stakeholder feedback, the supply risk of REE concentrates is greater than the supply risk of REE metals, therefore the extraction stage was selected for the criticality assessment.
Sapele wood	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). However, there is no strong evidence for significant refining production in the EU, therefore the extraction stage was selected for the criticality assessment.
Scandium		X	X	N/A	Global supply data was available at the refining stage only, therefore the extraction stage was selected for the criticality assessment.	N/A
Selenium		X	X	X	Global and EU supply data was available at the processing stage only.	Global and EU supply data was available at the processing stage only, therefore the processing stage was selected for the criticality assessment. Selenium is a by-product recovered during the refining of copper, therefore it is only the processing stage that is relevant for the assessment.

	Stage assessed		Overview of rationales		Detailed rationales for stage assessed	
Material	Extraction	Processing	Data quality / (un)availability	Known bottleneck	Data quality / (un)availability on EU and global supply	Known bottleneck / expert feedback
Silica sand	X		X	N/A	Global supply data was available at the extraction stage only, therefore the extraction stage was selected for the criticality assessment.	N/A
Silicon metal		X	X	X	Global supply data was available at the refining stage only. Therefore the processing stage was selected for the criticality assessment.	Global supply data was available at the refining stage only. In addition, expert feedback indicated that there is no significant bottleneck at the extraction stage. Therefore, the processing stage was selected for the criticality assessment based on expert feedback and data availability.
Silver	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). The extraction stage was selected for the criticality assessment based on data quality and the number of source countries.
Sulphur		X	X	X	Global supply data was available at the refining stage only.	Global supply data was available at the refining stage only. Therefore the processing stage was selected for the criticality assessment.
Talc	X		X	X	Global supply data was available at the extraction stage only.	Global supply data was available at the extraction stage only. Further, there is no strong evidence indicating a bottleneck at the refining stage, therefore the extraction stage was selected for the criticality assessment.
Tantalum	X		X	X	Global supply data was available at the extraction stage only.	Global supply data was available at the extraction stage only. Further, there is no strong evidence indicating a bottleneck at the refining stage, therefore the extraction stage was selected for the criticality assessment.
Tellurium		X	X	X	Global and EU supply data was available at the processing stage only.	Global and EU supply data was available at the processing stage only, therefore the processing stage was selected for the criticality assessment. Tellurium is mainly produced as a by-product of copper refining, therefore the processing stage is only relevant for this assessment.
Terbium	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). Based on expert opinion and stakeholder feedback, the supply risk of REE concentrates is greater than the supply risk of REE metals, therefore the extraction stage was selected for the criticality assessment.
Thulium	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). Based on expert opinion and stakeholder feedback, the supply risk of REE concentrates is greater than the supply risk of REE metals, therefore the extraction stage was selected for the criticality assessment.
Tin		X	X	X	Yes	Global supply data was available at both stages (extraction and refining). The processing stage was selected for the criticality assessment since evidence indicates that refined tin is the major traded product all over the world.

	Stage assessed		Overview of rationales		Detailed rationales for stage assessed	
Material	Extraction	Processing	Data quality / (un)availability	Known bottleneck	Data quality / (un)availability on EU and global supply	Known bottleneck / expert feedback
Titanium	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). The extraction stage was selected for the criticality assessment based on data quality and the number of source countries.
Tungsten	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). The extraction stage was selected for the criticality assessment since evidence indicates that extraction occurs in the EU.
Vanadium		X	X	N/A	Yes	Global supply data was available at both stages (extraction and refining). Originally the extraction stage was selected for assessment, however after further investigation, the stage assessed changed from extraction to processing. Updated expert input confirmed that even if the EI/SR results from the assessment of the extraction stage of vanadium may show higher SR values, it is based on highly uncertain trade data (vanadium ores) that is very likely to be inaccurate because of the large uncertainty relating to the shares of tantalum and niobium in the Comext CN product group (with which vanadium is aggregated). Expert input confirmed selection of the processing stage as the stage to be assessed based on much more reliable data on refined vanadium.
Ytterbium	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). Based on expert opinion and stakeholder feedback, the supply risk of REE concentrates is greater than the supply risk of REE metals, therefore the extraction stage was selected for the criticality assessment.
Yttrium	X		X	X	Yes	Global supply data was available at both stages (extraction and refining). Based on expert opinion and stakeholder feedback, the supply risk of REE concentrates is greater than the supply risk of REE metals, therefore the extraction stage was selected for the criticality assessment.
Zinc	X		X	X	Yes	G+A1:G80lobal supply data was available at both stages (extraction and refining). The extraction stage was selected for the criticality assessment based on data quality and the number of source countries.

Annex 4. Data sources used in criticality assessments

Please see the attached separate annex, which provides a list of the data sources used in the assessments. The data sources used in the assessments and overview of their quality are also provided in each of the material factsheets (see the separate critical and non-critical raw material factsheets).

Annex 5. Additional details on the criticality assessment results

Annex 5 provides the following additional criticality assessment results:

- Substitution indexes and $HHI_{(WGI)}$ (Table 18)
- Comparison of Supply Risk results when using different supply data (Table 19)
- Comparison of the results of the three assessments (Table 20)
- Individual and average EI and SR results of the grouped materials – HREEs, LREEs and PGMs (Table 21)

Table 18 provides the detailed results of the substitution indexes and $HHI_{(WGI)}$ for each of the candidate materials assessed.

Table 18: Substitution indexes and $HHI_{(WGI)}$ values

Material	SI(EI)	SI(SR)	Global Supply Risk (HHIWGI-t)GS	EU Supply Risk (HHIWGI-t)EU28
Aggregates	0.9	0.9	0.2	0.2
Aluminium	0.8	0.9	1.4	0.3
Antimony	0.9	0.9	7.1	5.7
Baryte	0.9	0.9	1.5	1.8
Bauxite	1.0	1.0	0.6	3.1
Bentonite	0.9	0.9	0.6	0.5
Beryllium	1.0	1.0	2.4	N/A
Bismuth	1.0	0.9	4.0	4.2
Borate	1.0	1.0	1.1	5.0
Cerium	1.0	1.0	9.2	2.6
Chromium	1.0	1.0	1.2	1.1
Cobalt	1.0	1.0	3.6	1.3
Coking coal	0.9	0.9	2.8	0.3
Copper	1.0	1.0	0.5	0.5
Diatomite	0.9	0.9	0.7	0.3
Dysprosium	0.9	0.9	9.2	1.8
Erbium	0.9	1.0	9.2	1.6
Europium	1.0	1.0	9.2	1.8
Feldspar	0.9	1.0	0.5	0.7
Fluorspar	1.0	1.0	2.6	0.7
Gadolinium	0.9	0.9	9.2	1.8
Gallium	0.9	1.0	3.5	1.1
Germanium	1.0	1.0	2.9	1.5
Gold	1.0	1.0	0.3	0.0
Gypsum	0.8	0.9	0.5	0.5
Hafnium	0.9	1.0	1.0	1.4
Helium	0.9	1.0	1.7	1.3
Holmium	1.0	1.0	9.2	1.8
Indium	0.9	1.0	2.5	0.8
Iridium	0.9	1.0	3.4	0.0
Iron ore	0.9	1.0	1.4	0.8
Kaolin clay	0.9	0.9	0.3	0.5
Lanthanum	1.0	1.0	9.2	1.8
Lead	1.0	1.0	1.8	0.3
Limestone	0.9	0.9	1.9	0.3
Lithium	0.9	0.9	0.8	1.4
Lutetium	1.0	1.0	9.2	1.8
Magnesite	1.0	1.0	3.9	0.7
Magnesium	0.9	0.9	4.4	5.2
Manganese	1.0	1.0	0.9	1.2
Molybdenum	1.0	1.0	1.4	1.1
Natural cork	0.9	0.9	1.0	1.3
Natural graphite	1.0	1.0	3.2	2.9

Material	SI(EI)	SI(SR)	Global Supply Risk (HHIWGI-t)GS	EU Supply Risk (HHIWGI-t)EU28
Natural Rubber	0.9	0.9	1.2	1.0
Natural Teak wood	0.9	0.9	1.0	1.8
Neodymium	0.9	0.9	8.8	1.8
Nickel	0.9	1.0	0.9	0.4
Niobium	0.9	0.9	4.1	2.5
Palladium	0.9	1.0	1.9	0.0
Perlite	0.9	0.9	0.8	1.7
Phosphate rock	1.0	1.0	1.8	0.8
Phosphorus	0.9	0.9	2.3	4.5
Platinum	0.9	1.0	2.5	0.0
Potash	1.0	1.0	0.6	0.8
Praseodymium	0.9	0.9	9.2	1.8
Rhenium	1.0	1.0	0.8	2.0
Rhodium	1.0	1.0	3.3	0.0
Ruthenium	0.9	1.0	4.0	0.0
Samarium	0.8	0.8	9.2	1.6
Sapele wood	0.9	0.9	0.0	1.8
Scandium	0.9	1.0	3.0	3.4
Selenium	0.9	0.9	0.5	0.4
Silica sand	1.0	1.0	0.5	0.3
Silicon metal	1.0	1.0	2.3	0.4
Silver	1.0	1.0	0.5	1.6
Sulphur	1.0	1.0	0.3	0.7
Talc	1.0	1.0	0.8	0.4
Tantalum	0.9	0.9	1.0	4.6
Tellurium	0.8	0.9	0.9	0.7
Terbium	0.8	0.9	9.2	1.8
Thulium	1.0	1.0	9.2	1.8
Tin	0.9	0.9	2.0	0.8
Titanium	0.9	0.9	0.4	0.5
Tungsten	0.9	1.0	7.5	1.9
Vanadium	0.9	0.9	2.5	3.3
Ytterbium	1.0	1.0	9.2	1.8
Yttrium	1.0	1.0	9.2	1.8
Zinc	0.9	0.9	0.9	0.4

Table 19 presents the results of the Supply Risk calculation when using different Supply Risk data, which is based either on global supply or EU sourcing data only, or based on both global supply and EU sourcing depending on the availability and quality of the data for a given material.

Legend

PGMs	Iridium, palladium, platinum, rhodium, ruthenium
LREEs	Cerium, lanthanum, neodymium, praseodymium and samarium
HREEs	Dysprosium, erbium, europium, gadolinium, holmium, lutetium, terbium, thulium, ytterbium, yttrium

Table 19: Comparison of SR results based on scope of supply data used

	Supply Risk parameters		
Material	Global supply	EU sourcing	Global & EU sourcing
Aggregates	0.2	0.2	0.2
Aluminium	1.1	0.2	0.5
Antimony	4.8	3.9	4.3
Baryte	1.4	1.7	1.6
Bauxite	0.6	3.1	2.0
Bentonite	0.3	0.2	0.2
Beryllium	2.4	N/A	N/A

	Supply Risk parameters		
Material	Global supply	EU sourcing	Global & EU sourcing
Bismuth	3.8	3.9	3.8
Borate	1.1	5.0	3.0
Cerium	9.0	2.5	5.7
Chromium	1.0	0.9	0.9
Cobalt	3.6	1.3	1.6
Coking coal	2.5	0.3	1.0
Copper	0.2	0.2	0.2
Diatomite	0.6	0.3	0.3
Dysprosium	8.7	1.7	5.2
Erbium	8.7	1.5	5.1
Europium	5.7	1.1	3.4
Feldspar	0.5	0.6	0.6
Fluorspar	2.4	0.6	1.3
Gadolinium	8.5	1.6	5.1
Gallium	3.4	1.0	1.4
Germanium	2.9	1.4	1.9
Gold	0.2	0.0	0.1
Gypsum	0.4	0.5	0.5
Hafnium	1.0	1.3	1.3
Helium	1.6	1.3	1.4
Holmium	9.1	1.7	5.4
Indium	2.4	0.7	0.7
Iridium	2.8	0.0	1.4
Iron ore	1.1	0.6	0.8
Kaolin clay	0.3	0.5	0.5
Lanthanum	9.0	1.7	5.4
Lead	0.4	0.1	0.1
Limestone	0.7	0.1	0.1
Lithium	0.8	1.3	1.0
Lutetium	9.1	1.7	5.4
Magnesite	3.8	0.7	0.7
Magnesium	3.7	4.3	4.0
Manganese	0.8	1.0	0.9
Molybdenum	0.9	0.8	0.9
Natural cork	0.8	1.1	1.1
Natural graphite	3.0	2.7	2.9
Natural Rubber	1.1	1.0	1.0
Natural Teak wood	0.9	1.6	1.3
Neodymium	8.0	1.6	4.8
Nickel	0.6	0.2	0.3
Niobium	3.8	2.3	3.1
Palladium	1.7	0.0	0.9
Perlite	0.4	0.9	0.9
Phosphate rock	1.5	0.6	1.0
Phosphorus	2.1	4.1	3.1
Platinum	2.1	0.0	1.0
Potash	0.6	0.8	0.7
Praseodymium	7.8	1.5	4.6
Rhenium	0.4	1.0	1.0
Rhodium	2.5	0.0	1.2
Ruthenium	3.4	0.0	1.7
Samarium	7.5	1.3	4.4
Sapele wood	0.0	1.4	0.7
Scandium	2.9	3.3	3.1
Selenium	0.4	0.4	0.4
Silica sand	0.5	0.3	0.3
Silicon metal	2.3	0.4	1.0
Silver	0.2	0.7	0.5
Sulphur	0.3	0.6	0.6

	Supply Risk parameters		
Material	Global supply	EU sourcing	Global & EU sourcing
Talc	0.7	0.4	0.4
Tantalum	1.0	4.3	2.7
Tellurium	0.8	0.6	0.7
Terbium	8.0	1.5	4.8
Thulium	9.1	1.7	5.4
Tin	1.2	0.5	0.8
Titanium	0.3	0.4	0.3
Tungsten	4.2	1.1	1.8
Vanadium	1.3	1.7	1.6
Ytterbium	9.1	1.7	5.4
Yttrium	6.3	1.2	3.8
Zinc	0.6	0.2	0.3

Table 20 compares the results of the 2017 and previous assessments.

Legend	
Critical	Identified as a critical raw material
Non-critical	Identified as a non-critical raw material
PGMs	Iridium, palladium, platinum, rhodium, ruthenium
LREEs	Cerium, lanthanum, neodymium, praseodymium and samarium
HREEs	Dysprosium, erbium, europium, gadolinium, holmium, lutetium, terbium, thulium, ytterbium, yttrium
-	Not assessed
SR*	In 2011 and 2014 assessments, the SR calculation was based on World Governance indicators

Table 20: Comparison of 2017 assessment results and previous assessments[68]

Criticality studies	2011		2014		2017	
Material	SR*	EI	SR*	EI	SR	EI
Aggregates	-	-	-	-	0.2	2.3
Aluminium	0.2	8.9	0.4	7.6	0.5	6.5
Antimony	2.6	5.8	2.5	7.1	4.3	4.3
Baryte	1.7	3.7	1.7	2.8	1.6	2.9
Bauxite	0.3	9.5	0.6	8.6	2.0	2.6
Bentonite	0.3	5.5	0.4	4.6	0.2	2.1
Beryllium	1.3	6.2	1.5	6.7	2.4	3.9
Bismuth	-	-	-	-	3.8	3.6
Borate	0.6	5.0	1.0	5.7	3.0	3.1
Chromium	0.8	9.9	1.0	8.9	0.9	6.8
Cobalt	1.1	7.2	1.6	6.7	1.6	5.7
Coking coal	-	-	1.2	9.0	1.0	2.3
Copper	0.2	5.7	0.2	5.8	0.2	4.7
Diatomite	0.3	3.7	0.2	3.0	0.3	3.8
Feldspar	0.2	5.2	0.4	4.8	0.6	2.4
Fluorspar	1.6	7.5	1.7	7.2	1.3	4.2
Gallium	2.5	6.5	1.8	6.3	1.4	3.2

[68] The 2011 assessment presented the results of the following materials as part of specific material groups:
PGMs - palladium, platinum, iridium, rhodium, ruthenium and osmium.
REEs - yttrium, scandium, lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium and lutetium. Heavy Rare Earth Elements, Light Rare Earth Elements and Scandium were considered together as Rare Earth Elements in the 2011 exercise.

The 2014 assessment presented the results of the following materials as part of specific material groups:
PGMs - palladium, platinum, rhodium, ruthenium, iridium and osmium.
LREEs - lanthanum, cerium, praseodymium, neodymium, and samarium.
HREEs - dysprosium, erbium, europium, gadolinium, holmium, lutetium, terbium, thulium, ytterbium, yttrium.

Criticality studies	2011		2014		2017	
Material	SR*	EI	SR*	EI	SR	EI
Germanium	2.7	6.3	1.9	5.5	1.9	3.5
Gold	-	-	0.2	3.8	0.2	2.0
Gypsum	0.4	5.0	0.5	5.5	0.5	2.2
Hafnium	-	-	0.4	7.8	1.3	4.2
Helium	-	-	-	-	1.6	2.8
HREEs	4.9	5.8	4.7	5.4	4.9	3.7
Indium	2.0	6.7	1.8	5.6	2.4	3.1
Iron ore	0.4	8.1	0.5	7.4	0.8	6.2
Kaolin clay	0.3	4.4	0.3	4.8	0.5	2.3
Lead	-	-	-	-	0.1	3.7
Limestone	0.7	6.0	0.4	5.8	0.1	2.5
Lithium	0.7	5.6	0.6	5.5	1.0	2.4
LREEs	4.9	5.8	3.1	5.2	5.0	3.6
Magnesite	0.9	8.9	2.2	8.3	0.7	3.7
Magnesium	2.6	6.5	2.5	5.5	4.0	7.1
Manganese	0.5	9.8	0.4	7.8	0.9	6.1
Molybdenum	0.5	8.9	0.9	5.9	0.9	5.2
Natural cork	-	-	-	-	1.1	1.5
Natural graphite	1.3	8.7	2.2	7.4	2.9	2.9
Natural Rubber	-	-	0.9	7.7	1.0	5.4
Natural Teak wood	-	-	-	-	0.9	2.0
Nickel	0.3	9.5	0.2	8.8	0.3	4.8
Niobium	2.8	9.0	2.5	5.9	3.1	4.8
Perlite	0.3	4.2	0.3	4.6	0.4	2.1
PGMs	3.6	6.7	1.2	6.6	2.5	5.0
Phosphate rock	-	-	1.1	5.8	1.0	5.1
Phosphorus	-	-	-	-	4.1	4.4
Potash	-	-	0.2	8.6	0.6	4.8
Rhenium	0.8	7.7	0.9	4.5	1.0	2.0
Sapele wood	-	-	-	-	1.4	1.3
Scandium	4.9	5.8	1.1	3.8	2.9	3.7
Selenium	-	-	0.2	6.9	0.4	4.5
Silica sand	0.2	5.8	0.3	5.8	0.3	2.6
Silicon metal	-	-	1.6	7.1	1.0	3.8
Silver	0.3	5.1	0.7	4.8	0.5	3.8
Sulphur	-	-	-	-	0.6	4.6
Talc	0.3	4.0	0.3	5.1	0.4	3.0
Tantalum	1.1	7.4	0.6	7.4	1.0	3.9
Tellurium	0.6	7.9	0.2	6.0	0.7	3.4
Tin	-	-	0.9	6.7	0.8	4.4
Titanium	0.1	5.4	0.1	5.5	0.3	4.3
Tungsten	1.8	8.8	2.0	9.1	1.8	7.3
Vanadium	0.7	9.7	0.8	9.1	1.6	3.7
Zinc	0.4	9.4	0.5	8.7	0.3	4.5

The average and individual EI and SR scores for each of the individual materials categorised in groups are presented in Table 21 to provide additional information to consider when analysing the results. The SR and EI averages for the PGMs, HREEs and LREEs groups should be considered very carefully because they were not assessed separately in the previous assessments. PGMs and REEs were treated as single groups in 2011 assessment, and accordingly PGMs, HREEs and LREEs were treated as single groups in 2014. The average results of the five materials that are part of the PGMs group, 10 materials of HREEs group and 5 materials of LREEs group, are presented to allow backwards comparability. Nevertheless, when looking at the individual materials' assessment results, all of them would be considered critical with the exception of erbium (EI=2.7) and lanthanum (EI=1.4) with EI results below the EI criticality threshold of 2.8).

Table 21: Individual and average EI and SR scores for material groups – LREEs, HREEs and PGMs

Materials	Supply Risk	Economic Importance	Import reliance (%)	EOL-RIR (%)	Supply data in SR
Cerium	5.7	3.2	100	1	Global supply and EU sourcing
Lanthanum	5.4	1.4	100	1	
Neodymium	4.8	4.2	100	1	
Praseodymium	4.6	3.8	100	10	
Samarium	4.5	5.5	100	1	
Dysprosium	5.2	6.3	100	0	Global supply and EU sourcing
Erbium	5.2	2.7	100	1	
Europium	3.4	3.7	100	38	
Gadolinium	5.1	4.1	100	1	
Holmium	5.4	3.3	100	1	
Lutetium	5.4	3.3	100	1	
Terbium	4.8	3.9	100	6	
Thulium	5.4	3.3	100	1	
Ytterbium	5.4	3.3	100	1	
Yttrium	3.8	3.2	100	31	
Iridium	2.8	4.3	100	14	Global supply only
Palladium	1.7	5.6	100	10	
Platinum	2.1	4.9	98	11	
Rhodium	2.5	6.6	100	24	
Ruthenium	3.4	3.5	100	11	
Group averages	Supply Risk	Economic Importance	Import reliance (%)	EOL-RIR (%)	Supply data in SR
LREEs	5.0	3.6	100	3	Global supply and EU sourcing
HREEs	4.9	3.7	100	8	
PGMs	2.5	5.0	99.6	14	Global supply only

Annex 6. Summary report of the stakeholder validation workshops

Workshop preparation

A balance between the involvement of relevant stakeholders and methodological rigour is essential. For example, in order to maintain objective and transparent results, the workshops should not allow for extensive participation, or even decision making of particular stakeholders regarding the project itself. On the other hand, the affirmation of a majority of stakeholder groups is essential to ensure that the results of the criticality assessments in particular, and the study as a whole, have the desired impact on EU business and policy making.

The aim of the stakeholder validation workshops therefore was not to discuss the revised criticality methodology, which had already been validated by the AHWG and the Commission, but to discuss in detail the criticality calculations for each of the materials covered during each workshop and to review and validate the data used in criticality assessments.

Table 22 lists the accomplished tasks for the organisation of the validation workshops.

Table 22: Summary of tasks carried out for the stakeholder validation workshops

Tasks	Description
Final list of stakeholders to invite	Submit first draft of priority stakeholders to invite – based on their expertise and ability to provide relevant input on one or several materials. Draft list sent to the Commission for review and final validation.
First round of invitation emails ("save the date email")	Send out the "save the date" emails to stakeholder participants. These emails briefly describe the objective of the study and workshop, potential venue as well as the proposed dates to determine availability of the stakeholder participants.
Set final dates for workshops	Establish the final dates, list of participants and materials to be covered by each workshop based on the maximum availability of stakeholders, the consultants and the Commission.
Send official invitations	Individual email invitations sent to confirmed participants indicating the final date and location of the workshop (one or more workshops based on the stakeholder's designated material(s) expertise), rules of the day, and details on teleconference connection provided to relevant participants.
Attribution of detailed calculation file(s)	Validation by the Commission and the AHWG on the list submitted by the consultants indicating the stakeholders and which detailed calculation file(s) were sent for review and feedback. Note: the materials' attribution list can be modified e.g. additions and removals as needed based on prior validation by the Commission.

Tasks	Description
Draft, validate and send background documents	Drafting and validation by the Commission of the relevant background documents to be sent to participants prior to the workshops: • Detailed agenda of the workshop(s) • Background document summarising the key elements of the revised criticality methodology • Questionnaire indicating the data needs for work packages 2 and 3 on the value chain assessments and factsheets • Detailed calculation files (based on the attribution list described above) • Non-disclosure agreement sent to stakeholders participating through teleconference.
Follow-up actions	• Summary of key comments and input provided by experts present at the workshop • Follow-up calls and emails with experts for further clarifications on discussions held at the workshops, particularly in terms of validating the final data used in the criticality assessments.

Submission of background documents to workshop participations

As listed in Table 22, prior to the workshops, several background documents have been drafted and submitted to participants by the consultants. This was to allow the opportunity for participants to familiarise themselves with the study and methodology used, as well as come prepared with any questions discussed during the introduction plenary session of the workshop. The background documents sent to confirmed participants include:

Detailed agenda of the workshop(s):

- Details on the conference centre location and key contact information
- Rules of the day specifying the main aims of the workshop in terms of what is expected from participants
- Timetable and agenda of the day, including when the parallel discussions will take place for each material
- List of expected participants (both present and through teleconference)

Protected detailed calculation files: sent to the relevant stakeholder participants based on the materials attribution list described above.

Background document on the revised criticality methodology: a short document outlining the key elements of the updated criticality methodology as well as a description of the excel-based calculation file used for the criticality assessments. The rationale behind this was to ensure that all participants have the opportunity to familiarise themselves with the revised methodology before the workshop (to avoid lengthy discussions on the methodology used for the assessments).

A questionnaire summarising the data needs for work packages 2 and 3: this is to allow key experts to anticipate any other input they can contribute to the other work packages.

Non-disclosure agreement (NDA): the NDA on information discussed during the workshops and related background documents was sent to all stakeholders who indicated their participation through teleconference. These participants were informed that their participation is dependent on timely reception of a signed NDA e.g. before the workshop. NDAs were distributed for signature at the start of each workshop for participants who are physically present.

Final workshop organisation

Several factors were considered in order to efficiently organise the stakeholder validation workshops. These factors are listed below in Table 23.

Table 23: Factors considered for optimal selection of workshop dates and coverage

Key factors	Description	Solutions/Mitigation actions
Availability of stakeholders	The confirmed participants do not cover all or priority materials. Key stakeholders are not available on the proposed dates.	Propose the possibility to participate through teleconference or to provide their feedback by email based on the background documents (see the above section) and assessment results.
	Too many confirmed participants in terms of capacity of rooms.	See if other venues are available/propose teleconference participation
Availability of partners and the EC	The partners responsible for the materials in question are not available on the proposed date(s).	Several possible dates based on the availability of relevant partners and the Commission were proposed to stakeholders. In the case, proposed dates needed to be adjusted based on stakeholder availability, the consultants ensured that another staff member was physically present at the workshop to present and lead discussions on the material concerned.
Proportion of priority materials in one workshop	A particular workshop has a proportionally high number of priority materials to be covered	In the case of workshops with a large number of priority materials, additional staff was to be present during the workshop to help lead the discussions.

As indicated in Table 23 above, a first email was sent out to the selected stakeholders with a request to indicate their availability on the proposed workshop dates, which were based on the availability of the consultants and Commission.

Based on the number of confirmed participants, their availability, and the number of materials covered by confirmed participants, three workshops were organised by the consultants. The three stakeholder validation workshops took place on **25, 28 October and 7 November 2016 at the TNO conference centre located in Brussels**[69]. In addition, the invited stakeholders also were granted the option to participate in the workshops through teleconference.

Several of the project consultants were present at each of the three stakeholder workshops to present and lead the discussions on the specific materials. The most relevant partner organisation was present at the workshop(s) where their materials were discussed. In the case of partner unavailability, an alternative team member with sufficient knowledge of the material concerned was present at the workshop to lead the discussions. In addition to the presence and active participation of the core project consultants, representatives from the European Commission (DG GROW and DG JRC) were also present at each of the workshops to assist in responding to any relevant questions and discussions.

[69] Workshop venue details: http://neth-er.eu/en/meetingrooms/Brussels-meeting-room

Table 24 provides details on the materials that were covered and the moderators of the three stakeholder validation workshops that were held on 25 October, 28 October and 7 November 2016.

Table 24: Organisation of the three stakeholder workshops

Workshop I: 25 October 2016							
10:00	Introduction & welcome, rules of the game, agenda						
Morning sessions	Time	Room 1 - TNO		Room 2 - TNO		Room 3 - BGS	
		Material	Experts	Material	Experts	Material	Experts
	11:00	Antimony	3	Teak wood Sapele wood Natural cork Natural rubber	2	Iron ore	4
	11:30	Tellurium Selenium	2			Manganese	2
	12:00	Bauxite Aluminium	3				
12:30	Lunch in room						
Afternoon sessions	Time	Room 1 - BGS		Room 2 - BGS		Room 3 - TNO	
		Material	Experts	Material	Experts	Material	Experts
	13:30	Gypsum	4	Gold	3	Molybdenum	3
	14:00	Bentonite	3	PGMs	5	Lead	2
	14:30	Diatomite	3	Cobalt	4	Bismuth	2
	15:00	Potash Perlite	4	Limestone	4	Sulphur	2
15:30	Wrap up						

Workshop II: 28 October 2016							
10:00	Welcome, rules of the game, ascertain timetable						
Morning sessions	Time	Room 1 - Deloitte		Room 2 - Deloitte		Room 3 - BRGM	
		Material	Experts	Material	Experts	Material	Experts
	11:00	Tungsten	2	Magnesite	4	LREE Scandium	3
	11:30	Germanium	2				
	12:00	Chromium	4	Magnesium	3		
12:30	Lunch in room						
Afternoon sessions	Time	Room 1 - Deloitte		Room 2 - Deloitte		Room 3 - BRGM	
		Material	Experts	Material	Experts	Material	Experts
	13:30	Fluorspar	3	Lithium	2	HREE	3
	14:00	Silicon metal	3	Borate	1		
	14:30	Silica sand	3				
15:00	Wrap up						

<table>
<tr><th colspan="8">Workshop III: 7 November 2016</th></tr>
<tr><td>10:00</td><td colspan="7">Welcome, rules of the game, ascertain timetable</td></tr>
<tr><td rowspan="5">Morning sessions</td><td rowspan="2">Time</td><td colspan="2">Room 1 - TNO</td><td colspan="2">Room 2 - BRGM</td><td colspan="2">Room 3 - TNO</td></tr>
<tr><td>Material</td><td>Experts</td><td>Material</td><td>Experts</td><td>Material</td><td>Experts</td></tr>
<tr><td>11:00</td><td>Aggregates</td><td>2</td><td>Beryllium</td><td>2</td><td>Coking coal</td><td>1</td></tr>
<tr><td>11:30</td><td>Baryte</td><td>1</td><td>Tin</td><td>2</td><td>Hafnium</td><td>3</td></tr>
<tr><td>12:00</td><td>Copper</td><td>3</td><td>Natural graphite</td><td>3</td><td>Nickel</td><td>3</td></tr>
<tr><td>12:30</td><td colspan="7">Lunch in room</td></tr>
<tr><td rowspan="7">Afternoon sessions</td><td rowspan="2">Time</td><td colspan="2">Room 1 - TNO</td><td colspan="2">Room 2 - BRGM</td><td colspan="2">Room 3 - TNO</td></tr>
<tr><td>Material</td><td>Experts</td><td>Material</td><td>Experts</td><td>Material</td><td>Experts</td></tr>
<tr><td>13:30</td><td>Silver</td><td>1</td><td>Indium</td><td>3</td><td>Vanadium</td><td>2</td></tr>
<tr><td>14:00</td><td>Talc</td><td>3</td><td>Gallium</td><td>2</td><td rowspan="2">Phosphate rock Phosphorus</td><td rowspan="2">2</td></tr>
<tr><td>14:30</td><td>Titanium</td><td>2</td><td>Lead</td><td>1</td></tr>
<tr><td>15:00</td><td>Zinc</td><td>2</td><td>Rhenium</td><td>1</td><td>Feldspar</td><td>2</td></tr>
<tr><td>15:30</td><td>Helium</td><td>0</td><td>Tantalum</td><td>2</td><td>Kaolin clay</td><td>0</td></tr>
<tr><td>15:20</td><td colspan="7">Wrap up</td></tr>
</table>

Follow-up of the validation workshops

Several follow-up actions were carried out after the validation workshops:

- A summary of key discussion points raised by workshop attendees related to the overall work carried out on the criticality assessments.
- Follow-up with individual stakeholders who indicated willingness and capability to contribute relevant data and input for specific criticality assessments. Participants were reminded during the introduction session and throughout the day of the workshop that any of the data provided should be publishable and able to be sourced and cited. In other words, any (confidential) data provided that cannot be sourced or published could not have been accepted.
- E-mails were sent out to all participants thanking them for their interest, time and contributions as well as indicating any relevant follow-up actions e.g. deadlines for input, clarifications on specific input provided, etc.

The list of participants is displayed in the following Table 25.

Table 25: Validation workshops attendance list

Organisation	25/10/16 Workshop	28/10/16 Workshop	7/11/16 Workshop
Spanish Confederation of Extractive Industries of Rocks and Industrial Minerals (Cominroc)			x
European Sustainable Phosphorus Platform (ESPP)			x
Industrial Minerals Association – Europe (IMA-Europe)	x	x	x
Nyrstar (mining and metals business specialising in zinc)	x	x	
Geological Survey of Norway (NGU)			x
The International Chromium Development Association (ICDA)		x	
Imerys (production and processing of industrial minerals)			x
European manufacturers of gypsum products (Eurogypsum)	x		
Saint Gobain (producer of construction materials)	x		
NERA Economic Consulting (NERA)	x		
World Coal Association (WCA)			x
European Association of Mining Industries, Metal Ores & Industrial Minerals (Euromines)	x	x	x
International Lead and Zinc Study Group (ILZ)			x
Umicore	x		
International Magnesium Association (IMA)		x	
Magnesium Elektron		x	
Less Common Metals Ltd.		x	
Austrian Association for Building Materials and Ceramic Industries			x
European Tyre & Rubber Manufacturers' Association (ETRMA)	x		
Renault			x
Nickel Institute			x
Tantalum-Niobium International Study Center			x
The Critical Raw Materials Alliance (CRM Alliance)		x	x
Indium Corporation			x
Fauris Management (Magnesium experts)		x	
European Federation of Geologists (EFG)			x
Association of European ferro-alloy producers (Euroalliages)	x	x	x
University of Augsburg	x		
International Tin Research Institute (ITRI)			x
Magnesitas Navarras S.A		x	
European Chemical Industry Council (CEFIC)			x
The Geological Survey of Denmark and Greenland (GEUS)	x	x	x
European Aggregates Association (UEPG)			x
The German Federal Institute for Geosciences and Natural Resources (BGR)	x	x	
Cobalt Development Institute (CDI)	x		
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European Steel Association (Eurofer)			x
European Borates Association (EBA)		x	

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