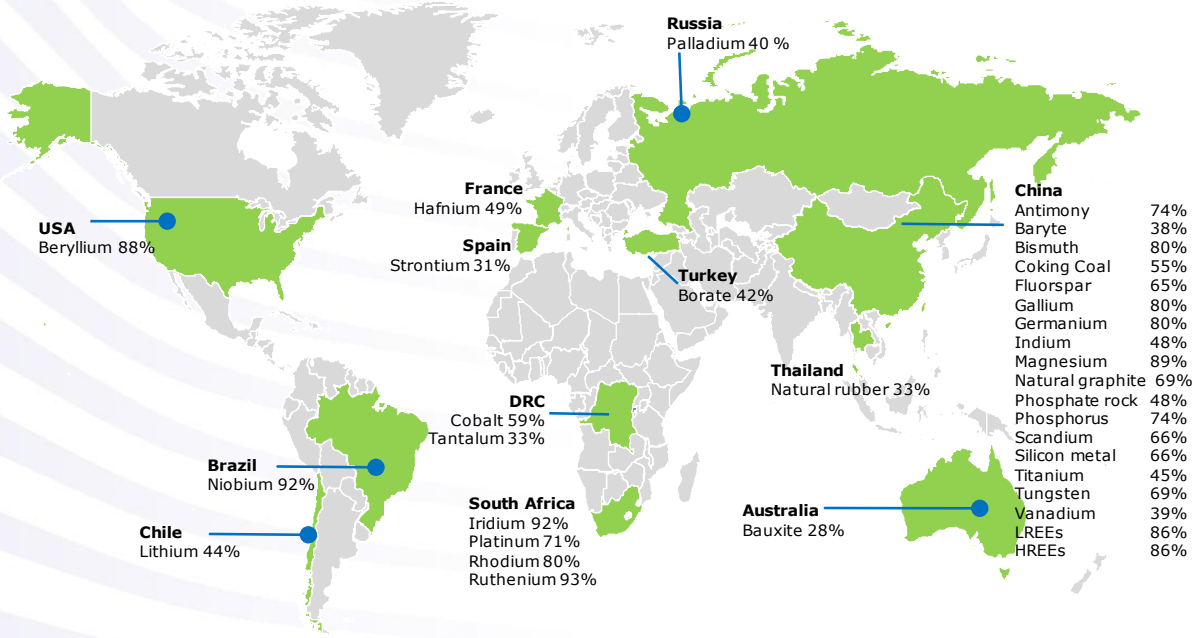
European Commission

Study on the EU's list of Critical Raw Materials (2020)

Non-Critical Raw Materials Factsheets



Raw Materials

Authors: Umberto Eynard, Konstantinos Georgitzikis, Dominic Wittmer, Cynthia EL Latunussa, Cristina Torres de Matos, Lucia Mancini, Manuela Unguru, Darina Blagoeva, Silvia Bobba, Claudiu Pavel, Samuel Carrara, Fabrice Mathieux, David Pennington, Gian Andrea Blengini.

LEGAL NOTICE

This document has been prepared for the European Commission however it reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

More information on the European Union is available on the Internet (http://www.europa.eu).

Luxembourg: Publications Office of the European Union, 2020

Print	ISBN 978-92-76-21052-8	doi: 10.2873/867993	ET-03-20-529-EN-C
PDF	ISBN 978-92-76-21052-8	doi: 10.2873/587825	ET-03-20-529-EN-N

© European Union, 2020

EUROPE DIRECT is a service to help you find answers to your questions about the European Union

Freephone number (*):
00 800 6 7 8 9 10 11

(*) The information given is free, as are most calls (though some operators, phone boxes or hotels may charge you)

Reproduction is authorised provided the source is acknowledged.

How to cite this report: "European Commission, Study on the EU's list of Critical Raw Materials (2020), Factsheets on Non-critical Raw Materials"

EUROPEAN COMMISSION

Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs | DG Joint Research Centre
Directorate GROW.C | JRC.D
Unit GROW.C.2 – Energy-intensive Industries and Raw Materials | JRC.D.3 – Land Resources

Contact: GROW.C.2

E-mail: GROW-C2@ec.europa.eu

European Commission
B-1049 Brussels

CONTENTS

1. Aggregates 5
2. Arsenic 26
3. Bentonite 40
4. Cadmium 52
5. Chromium 67
6. Copper 100
7. Diatomite 126
8. Feldspar 137
9. Gold 151
10. Gypsum 172
11. Helium 192
12. Hydrogen 205
13. Iron ore 218
14. Kaolin 255
15. Lead 270
16. Limestone 288
17. Magnesite 302
18. Manganese 318
19. Molybdenum 339
20. Natural cork 355
21. Natural teak wood 365
22. Nickel 376
23. Perlite 392
24. Potash 406
25. Rhenium 420
26. Sapele wood 432
27. Selenium 441
28. Silica sand 457
29. Silver 469
30. Sulphur 492
31. Talc 505
32. Tellurium 519
33. Tin 535
34. Zinc 557
35. Zirconium 574

1. AGGREGATES

1.1 Overview

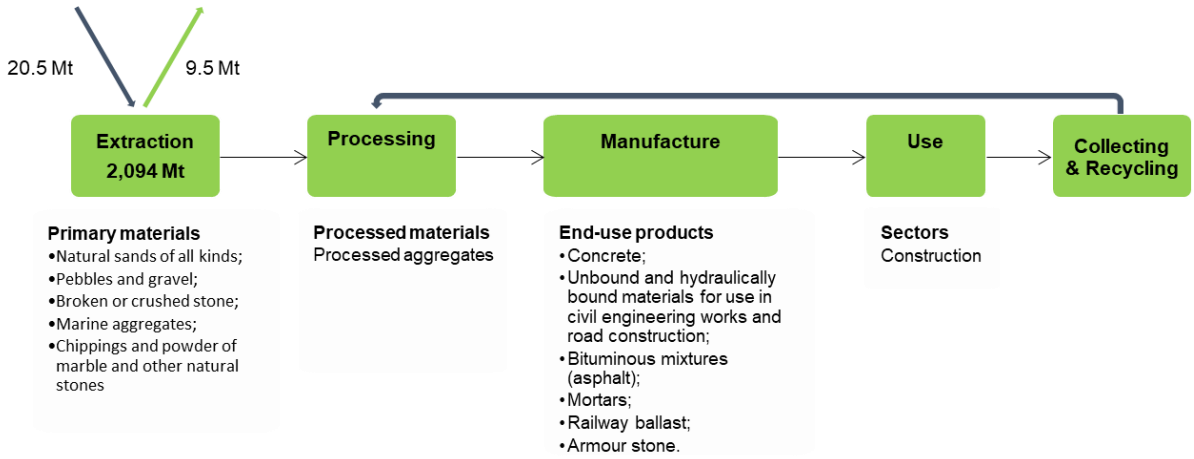


Figure 1: Simplified value chain for aggregates in the EU[1] (average 2012-16)

Aggregates are granular materials used in construction. They are also referred to as 'construction aggregates' as they are a core element of a wide range of construction purposes in buildings and civil engineering structures. Aggregates may be used on their own in unbound condition as a structural material, e.g. road stone, armour stone, railway ballasts, or in bound condition with the addition of water, cement, bitumen or other binders to form construction products such as concrete, mortar, and asphalt. The most significant supply by volume is natural aggregates, i.e. crushed rock, sand & gravel. Natural aggregates are mineral construction materials from naturally occurring deposits, which have been subjected to nothing more than mechanical processing. Other types of aggregates are manufactured aggregates produced from wastes from other industries, and recycled aggregates produced from construction and demolition wastes.

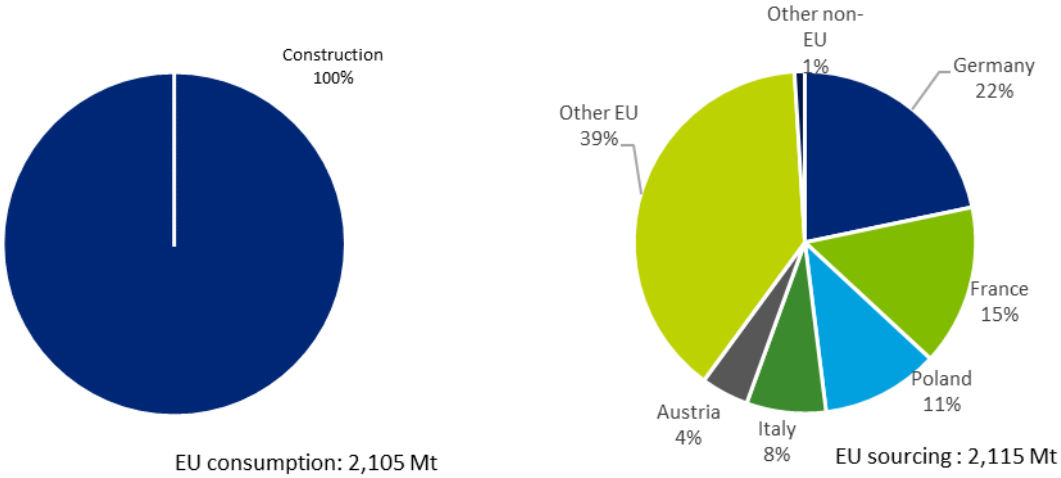


Figure 2: End uses (UEPG, 2018) and EU sourcing (UEPG, 2018; Eurostat, 2019a) of aggregates (average 2012-16).

[1] JRC elaboration on multiple sources (see next sections)

The assessment was carried out at the extraction stage for natural aggregates. The following CN product groups are used to analyse the international trade of aggregates.

- CN 2505 90 00, 'Natural sands of all kinds, whether or not coloured (excl. silica sands, quartz sands, gold- and platinum-bearing sands, zircon, rutile and ilmenite sands, monazite sands, and tar or asphalt sands)';
- CN 2517 10 10, 'Pebbles and gravel for concrete aggregates, for road metalling or for railway or other ballast, shingle and flint, whether or not heat-treated';
- CN 2517 10 20, 'Broken or crushed dolomite and limestone flux, for concrete aggregates, for road metalling or for railway or other ballast';
- CN 2517 10 80, 'Broken or crushed stone, for concrete aggregates, for road metalling or for railway or other ballast, whether or not heat-treated (excl. pebbles, gravel, flint and shingle, broken or crushed dolomite and limestone flux)';
- CN 2517 41 00, 'Marble granules, chippings and powder, whether or not heat-treated';
- CN 2517 49 00, 'Granules, chippings and powder, whether or not heat-treated, of travertine, ecaussine, alabaster, basalt, granite, sandstone, porphyry, syenite, lava, gneiss, trachyte and other rocks of heading 2515 and 2516 (excl. marble)'.

The production (Prodcom) codes used are the following:

- PRC 8121190, 'Construction sands such as clayey sands; kaolinic sands; feldspathic sands (excluding silica sands, metal bearing sands)';
- PRC 8121210, 'Gravel and pebbles of a kind used for concrete aggregates, for road metalling or for railway or other ballast, shingle and flint';
- PRC 8121230, 'Crushed stone of a kind used for concrete aggregates, for road metalling or for railway or other ballast (excluding gravel, pebbles, shingle and flint)';
- PRC 8121250, 'Granules, chippings and powder of marble';
- PRC 8121290, 'Granules, chippings and powder of travertine, ecaussine, granite, porphyry, basalt, sandstone and other monumental stone'.

All quantities are expressed in million tonnes (Mt) of aggregates. Data provided in this factsheet is an average over 2012-2016 unless otherwise stated.

The aggregates industry is closely related to the activity and economic growth of the construction sector. Aggregates consumption in the EU decreased considerably after the global financial crisis in 2008, reflecting the significant decline in construction markets, but has started to recover since 2013. Aggregates are mostly consumed regionally because of the high costs of transport; thus there is little international trade. The EU market value of natural aggregates is estimated at EUR 16.7 billion in 2016.

The price of aggregates is relatively low and stable compared to other minerals and metals. The average EU unit value of natural aggregates shipments in 2017 was EUR 7.67 per tonne (ESTAT Prodcom, 2019).

The EU consumption of natural aggregates is around 2,105 Mt. The use of natural mineral construction materials such as sand, gravel, and crushed rock aggregates constitutes the biggest raw material flow through the economy. The EU is largely self-sufficient in the material group of construction aggregates as domestic production covers almost entirely demand. The import reliance as a percentage of apparent consumption is 0.5%.

The construction sector relies upon the supply of aggregates, which represent the most considerable tonnage of material consumed by this sector. Construction and demolition waste, as well as industrial by-products such as ferrous slags, are commercially available substitutes of natural aggregates.

Aggregate resources are plentiful throughout the EU and the world. Reserves are determined mostly by land uses, proximity to consumption centres, and local environmental concerns.

Little publicly available data exists on the world output of aggregates. Construction aggregates global demand is estimated between 25,900 to 29,600 Mt in 2012 (UNEP, 2019). Natural aggregates production in the EU is around 2,100 Mt per year. Supply from secondary materials and recycling (recycled and manufactured aggregates) accounts for almost 240 Mt per year(UEPG, 2019c). Eight per cent of the total annual demand for aggregates in the EU is covered by recycled aggregates. The potential of aggregates to be recycled is higher than the average current rate, but even with complete recycling of the officially reported C&D waste, the extraction of natural aggregates will continue to supply the largest part of total aggregate EU market demand.

Aggregates and the aggregates industry are not assessed as key materials and industrial sectors[2] for the implementation of the EU strategy[3] to reduce greenhouse gas emissions.

UNEP (2019) highlights the potential for sand and gravel shortages in some parts of the world and the consequences of unregulated extraction. Land use competition is considered a bottleneck for aggregates supply in the EU. Also, social conflicts may cause market supply shortages at local level.

1.2 Market analysis, trade and prices

1.2.1 Global market

The aggregates industry is following the economic cycles, reacting to the levels of activity in the construction sector (USGS, 2018b). In terms of volume, aggregates are the materials used the most by the construction sector (BGS, 2013) and account for the most substantial amount of solid material extracted globally (UNEP, 2019). The consumption of aggregates for concrete can be roughly estimated using the global production of cement as a proxy, but for the other applications of aggregates, comprehensive statistics are unavailable (UNEP, 2014).

The onset of the global recession of 2008 had a drastic impact on the construction sector. According to the volume index of production for construction monitored by Eurostat, the construction activity in the EU declined for six years, from the peak in 2007 to the post-crisis trough of 2013 (Eurostat, 2019g). The overall decline in the volume index of construction was almost 22%, showing a slow recovery after 2013. According to data by the British Geological Survey (BGS 2019a), the corresponding overall decrease of natural aggregates production was more than 30%. As a consequence, the average annual output for aggregates decreased in the EU+EFTA from approximately 7.2 tonnes per capita in 2006 to 5.5 tonnes per capita in 2016(UEPG, 2018). Despite the gradual recovery, the production level is still well below the pre-crisis levels of a decade ago.

In 2016, the EU production of natural aggregates (crushed rock and sand & gravel)[4] was about 2,122 Mt(UEPG, 2018). The annual turnover in the EU is estimated at approximately EUR 16.7

[2] The cement industry belongs to a different value chain than construction aggregates; therefore, their role is not mentioned in the reduction of GHG emissions, neither the role of the construction industry.
[3] https://ec.europa.eu/clima/policies/strategies/2050_en

billion[4]. At a global scale, the value of production is estimated roughly to be between EUR 310 and 390 billion[5].

International trade is limited as aggregates are mostly consumed regionally because of the high costs of transport. It is estimated that less than 5% of global aggregates production moves across borders, in particular to countries that have less geological availability of suitable materials for aggregates in combination with strong demand for large development projects (e.g. Singapore) (UNEP, 2019).

Given the regional focus of aggregates, the abundant resources worldwide as well as the small amount of international trade, the impact on trade and global supply of export restrictions applied to construction aggregates is negligible. The OECD inventory of Export Restrictions on Industrial Raw Materials (OECD, 2019b)mention some export restrictions in place in 2017 by Vietnam and Morocco for natural sand (HS code 250590).

1.2.2 Outlook for supply and demand

The demand of aggregates is driven by activity in the construction industry, and it is closely linked to economic growth, urbanisation and increasing population (UEPG 2018)(UNEP 2019). Foresights of the global trends in economic development predicts a GDP growth up to 2035, especially in the emerging economies (EPRS, 2018); thus, the outlook for aggregates demand growth in the coming years is positive, depending on the level of economic growth (UNEP, 2019). According to a recent study published by the OECD, the use of construction materials is projected to almost double between 2017 and 2060 with the largest growth in aggregates (sand, gravel and crushed rock), while construction materials use per capita is projected to rise in most countries(OECD, 2019c). For the EU, the increase is projected to be stronger in the 2030-2060 period than the 2017-2030 period.

Given, the wide distribution and abundant resources of natural aggregates, supply is expected to keep up with the projected increase of demand (Table 1).

Table 1: Qualitative forecast of supply and demand of aggregates

Material	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Aggregates		X	+	+	+	+	+	+

1.2.3 EU trade

Given aggregates' low value/weight ratio and relatively high transport costs, their trade is highly sensitive to transport distances. Therefore, international trade is limited to local transactions across neighbouring countries (BGS, 2013; USGS, 2017a).

The traded volumes of aggregates (see Figure 3) are small compared to domestic production. The total annual EU imports between 2012 and 2016 were on average 20.5 Mt, and the total annual exports between 2012 and 2016 on average amounted to 9.5 Mt; hence, the average

[4] Estimation based on the average unit value of sold production in 2016 in the EU (EUR 7.85 per tonne of natural aggregates).

[5] Estimation based on the average unit value of sold production in 2016 in the EU (EUR 7.85 per tonne of natural aggregates) and world production of aggregates between 40 and 50 billion tonnes.

yearly net imports from 2012 to 2016 of aggregates were 11 Mt(ESTAT Comext, 2019). Norway is the leading trading partner for EU imports (Figure 4), which belongs to the European Free Trade Association (EFTA) states.

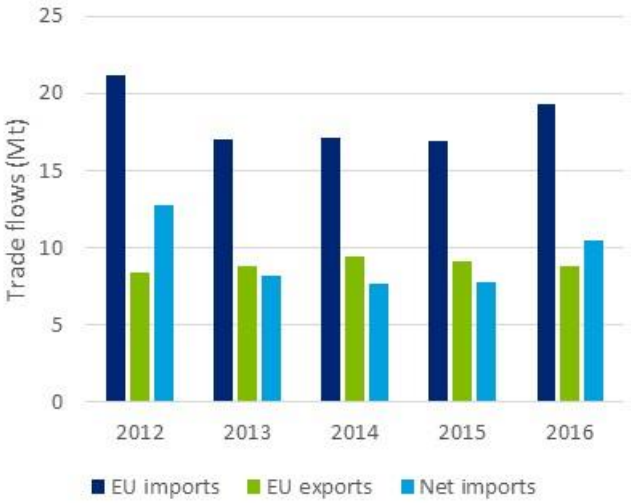


Figure 3: EU trade flows for aggregates[6]. (ESTAT Comext, 2019)

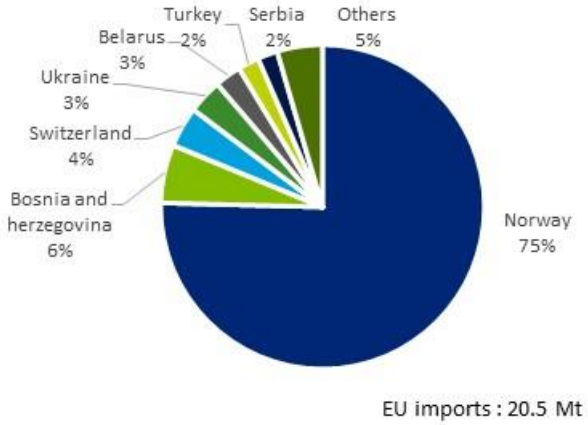


Figure 4: EU imports of aggregates[6]. (ESTAT Comext 2019)

1.2.4 Prices and price volatility

Compared to other minerals and metals, the price of aggregates is relatively low, as well as stable(UEPG, 2019). The price depends on the specifications of the various products for particular end uses, e.g. aggregates for railway ballast attract higher prices as specifications are difficult to attain (SCRREEN workshops, 2019).

[6] UK is included

The yearly average unit value of the main natural aggregate products sold in the EU increased notably from 2003 to 2009 by 20%, followed by a decrease of 13% in 2010. Since then, the average unit value of sold natural aggregate products in the EU has remained steady in real terms, i.e. after correcting for inflation. (see Figure 5).

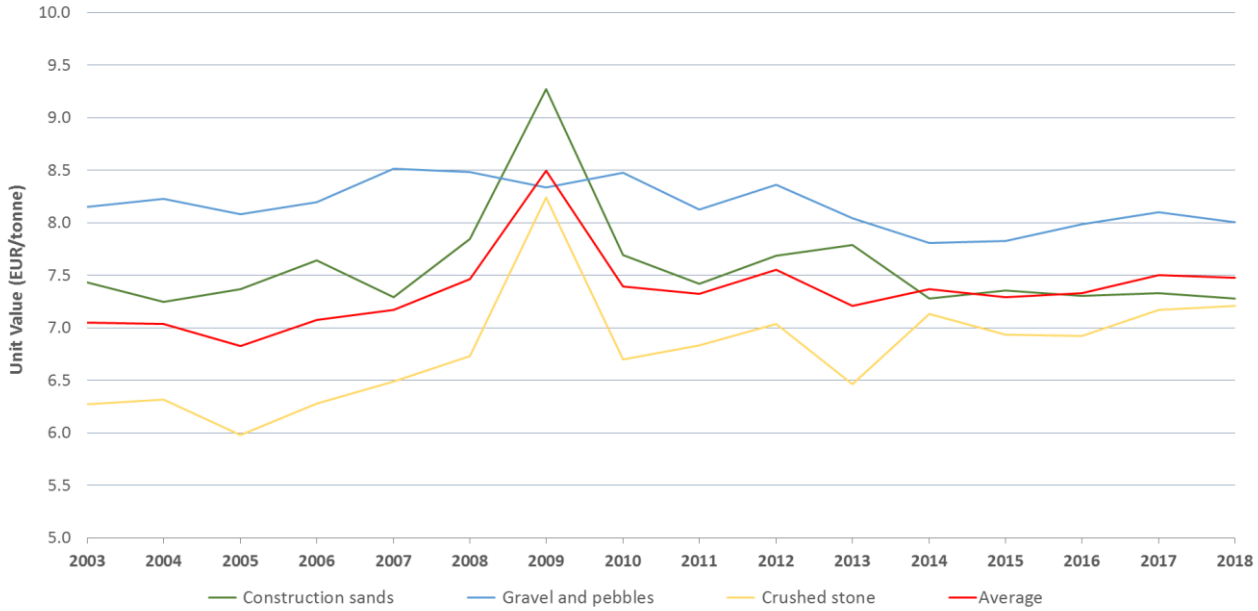


Figure 5*:* Unit value[7] of sold natural aggregates[8] in the EU per product group, yearly average (EUR/tonne). (ESTAT Prodcom, 2019)

Construction aggregates are low-value products with high sensitivity to transport distance, and each construction use demands a specific product specification. The price increases when in a particular area the appropriate aggregate quality for a required use does not exist, and it is necessary to transport it from long distances. In some cases, as in island territories, or when aggregates with strict specifications are required (e.g. for railway ballast for High-Speed train or river sand for pipes) which are produced in only a few sites in a country, the price surge can be severe (CRM experts 2019).

1.3 EU demand

1.3.1 EU consumption

The annual EU consumption (based on the average between 2012 and 2016) of natural aggregates is estimated to be around 2,105 Mt. The EU does not rely on imports for its consumption, and the import reliance as a percentage of apparent consumption is only 0.5%. The use of mineral construction materials constitutes the largest raw material flow in the EU economy (European Commission 2018b).

[7] Inflation adjusted with the Harmonised Index of Consumer Prices (HICP). Base 2015 = 100

[8] PRC (Prodcom) codes used: 8121190, 8121210, 8121230.

1.3.2 Uses and end-uses of aggregates in the EU

The use of aggregates takes place entirely in construction (Figure 6). Aggregates are essential raw materials for residential and commercial buildings, public infrastructure projects, and other types of construction which shape the built environment on which modern society depends. They can be used directly without any binder in road construction and civil engineering for numerous applications such as roadbed layers, macadam construction, constructional fill in engineering structures, armour stone, railway ballast, filter stone etc. Aggregates are also used in bound condition after mixing with a binding material such as cement, lime, gypsum or bituminous pitch for the manufacture of ready-mixed and precast concrete, asphalt, mortar, and other products for a variety of applications in buildings and infrastructure works. For example, aggregates are mixed with cement and water in standardised volumetric proportions to produce various concrete grades; aggregates may comprise up to 80% in mass of the concrete mix (PCA 2019)(UEPG 2019a).

The type of aggregate used in construction involves specific properties, and different types of aggregates may be fit for one particular end-use but not for another. The suitability of a specific aggregate for one particular construction application depends principally on its physical and mechanical properties, although in some applications mineralogical or chemical properties are also important. Demanding applications such as concrete manufacture and road construction require the most stringent technical specifications. For general-purpose applications, an aggregate of high strength and durability with low porosity is generally suitable. Lower quality aggregates may be acceptable for applications of low intensity of use, e.g. constructional fill (BGS 2013).

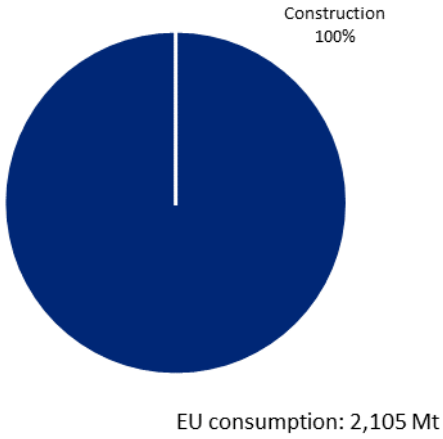


Figure 6: EU end uses (UEPG, 2018; BIO Intelligence Service, 2015), and EU consumption of aggregates (average 2012-2016).

The European Standards developed by the Technical Committee CEN/TC 154 specify aggregate performance requirements, sampling and methods of test. e.g. the European standard EN 12620:2002+A1:2008 'Aggregates for concrete' (CEN, 2008).Specifications for products cover aggregates obtained by processing natural, manufactured or recycled materials and mixtures of these aggregates for different end-use products, in respect of particle shape and size distribution, particle density and water absorption, resistance to fragmentation, wear, impact, abrasion and polishing and other factors.

Relevant industry sectors are described using the NACE sector codes in Table 2.

Table 2: Aggregates applications, 2-digit and examples of associated 4-digit NACE sectors, and value-added per sector (UEPG, 2018; Eurostat, 2019a)

Applications	2-digit NACE sector	Value-added of NACE 2 sector (M€)	Examples of 4-digit NACE sector(s)
Construction	C23 - Manufacture of other non-metallic mineral products	57,255	C2363 - Manufacture of ready-mixed concrete

According to data provided by (BIO Intelligence Service, 2015) and (UEPG, 2018), in the EU 40% of the aggregates are directly used in construction works as structural (unbound) materials, 45% are used in concrete manufacture, 10% in asphalt products, and 5% in other products (railway ballast and armour stone). With respect to the end-use construction sub-sector, aggregates and construction products containing aggregates are used in road construction (20%), infrastructure works (15%), residential buildings (25%), commercial and public buildings (20% each).

1.3.3 Substitution

Construction and demolition waste (C&DW) and industrial by-products such as ferrous slags and incinerator ashes are commercial substitutes of natural aggregates in specific applications (see Section 1.4.3). The substitution options are diverse in terms of technical requirements, and their performance is generally similar (Blengini and Garbarino 2010)(Reid et al. 2001). In addition, substituting aggregates and increasing materials efficiency in concrete production with innovative designs like lightweight foamed cement and geopolymer cement is possible. Finally, wood is also a substitute for concrete in construction, and therefore for aggregates (UNEP, 2019).

The EU Horizon 2020 SUS-CON project explored the feasibility of substituting entirely primary raw materials with secondary materials derived from waste streams to produce non-structural, low-cost and light-weight concrete, i.e. by combining lightweight secondary aggregates (rigid polyurethane foams, shredded tyre rubber and mixed plastic scrap) with secondary raw materials (fly ash, slag and perlite tailings) for the binder (SUS-CON 2015).

1.4 Supply

1.4.1 EU supply chain

The flows of aggregates through the EU economy are shown in Figure 7.

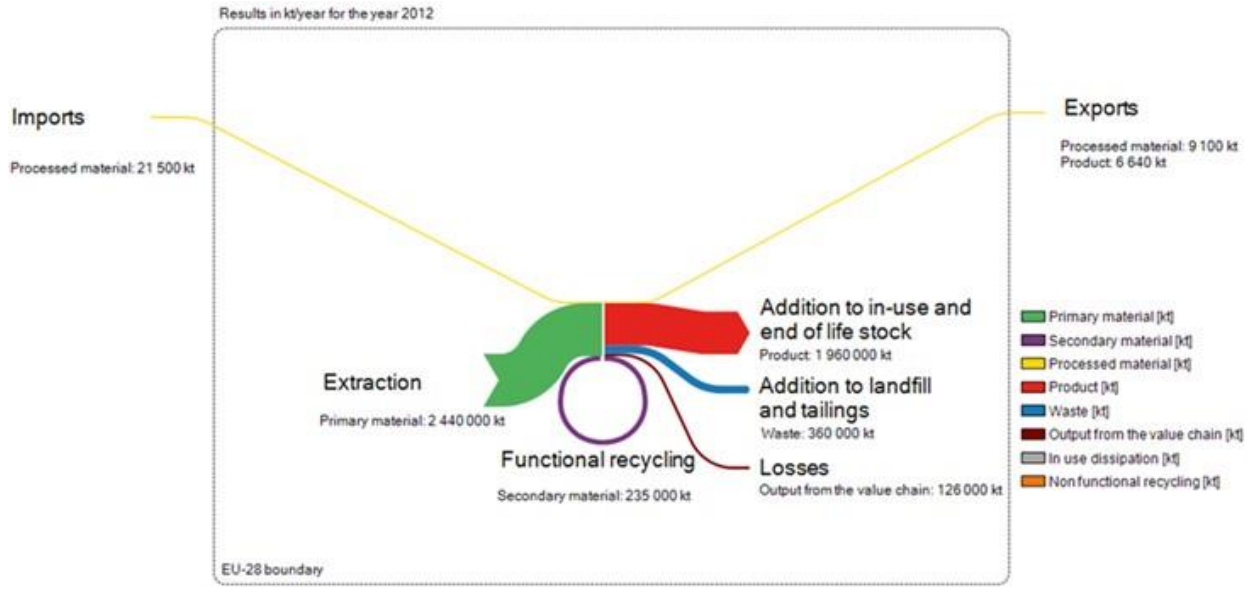


Figure 7: Simplified MSA of aggregates' flows in the EU (BIO Intelligence Service 2015).

The aggregates industry is characterised by thousands of operations serving local or regional markets. A network of local quarries allows achieving relatively short distribution distances.

According to data reported by the European Aggregates Association, in 2016 the aggregates industry comprised 13,458 companies (mostly SMEs) which operated 22,290 extraction sites across the EU (see Figure 8). The aggregates sector is by far the largest amongst the non-energy extractive industries in the EU (UEPG 2018)and the total volume of aggregates extraction exceeds the total volume of all other minerals produced in the EU (BGS 2019a).

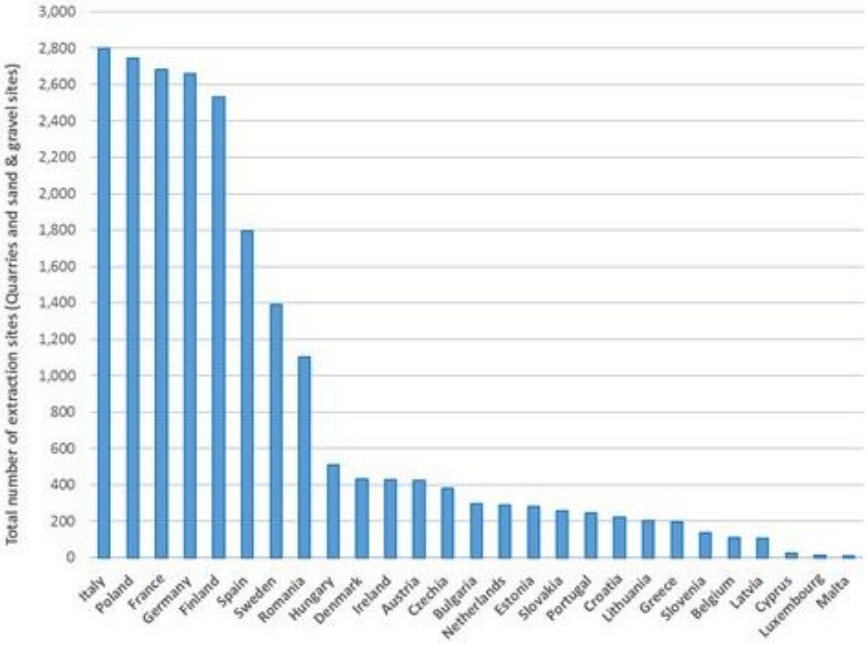


Figure 8: Number of extraction sites in the EU in 2016 (UEPG 2018)

Construction aggregates production from all sources was roughly 2,300 Mt, of which 2,100 Mt were natural aggregates. Crushed rock accounted for 46.5% of the total output, sand & gravel for 40.7%, marine aggregates for 2.2%, recycled aggregates for 8.2% (including C&DW reused on site), and manufactured aggregates for 2.4%. The EU is essentially self-sufficient in aggregates, which are produced in all Member States.

Figure 9 presents the EU sourcing (domestic production + imports) of aggregates, which is dominated by domestic supply. The import reliance is 0.5%.

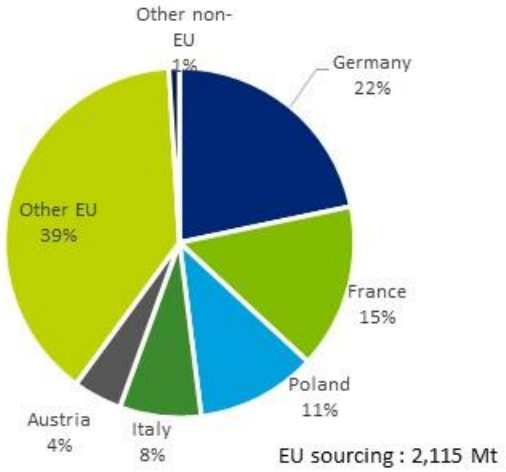


Figure 9: EU sourcing of aggregates. Average 2012-2016

1.4.2 Supply from primary materials

1.4.2.1 Geology, resources and reserves of aggregates

Geological occurrence: Natural aggregates are extracted from hard rock formations and deposits of sand and gravel (LafargeHolcim, 2019), and in some countries by sea-dredging as marine aggregates (UEPG, 2019a). The resources of natural aggregates are among the most abundant and widely distributed in the earth's crust, occurring in a variety of geologic environments.

Most hard rocks are potentially suitable for crushed rock aggregates. The typical rock types quarried are the hard, dense and cemented sedimentary rocks (limestone, dolomite and certain sandstones), as well as the tougher, crystalline igneous rocks (e.g. granite, diorite, basalt, diabase, andesite) (BGS, 2013).

Sand & gravel deposits are accumulations of unconsolidated granular materials resulting from rock erosion and weathering. Sand & gravel are sourced from fluvial, glaciofluvial, glacial, marine, eolian and lake sediments (Pfleiderer, 2017). The main onshore deposit types are the near-surface fluvial (river) and the glaciofluvial sediments. Sand to gravel ratios are variable, but river deposits typically have lower fines content (silt and clay) than glacial deposits. Glaciofluvial deposits are generally thicker, but the overburden thickness can also be high (BGS 2013). Marine deposits of sand & gravel occur as small patches separated or covered by extensive areas of uneconomic deposits of gravel-bearing sediments. They vary in their thickness, composition and particle size, and their proximity to the shore. Their formation is substantially similar to those on land, but became submerged due to sea-level rise after the most recent glacial period and subsequently re-worked by tidal currents (BGS, 2013)

Global resources and reserves*:* Natural aggregates resources are abundant all over the world. Reserves of crushed rock and sand & gravel are assessed as adequate, except in cases in which extraction and extraction economics are controlled by factors such as environmental regulations, land use, geographic distribution and quality requirements for specific uses (USGS, 2019d). The economic viability of a deposit is also determined by the thickness of the geologic overburden, and the thickness of the deposit of a particular quality, e.g. fines content (BGS, 2013). As a general rule, resources and reserves data are not reported internationally (Cao et al., 2018), neither at a company level (SCRREEN workshops, 2019).

EU resources and reserves[9]: Deposits of suitable quality for natural aggregates production are plentiful in most parts of Europe. However, access restrictions at the local level and not the availability is considered as the major issue that may constrain aggregates supply (UEPG, 2017- 2018).

[9] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for aggregates. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for aggregates, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historical estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for aggregates the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU, 2019). Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However, a very solid estimation can be done by experts.

Table 3: Resources of aggregates (crushed rock) in the EU. (Minerals4EU, 2019)

Country	Sub-commodity	Classification	Quantity	Unit	Reporting Code
Finland	Crushed rock	not specified	18,314	Mm^3	None
Estonia	Dolomite	Measured+Indicated	368	Mm^3	National reporting code
	Limestone	Measured+Indicated	964	Mm^3	
Latvia	Dolomite	Explored deposits	188	Mm^3	National reporting code
		Evaluated deposits	485	Mm^3	
Lithuania	Dolomite	Measured (explored in detail)- code 111, 121, 211, 221, 334	115	Mm^3	National reporting code
		Indicated (preliminary explored)- code 122, 335	120	Mm^3	
		Inferred (prognostic) - code 333, 337	300	Mm^3	
	Limestone	Measured (explored in detail)- code 111, 121, 211, 221, 335	211	Mm^3	
		Indicated (preliminary explored)- code 122, 336	343	Mm^3	
		Inferred (prognostic) - code 333, 338	915	Mm^3	
Poland	Dolomite	Poland (A+B+C1)	259	Mt	National reporting code
		Poland (C2 + D)	75	Mt	
		Poland - total	335	Mt	
Czechia	Crushed stone	Potentially economic	227,685	km^3	National reporting code
		P1	61,357	km^3	
		P2	408,807	km^3	
		P3	ZERO	km^3	
	Dolomite	Potentially economic	12,212	kt	
		P1	23,946	kt	
		P2	ZERO	kt	
		P3	ZERO	kt	
	Limestone	Potentially economic	744,752	kt	
		P1	82,489	kt	
		P2	350,957	kt	
		P3	ZERO	kt	
Slovakia	Crushed rock (economic)	verified (Z1)	128	Mm^3	National Reporting code
		probable (Z2)	401	Mm^3	
		anticipated (Z3)	249	Mm^3	
	Crushed rock (non-reserved)	not specified	753	Mm^3	
	Crushed rock (subeconomic)	not specified	7	Mm^3	
	Dolomite (economic)	verified (Z1)	75	Mt	
		probable (Z2)	167	Mt	
		anticipated (Z3)	442	Mt	
	Dolomite (subeconomic)	not specified	9	Mt	
	Limestone (economic)	verified (Z1)	198	Mt	
		probable (Z2)	605	Mt	
		anticipated (Z3)	1313	Mt	
	Limestone	not specified	41	Mt	

Country	Sub-commodity	Classification	Quantity	Unit	Reporting Code
	(subeconomic)				
Hungary	Crushed stone	(RUS) A+B	99	Mm^3	Russian Classification
		(RUS) C1	438	Mm^3	
		(RUS) C2	565	Mm^3	
Slovenia	Dolomite	National	38	Mt	National reporting code
	Limestone	National	79	Mt	
Greece	Aggregates		unlimited		None
Cyprus	Rocks for aggregates	known	136	Mt	None
	Rocks for armourstone	estimated	27	Mt	
Spain	Crushed rock		unlimited		None

Table 4: Resources of aggregates (sand & gravel) in the EU. (Minerals4EU, 2019)

Country	Sub-commodity	Classification	Quantity	Units	Reporting Code
Finland	Sand & gravel	not specified	46,861	Mm^3	None
Estonia	Gravel	Measured+Indicated	150	Mm^3	National reporting code
	Sand	Measured+Indicated	945	Mm^3	
Latvia	Sand	Explored deposits	365	t	National reporting code
		Evaluated deposits	797	t	
	Sand & gravel	Explored deposits	381	Mm^3	
		Evaluated deposits	708	Mm^3	
Lithuania	Gravel	Measured (explored in detail)- code 111, 121, 211, 221, 331	650	Mm^3	National Reporting code
		Indicated (preliminary explored)- code 122, 332	679	Mm^3	
		Inferred (prognostic) - code 333, 334	2,146	Mm^3	
	Sand	Measured (explored in detail)- code 111, 121, 211, 221, 332	293	Mm^3	
		Indicated (preliminary explored)- code 122, 333	286	Mm^3	
		Inferred (prognostic) - code 333, 335	919	Mm^3	
Denmark	Marine Sand, gravel, rubble and stone	Not specified	14,000	Mm^3	None
Poland	Sand & gravel	Poland (A+B+C1)	10,005	Mt	National reporting code
		Poland (C2 + D)	7,967	Mt	
		Poland - total	17,973	Mt	
Czechia	Sand & gravel	Potentially economic	461,808	km^3	National reporting code
		P1	149,027	km^3	
		P2	946,239	km^3	
		P3	ZERO	km^3	
Slovakia	Sand & gravel (economic)	verified (Z1)	83	Mm^3	None
	Sand & gravel (economic)	probable (Z2)	67	Mm^3	
	Sand & gravel (economic)	anticipated (Z3)	5	Mm^3	

Country	Sub-commodity	Classification	Quantity	Units	Reporting Code
	Sand & gravel (non-reserved)	not specified	352	Mm^3	
	Sand & gravel (sub-economic)	not specified	5	Mm^3	
Austria	Sand & gravel	None	19,677	Mm^3	None
Hungary	Gravel	(RUS) A+B	925	Mm^3	Russian Classification
		(RUS) C1	4,071	Mm^3	
		(RUS) C2	2,203	Mm^3	
Slovenia	Sand & gravel	National	23	Mt	National
Romania	Sand & gravel	(UNFC) 333	1,250	Mt	UNFC
Spain	Sand & gravel		Unlimited		None

Despite the information gaps and classification discrepancies, (Velegrakis et al. 2010) provides an overview of the proven recoverable marine aggregate reserves in some EU Member states. Marine sand reserves in Denmark have been estimated to be significant (in the order of several billion m^3), but coarse sand/gravel resources are somewhat limited in the North Sea. The German recoverable marine aggregate reserves of the Baltic Sea are limited (of the order of 40-50 million m^3), whereas the Polish reserves have been estimated to be close to a 100 million m^3.

1.4.2.2Aggregates extraction and mechanical processing

Crushed rock is extracted in surface quarries. Overburden is removed by a combination of hydraulic excavators, ripping and blasting to be used for restoration and landscaping. Blasting is the commonly applied technique to release the required rock from the operating quarry face, which is normally developed in distinct benches. After any subsequent breaking of larger rock blocks by mobile machinery like hydraulic breakers, the extracted rock is transported by haul trucks to the crushing plant or a mobile crusher on the quarry floor (BGS, 2013).

Sand & gravel are extracted from fluvial deposits by open-pit mechanical excavation, from lakes and rivers by dredging or pumping, from coastal beaches, or from the sea bed by dredging (marine aggregates) (BGS, 2013; UNEP, 2019).

The extracted materials are then processed into final products by a multi-stage operation that may involve successive stages of crushing and screening to reduce the raw material to the required size and shape and segregate particle sizes. Washing is included in the process when required to remove harmful materials such as clay and silt (Garbarino et al. 2018)(LafargeHolcim 2019).

1.4.2.3 World and EU mine production

Sand and gravel are mined worldwide and account for the most significant volume of solid material extracted globally. However, there is no global monitoring or reporting for aggregates production. A recent report by UN Environment estimates total extraction from quarries, pits, rivers, coastlines and the marine environment at 40,000 to 50,000 Mt per year (UNEP, 2019). The construction industry consumes over half for concrete, i.e. 25,009 to 29,600 Mt in 2012, estimated indirectly through the global production of cement for concrete(UNEP, 2014). In total, China, India and Asia represent 67% of global aggregates production (UNEP, 2019).

The average annual production of natural aggregates in the EU between 2012 and 2016 was 2,094 Mt, of which 1,089 Mt consisted of crushed rock, 953 Mt of sand and gravel and 52 Mt of

marine aggregates (UEPG, 2019c). Germany is the leading EU producer by volume, followed by France, Poland and Italy.

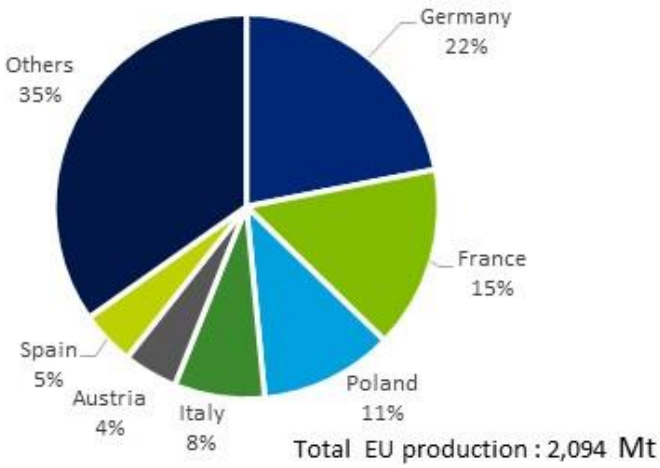


Figure 10: EU production of natural aggregates. Average for the period 2012-2016. (UEPG 2019c)

1.4.3 Supply from secondary materials/recycling

Recycled aggregates from construction and demolition waste (C&DW) are an important source of aggregate supply. Concrete, bricks, tiles and asphalt are the most commonly recycled C&D waste materials. Recycling reduces natural aggregates resource depletion and landfilling of waste.

Concrete, the most used material in buildings, is often recycled at its end of life at demolition or construction sites close to urban areas. Unless transported in large volumes by rail or waterway, transportation in long distances (usually maximum 35 km) is not economically attractive. Environmental benefits of recycling diminish over longer distances as well (CSI, 2009; Ecorys, 2016). Concrete from C&D waste can be reprocessed into coarse or fine aggregates after impurities removal (e.g. insulation, steel reinforcement, wood, joint sealants and plastics) before crushing and grading. An effective sorting out at the construction site or the treatment facility is essential to enlarge the recycling potential. Processing by mobile sorters and crushers often takes place at the demolition or construction sites. Coarse aggregates are used in various civil engineering applications and as backfilling material in quarries, but mostly in road construction for the sub-base and base layers. Recycled aggregates from C&D concrete often have better compaction properties and require less cement for sub-base uses. Fine aggregates obtained from crushed concrete waste can be used in place of natural sand in mortars and, in case of appropriate quality, may substitute a portion (up to 20 %) of natural aggregates in new concrete (CSI, 2009; Bio Intelligence Service, 2011; SCRREEN workshop, 2019).

Economic and quality limitations of recycling are recognised for mixed C&D waste consisting of bricks, concrete, ceramics, etc., contaminated with wood, plastic, metals and other materials (SCRREEN workshops, 2019). Crushed bricks, tiles and ceramics from C&D waste are recycled as a substitute of natural aggregates in certain less demanding end uses, such as constructional fill and in road sub-base (Bio Intelligence Service, 2011).

Reclaimed asphalt is recycled by adding to new asphalt mixes, with the aggregates and the old bitumen performing the same function as in their original application. The recycling processes involve hot or cold mix techniques that may take place offsite or in-situ by direct incorporation into the new asphalt pavement. Screening and crushing of the reclaimed asphalt may be necessary.

Due to the massive amounts of waste generated, C&DW has been identified as a priority waste stream for reuse and recycling (European Commission 2015). The EU Waste Framework Directive (Directive 2008/98/EC) stimulates recycling by requiring the Member States to take the necessary measures to achieve a minimum recovery target of 70% by weight (re-use, recycling and other material recovery, including backfilling) of non-hazardous construction and demolition waste by 2020.

According to production data published by the European Aggregates Association, the average annual production of recycled aggregates from C&DW (including those reused on-site) is 191 Mt for the 2012-2016 period (UEPG, 2019c); from these data the end-of-life recycling input rate (EOL-RIR) is estimated at 8%. Even with full recycling of all generated quantities of C&DW as they are officially reported by Eurostat waste management statistics (Eurostat, 2019d), up to 12% of the current total demand of aggregates could be covered by recycled aggregates. In practice, this means that the extraction of natural aggregates will continue to supply the most substantial part of market needs.

Also, industrial by-products such as iron and steel slags, coal-fired power station ash, china clay residues, fly ash leftover from waste incineration, and spent foundry sand are other sources of secondary aggregates supply. Aggregates derived from industrial by-products are classified as 'manufactured' aggregates, which are mainly valorised in road construction (BGS, 2013; USGS, 2019d; UEPG, 2019a). According to the statistics published by the European Aggregates Association, approximately 46 million tonnes of manufactured aggregates are produced in the EU annually (UEPG, 2018).

The natural rocks removed as an overburden during surface mining of ores, industrial minerals, and coal is another potential source of secondary raw materials, when complying with Regulation (EU) No 305/2011 for the marketing of construction products. This option includes, for example, aggregates used in earthworks and infrastructure construction, hydraulic engineering, landfill construction (Garbarino et al. 2018).

In the assessment, 8% was used as the EOL-RIR (background data from UEPG (2018)).

1.5 Other considerations

1.5.1 Environmental issues

In Europe, land-use conflicts and absence or complexity of aggregates policies are among the challenges for long-term and sustainable aggregates supply. National or regional planning for securing access to aggregates' deposits and address interactions with conflict zones is considered essential (SnapSEE, 2014; UEPG, 2015).

Given that aggregates represent by far the largest number of extraction sites in the EU (Garbarino et al., 2018), it is important to note that the European Aggregates industry is actively involved in initiatives for extraction sites rehabilitation and biodiversity preservation. More than 150 biodiversity cases studies are available online (www.uepg.eu) to demonstrate

the compatibility of aggregates extraction and environmental protection (UEPG 2019b; UEPG, 2019d).

A recently published UN report acknowledges the need for improved governance of global sand resources and adequate assessment of environmental impacts of over-exploitation. In some parts of the world among emerging and developing countries, illegal extraction of sand from riverine and marine ecosystems results in environmental damages on rivers, deltas and coastal and marine ecosystems such as land loss through river and coastal erosion, impacts to biodiversity, lowering of the water table and pollution, impacts on landscape and hydrological function etc. (UNEP, 2014-2019). Instream gravel mining, which involves the extraction of sand and gravel directly from the active channel of rivers and streams, is a source of high-quality and low-cost construction aggregates. Instream gravel mining may have beneficial impacts as it is a useful tool in flood control and river stabilisation in aggrading rivers. In different circumstances, instream gravel mining could cause incision of the channel bed, which can propagate upstream and downstream for kilometres with detrimental effects on structures and the environment (Chen, 2011; Kondolf, 1994).

1.5.2 Contribution to low-carbon technologies

Aggregates and the aggregates industry are not assessed as key materials and industrial sector for the implementation of the EU strategy[10] to reduce greenhouse gas emissions. The cement industry belongs to a different value chain than construction aggregates; therefore, its role for the reduction of GHG emissions is not discussed, neither the role of the construction industry.

Concrete recycling for the production of high-strength aggregates has the potential of saving CO_2 emissions from cement manufacturing, as the recovered cement (containing up to 30-40% of unused clinker from end-of-life concrete) can replace new cement in construction (European Commission 2018c).

1.5.3 Socio-economic issues

The EU is self-sufficient for aggregate materials, and no particular threats exist for what concerns social sustainability and security of supply. Aggregates are involved in responsible sourcing initiatives (standards and sustainable procurement schemes) developed for the construction sector (e.g. BES 6001, BS 8902).

However, at the local level, social conflicts may disturb the cost-effective supply of aggregates resulting in a market deficit. The extraction of aggregates consists of a largely mechanical process involving the transport of large quantities of materials, and this may disturb local communities in various ways, e.g. changing landscape of neighbouring sites, creating continuous disturbance due to transport of materials etc. Moreover, residents and authorities are concerned about the post-closure management and use of exhausted quarries. Also, the absence of land use planning and the lack of extraction priority zones may restrict the development of aggregates operations by the expanding communities in the periphery of the extraction site. Consequently, considerable obstacles created by local communities in the development and smooth operation of aggregates extraction sites are not infrequent. As a conclusion, social acceptance of the extractive activities by the local communities is necessary to ensure the undisturbed flow of aggregates that society needs for infrastructure development and building purposes (Chalkiopoulou and Hatzilazaridou 2011).

[10] https://ec.europa.eu/clima/policies/strategies/2050_en

1.6 Comparison with previous EU assessments

The same methodology with the 2017 assessment has been applied. The world production of non-EU countries is not analysed in the assessment, but it is not considered as a limitation given the regional character of the aggregates market. Therefore, the SR indicator is calculated using the EU-HHI only. The results of this and earlier assessments are presented below in Table 5.

Table 5: Economic importance and supply risk results for aggregates in the assessments of 2011, 2014, 2017, 2020 (European Commission 2017d)

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Aggregates	Not assessed		Not assessed		2.3	0.2	2.7	0.2

In the current assessment, the Supply Risk indicator (SR) is unchanged and remains at very low level due to the self-sufficiency of EU for aggregates. The economic importance indicator (EI), appears slightly increased in comparison to the 2017 assessment. However, this is due to the results scaling step [11] prescribed in the methodology, as the value-added of the construction sector (the only manufacturing sector corresponding to aggregates end uses) in the current assessment is lower because it refers to 27 Member States (i.e. excluding UK), whereas in the 2017 assessment it corresponded to 28 Member States.

1.7 Data sources

Aggregates production data are characterised from uncertainty and incompatibility of countries statistics (European Commission, 2017d) due to different reporting requirements across countries, which leads to data inconsistencies and gaps (Cao et al., 2018). Reliable data for the global production of aggregates are not available (UNEP, 2019).

Production data published by the European Aggregates Association were used in the assessment. The EOL-RIR was estimated from the same background data. Eurostat was the source of EU trade flows.

1.7.1 Data sources used in the factsheet

BGS (2013) 'Mineral Planning Factsheets. Construction aggregates'. British Geological Survey, pp. 1–31. Available at: https://www.bgs.ac.uk/mineralsUK/planning/mineralPlanningFactsheets.html.

BGS (2019) World mineral statistics data, British Geological Survey. Available at: https://www.bgs.ac.uk/mineralsuk/statistics/wms.cfc?method=searchWMS.

Bio Intelligence Service (2011) Service contract on management of construction and demolition waste. Available at: https://publications.europa.eu/en/publication-detail/-/publication/0c9ecefc-d07a-492e-a7e1-6d355b16dde4 (Accessed: 31 July 2019).

BIO Intelligence Service (2015) Study on Data for a Raw Material System Analysis: Roadmap and Test of the Fully Operational MSA for Raw Materials. Available at:

[11] The results are scaled by dividing the calculated EI score by the value of the largest manufacturing sector NACE Rev. 2 at the 2-digit level and multiplied by 10, in order to reach the value in the scale between 0-10.

https://ec.europa.eu/jrc/en/scientific-tool/msa.

Blengini, G. A. and Garbarino, E. (2010) 'Resources and waste management in Turin (Italy): the role of recycled aggregates in the sustainable supply mix', Journal of Cleaner Production. Elsevier, 18(10–11), pp. 1021–1030. doi: 10.1016/J.JCLEPRO.2010.01.027.

Cao, Z. et al. (2018) MinFuture. Deliverable 4.2. Report on workshop summary for results and implications of the pilot case.

CEN (2008) 'European Standard EN 12620:2002+A1:2008. Aggregates for concrete.' European Committee for Standardization.

Chalkiopoulou, F. and Hatzilazaridou, K. (2011) SARMA. How to Achieve Aggregates Resource Efficiency in Local Communities. Manual. Available at: http://www.sarmaproject.eu.

Chen, D. (2011) 'Modeling Channel Response to Instream Gravel Mining', Sediment Transport - Flow and Morphological Processes. doi: 10.5772/21348.

CRM experts (2019) 'Comments provided to DG GROW following the SCRREEN Experts Workshop. Aggregates'.

CSI (2009) Recycling concrete, Engineering Stability. doi: 10.1680/ensu.2004.157.1.9.

Ecorys (2016) EU Construction & Demolition Waste Management Protocol. Available at: https://ec.europa.eu/docsroom/documents/20509/attachments/1/translations/en/renditions/native.

EPRS (2018) Global Trends to 2035. Economy and Society. European Parliament. Available at: http://www.europarl.europa.eu/RegData/etudes/STUD/2018/627126/EPRS_STU(2018)627126_EN.pdf.

ESTAT Comext (2019) Easy Comext database. Available at: http://epp.eurostat.ec.europa.eu/newxtweb/.

ESTAT Prodcom (2019) Statistics on the production of manufactured goods (PRODCOM NACE Rev.2), Prodcom - Statistics by Product. Available at: https://ec.europa.eu/eurostat/web/prodcom (Accessed: 14 July 2019).

European Commission (2015) COM(2015) 614 final. Closing the loop - An EU action plan for the Circular Economy. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0614 (Accessed: 2 August 2019).

European Commission (2017) Study on the review of the list of critical raw materials. Non-Critical Raw Materials Factsheets. European Commission. doi: 10.2873/876644.

European Commission (2018) In-depth analysis in support of the Commission Communication COM(2018)/773. 'A Clean Planet for all. A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy'. Available at: https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf.

European Commission (2018b) Raw Materials Scoreboard 2018, Vidal-Legaz, B. et al.. European Commission. doi: 10.2873/13314.

Eurostat (2019) Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). Available at: https://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2 (Accessed: 7 July 2019).

Eurostat (2019) Circular Economy Indicators. Waste Management. Recovery rate of construction and demolition waste (cei_wm040). Available at: https://ec.europa.eu/eurostat/web/circular-economy/indicators/main-tables.

Eurostat (2019) Short-term business statistics database. Available at: https://ec.europa.eu/eurostat/web/short-term-business-statistics/data/database (Accessed: 25 July 2019).

Garbarino, E. et al. (2018) Best Available Techniques (BAT) Reference Document for the Management of Waste from Extractive Industries in accordance with Directive 2006/21/EC. Available at: https://ec.europa.eu/environment/waste/mining/bat.htm.

Kondolf, M. (1994) 'Geomorphic and environmental effects of instream gravel mining', Landscape and Urban Planning, 28(2–3), pp. 225–243. doi: 10.1016/0169-2046(94)90010-8.

LafargeHolcim (2019) Aggregates. Available at: https://www.lafargeholcim.com/aggregates-solutions (Accessed: 25 July 2019).

Minerals4EU (2019) European Minerals Yearbook. Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html.

OECD (2019a) Export Restrictions on Industrial Raw Materials. Available at: https://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials (Accessed: 5 July 2019).

OECD (2019b) Global Material Resources Outlook to 2060, Global Material Resources Outlook to 2060. doi: 10.1787/9789264307452-en.

PCA (2019) Aggregates. Available at: https://www.cement.org/cement-concrete-applications/concrete-materials/aggregates (Accessed: 25 July 2019).

Pfleiderer, S. (2017) Reserves of aggregates – status , mapping and exploration in the EU. Available at: http://www.uepg.eu/mediaroom/52/30/EU-Presidency-Conference-on-Aggregates/.

Reid, J. M. et al. (2001) 'ALT-MAT project: Alternative materials in road construction. Final Report', (January 2001), pp. 1–190.

SnapSEE (2014) Data and Analysis Methodologies for Aggregates Planning: In support of best practices in Sustainable Aggregates Planning. Available at: http://www.snapsee.eu/.

SUS-CON (2015) SUStainable, innovative and energy-efficient CONcrete, based on the integration of all-waste materials | SUS-CON Project | FP7 | CORDIS | European Commission. Available at: https://cordis.europa.eu/project/rcn/101644/factsheet/en (Accessed: 25 July 2019).

UEPG (2015) 2020 Vision Sustainable Aggregates Industry. Available at: http://www.uepg.eu/publications/special-editions.

UEPG (2017) 'Life Cycle of Aggregates'. European Aggregates Association. Available at: http://www.uepg.eu/publications/special-editions.

UEPG (2018) Annual Review 2017-2018. Available at: http://www.uepg.eu/publications/annual-reviews.

UEPG (2019a) About Aggregates. Available at: http://www.uepg.eu/what-are-aggregates (Accessed: 25 July 2019).

UEPG (2019b) Case Studies Biodiversity, European Aggregates Association. Key activities. Available at: http://www.uepg.eu/key-uepg-topics/case-studies/biodiversity (Accessed: 4 August 2019).

UEPG (2019c) Estimates of Production data, European Aggregates Association Statistics. Available at: http://www.uepg.eu/statistics/estimates-of-production-data (Accessed: 24 July 2019).

UEPG (2019d) Sustaibable development awards, European Aggregates Association. Publications. Available at: http://www.uepg.eu/publications/sd-awards (Accessed: 4 August 2019).

UNEP (2014) Sand, rarer than one thinks. Available at: http://wedocs.unep.org/handle/20.500.11822/8665.

UNEP (2019) Sand and Sustainability: Finding New Solutions for Environmental Governance of Global Sand Resources. Geneva, Switzerland. Available at: https://wedocs.unep.org/handle/20.500.11822/28163.

USGS (2017) '2015 Minerals Yearbook. Crushed Stone'. The United States Geological Survey. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/stone_crushed/myb1-2015-stonc.pdf.

USGS (2018) 2015 Minerals Yearbook. Construction sand and gravel. The United States Geological Survey. doi: 10.1016/j.ijporl.2012.07.018.

USGS (2019) Mineral Commodity Summaries 2019. U.S Geological Survey. doi: 10.1007/978-3-540-47108-0-4.

Velegrakis, A. et al. (2010) 'European marine aggregates resources: Origins, usage, prospecting and dredging techniques', Journal of Coastal Research. Special Issue EUMARSAND: European Marine Sand and Gravel Resources., 51(51), pp. 1–15. Available at: https://core.ac.uk/download/pdf/35114773.pdf.

1.7.2 Data sources used in the criticality assessment

UEPG (2019c) *Estimates of Production data*, *European Aggregates Association Statistics*. Available at: http://www.uepg.eu/statistics/estimates-of-production-data (Accessed: 24 July 2019).

Eurostat (2019c) *Easy Comext database*. Available at: http://epp.eurostat.ec.europa.eu/newxtweb/.

1.8 Acknowledgements

The JRC prepared this factsheet. The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials, as well as experts participating in the SCRREEN H2020 project workshops for their contribution and feedback.

2. ARSENIC

2.1 Overview

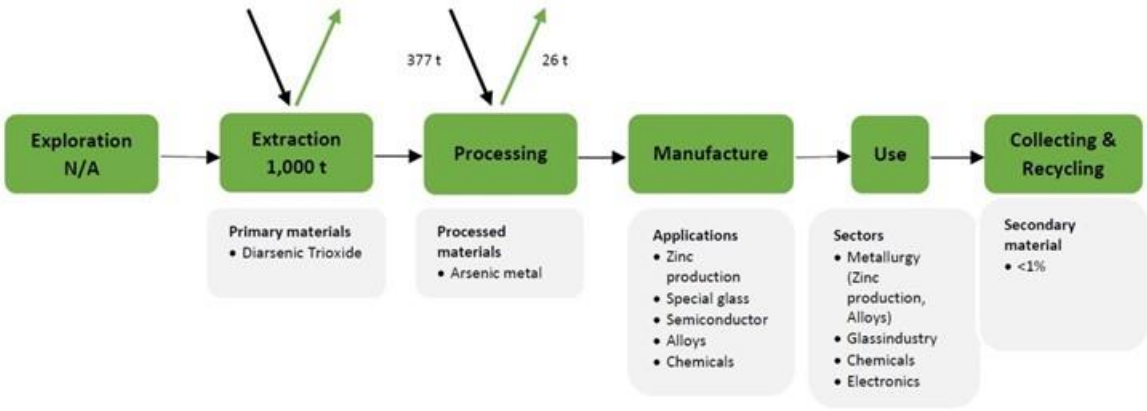


Figure 11: Simplified value chain for Arsenic for the EU[12] (average 2012-2016)

Arsenic (chemical symbol As) is a metalloid that is best known because of its toxicity. It is a natural component in many minerals and is naturally released into the atmosphere for example through volcanic eruptions. However, arsenic is also released through mining, metallurgy, and burning fossil fuels. Arsenic was previously used in the production of pesticides, fertilisers and wood preservatives, applications which are prohibited today.

Arsenic is found in different forms (inorganic and organic), which have different levels of toxicity. Inorganic arsenic is found mainly in our soil, while water contains mainly organic arsenic compounds. (AGES, 2015)

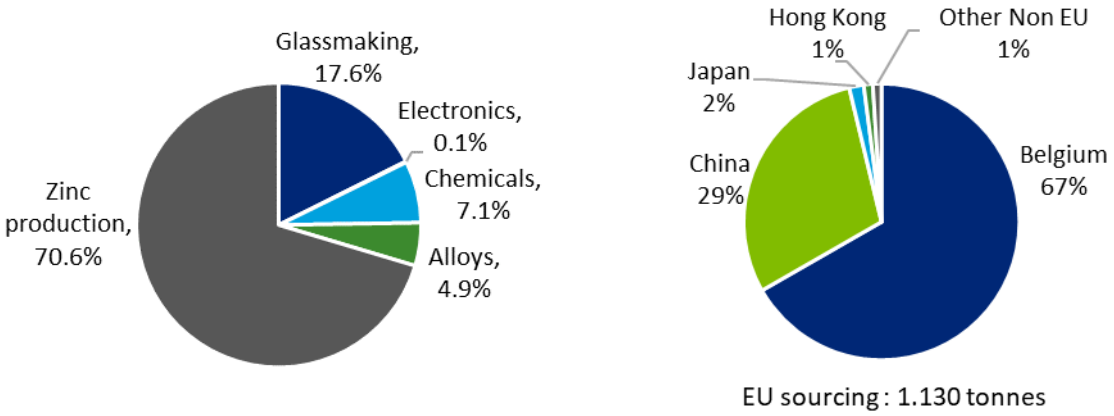


Figure 12: End uses of arsenic[13] and EU sourcing of arsenic metal[14] (2012-16) (Estat 2019a)

[12] JRC elaboration from multiple sources
[13] JRC calculated based on the report by ECHA (2010)
[14] Assuming the production of Belgium as in arsenic content

For the purpose of this assessment arsenic is evaluated in the form of arsenic metal and diarsenic trioxide. The global production figures of arsenic refers to diarsenic trioxide, as reported by World Mining Data 2019 (WMD, 2019). Trade is analysed using data by Eurostat Comext (Eurostat, 2019a). The following codes was considered for arsenic metal: CN8 codes 28048000 Arsenic. It was not possible to obtain the trade figures for diarsenic trioxide since it is reported as a mix with another substance . The trade code for this commodity is CN8 28112910 "Sulphuric Anhydride"; Diarsenic Trioxide. The data limitation also means that the figure for EU import and EU apparent consumption of arsenic could not be estimated. As a result, the EU supply risk is excluded in the calculation of supply risk

The world arsenic market has a total value of about USD 20 million, showing an increase USD of 5 million between 2012 and 2016. The major exporting countries are Japan and China, followed by the US and Germany. In recent years Germany has been the largest importer of arsenic. France, the Netherlands, and the US are further important arsenic importers. (OEC, 2019)

The EU is a net importer of arsenic metal with an import of 377 per year tonnes and export of 26 tonnes per year between 2012 and 2016. The only domestic producer of arsenic is Belgium, with annual production of 1,000 tonnes of diarsenic trioxide, equal to 757 tonnes of arsenic per year. China, Hong Kong and Japan are the main suppliers of arsenic metal to the EU. There was no import and export publicly available information of diarsenic trioxide to/from the EU. Considering this limitation, a reliable EU apparent consumption figure for arsenic could not be calculated.

Arsenic is used in the production of fertilisers, pesticides and wood preservatives. The US is the biggest consumer of diarsenic trioxide for the production of arsenic acid used in the formulation of chromated copper arsenate (CCA), a pesticide and preservative used to treat wood products for non-residential applications (USGS, 2018a). In the EU the use of arsenic for organic fertilisers and wood treatment in consumer applications is prohibited and highly restricted in industrial applications (European Commission, 2003). The main consumer of arsenic in the EU is the zinc industry utilising it for the electrowinning process for zinc production. Other uses include glassmaking, production of chemicals, and alloys. (European Commission, 2018a)

Arsenic is investigated as a doping agent for Cadmium Tellurium solar panels for increasing cell voltage of these thin film solar devices. Traditionally copper is used for this treatment. However, studies have shown great potential for arsenic, phosphorus, and antimony (Kartopu, G. et al., 2019). Moreover, it is already used for the production of indium arsenide or gallium indium arsenide for semiconductors which are used in photovoltaic applications. (USGS, 2018a)

World reserve data are unavailable but are thought to be more than 700,000 t (20 times world production). (USGS, 2019)

Worldwide an average of 43,600 tonnes of diarsenic trioxide was produced per year between 2012 and 2016. The biggest producer of diarsenic trioxide is China with an estimated production of 25,000 tonnes in 2016 (WMD, 2019), followed by Perù (BGS, 2019). In the EU Belgium is the only supplier, producing about 1,000 tonnes per year. Commercial-grade diarsenic trioxide was thought to have been recovered from processing non-ferrous ores and concentrates. Chinese production is believed to recover arsenic as a by-product of smelting gold ores containing orpiment As_2S_3 and realgar AsS, in addition to reclaiming arsenic as a by-product of nonferrous smelting (USGS, 2018a).

Depending on the chemical compound of arsenic it has different levels of toxicity, with inorganic arsenic being classified a carcinogen. Therefore there are regulations in place both in the EU and the USA defining limits of arsenic in food and the WHO provides guidelines for arsenic in drinking water, and, the output of anthropogenic arsenic by the metal industry, fossil fuels and non-ferrous metals mining and smelting has to be monitored.

The use of arsenic for the production of pesticides, fertilisers and wood preservatives for all consumer applications is prohibited today. (AGES, 2015)

Arsenic compounds are present in dust formed by the processes. Many workers potentially exposed to inorganic arsenic in the workplace (European Commission, 2018). People are also exposed to elevated levels of inorganic arsenic through drinking contaminated water, using contaminated water in food preparation and irrigation of food crops, industrial processes. Long-term exposure to inorganic arsenic, mainly through drinking-water and food, can lead to chronic arsenic poisoning. Skin lesions and skin cancer are the most characteristic effects (WHO, 2019). WHO (2019) provides guidelines for values of arsenic in drinking water.

2.2 Market analysis, trade and prices

2.2.1 Global market analysis and outlook

The US is the world's leading consumer of chromated copper arsenate (CCA) ed in wood preservatives. This application, as well as many other applications of arsenic, is highly restricted in the EU for consumer protection.

However, globally the main use of arsenic nowadays is for the production of gallium-arsenide, indium-arsenide and indium-gallium-arsenide semiconductors found in solar cells, in other electronic equipment such as mobile phones, and in various forms of herbicides, pesticides and insecticides (Mmta, 2016). The EU market shows different consumption patterns, as the main use (approx. 70% of total arsenic consumption) is zinc production.

Gallium-arsenide (GaAs) dominated the radio frequency compound semiconductor market in 2016, applied particularly in third (3G) and fourth-generation (4G) smartphones. The value of GaAs wafers consumed increased by an estimated 12% between 2015 and 2016 to USD 700 million and a further increase is expected due to the rising sales of smartphones and the installation of 3G and 4G mobile networks in India and the Republic of Korea. Moreover, new applications of GaAs wafers in Wi-Fi applications will increase the demand further (USGS, 2018b).

China and Morocco are the leading global producers of diarsenic trioxide, accounting for about 85% of world production and China accounting for 90% of global arsenic metal production (USGS, 2019).

The volume of arsenic placed on the market depends on the production of copper (most diarsenic trioxide is won as a by-product of copper refining) and on consumer demand. For example, if zinc production (main application of arsenic in EU) increases so does the demand for diarsenic trioxide. The EU places approx. 2,200 tonnes of diarsenic trioxide per year on the global market (production plus imports). More than half of this amount is exported, mainly in the form of diarsenic trioxide and some as CCA (ECHA, 2010).

The top exporters of arsenic are Japan (USD 8.08 million), China (USD 6.81 million), Germany (USD 2.14 million), the United States (USD 1.56 million), and France (USD 1.32 million). The largest importers are Germany (USD 4.74 million), France (USD 3.39 million), the Netherlands

(USD 2.58 million), the United States (USD 2.24 million) and India (USD 0.86 million) (OEC, 2019).

Table 6: Qualitative forecast of supply and demand of Arsenic

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Arsenic		X	+	?	?	?	?	?

2.2.2 EU trade

Eurostat (2019a) reports two trade codes including arsenic: CN8 28048000 "Arsenic" and CN8 28112910 "Sulphur Trioxide "Sulphuric Anhydride"; Diarsenic Trioxide". However, it has been decided not to use the trade code 28112910 in further evaluation of criticality, as it could not be determined whether this code measures only diarsenic trioxide or sulphur trioxide as well. Therefore, the following trade figure is based solely on arsenic metal. The EU is a net importer of arsenic metal (CN8 28048000) between 2012 and 2016. The annual imports of arsenic metal during this period were in the mid 300 tonnes area with a peak in 2015 reaching 451 tonnes. The exports range between 20 and 43 tonnes.

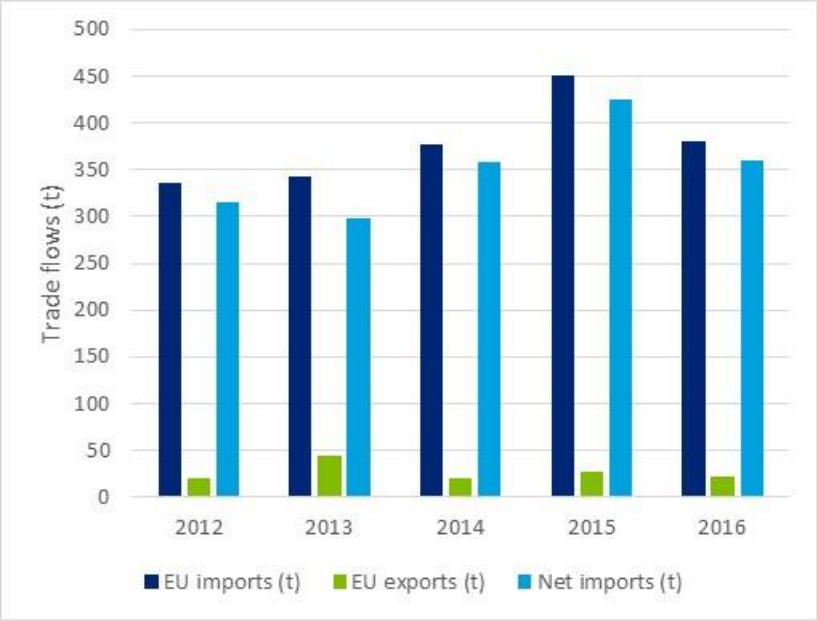


Figure 13: EU trade flows for Arsenic metal (Eurostat, 2019)

The main supplier of arsenic metal for the EU is China covering 89% of a total of 377 tonnes imports. Other suppliers are Japan (5%) and Hong Kong (3%) (Eurostat, 2019).

There are no export quotas or restrictions by suppliers of the EU; however, Morocco imposes taxes of up to 25% on arsenic and arsenic sulphides. The EU has trade agreements with Namibia and Japan in place. (OECD, 2019).

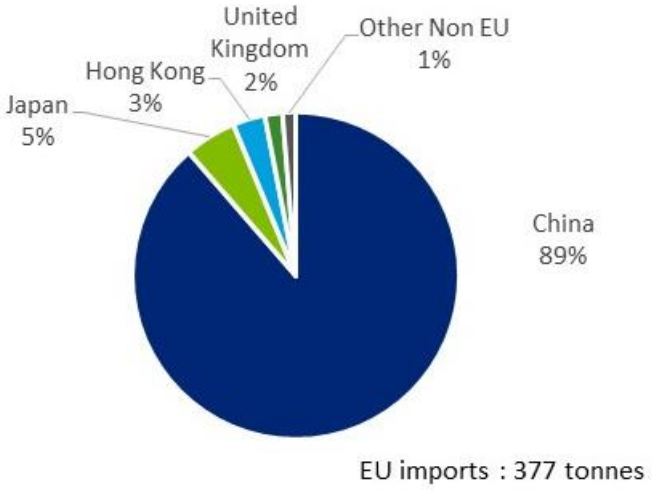


Figure 14: Import of Arsenic metal, average 2012-2016 (Eurostat, 2019)

2.2.3 Prices and price volatility

USGS provides records of arsenic prices since 1900. The trend of price development can be seen in Figure 5 in USD per tonne converted to the 1998 consumer price index to allow comparability. As Figure 5 shows there have not been major changes or irregularities since 2005 but for a steady increase of arsenic prices.

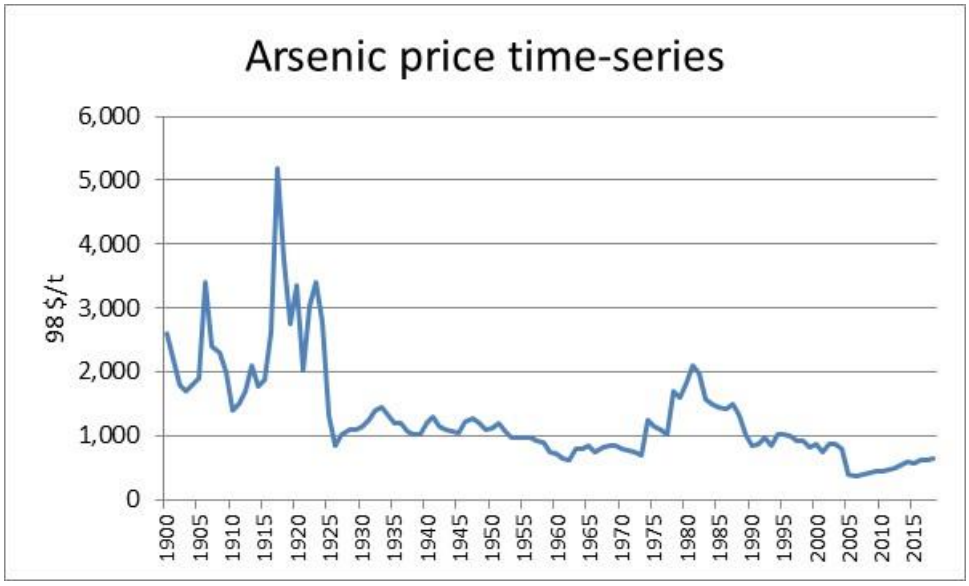


Figure 15: Value of arsenic (USD per tonne arsenic content, converted to 1998 consumer price index) from 1900-2018 (USGS, 2017a; USGS, 2019)

In the period of 2012 to 2016 prices for arsenic metal increased from USD 1,653 per tonne to USD 1,890 per tonne and for arsenic trioxide from USD 529 per tonne to USD 683 per tonne. This trend continues for arsenic trioxide in 2017 and 2018 increasing to USD 750 per tonne. However, arsenic metal prices showed a relatively strong decrease to USD 1,560 per tonne and USD 1,400 per tonne respectively. (USGS, 2017b; USGS, 2019)

2.3 EU demand

The world global market value of arsenic is about USD 20 million. Average annual production of diarsenic trioxide between 2012 and 2016 is about 33,000 tonnes (WMD, 2019, BGS, 2019)

2.3.1 EU demand and consumption

The apparent consumption is calculated as imports minus exports plus domestic production. The EU has an average apparent consumption of arsenic of about 1,300 tonnes per year in the period of 2012-2016. In order to be able to compare trade and production figures, production figures were converted to arsenic content by multiplying the diarsenic trioxide production with the arsenic content (75.7%).

This demand is mainly covered by only one domestic source – Belgium is producing 67% of EU supplies of arsenic (content). (Eurostat 2019a; WMD, 2019)

2.3.2 Uses and end-uses of Arsenic in the EU

Uses of inorganic arsenic are widespread and occur in many different sectors (ECHA, 2010; ISE, 2019; USGS, 2018a):

- Metallurgy:
  - The main application of diarsenic trioxide in the EU is the electrowinning process for zinc production.
  - Arsenic metal is used in lead alloys to improve strength and castability
  - It is used as antifriction additive in alloys for bearings.
- Glass sector:
  - Diarsenic Trioxide is used in the special glass sector for the production of lighting glass, optical glass, laboratory and technical glassware, etc.
  - Production of germanium-arsenide-selenide or gallium arsenide for specialty optical materials. GaAs is an alternative for zinc selenide in laser systems for lenses and rear mirrors, providing high toughness and durability. (II-VI INFRARED, 2016)
  - In glassmaking for decolouration purposes, as enamel or as fining agent.
- Chemicals:
  - Production of arsenic compounds and ultra-pure arsenic metal for its application in the electronics sector.
  - A small amount of arsenic is used in vitrifiable enamels.
- Electronics sector:
  - Manufacture of gallium arsenide semiconductors.
  - Use for epitaxial layers on wafers in form of indium arsenide phosphide and gallium arsenide phosphide for manufacturing of high frequency devices such as integrated circuits, light emitting diodes and laser diodes.
- Renewable energies:
  - Arsenic is used for the production of indium arsenide or gallium indium arsenide for semiconductors which are used in photovoltaic applications.
  - Arsenic is investigated as a doping agent for Cadmium Tellurium solar panels for increasing cell voltage of these thin film solar devices. Traditionally copper is used for this treatment. However, studies have shown great potential for arsenic, phosphorus, and antimony. (Kartopu, G. et al., 2019)
- Other: fertilizers, fireworks, wood preservation, and pesticides (all highly restricted in EU).

In the EU, arsenic at industrial sites is used for the manufacture of: fabricated metal products, chemicals, mineral products (e.g. plasters, cement) and electrical, electronic and optical equipment. It is also used building & construction work and municipal supply (e.g. electricity, steam, gas, water) and sewage treatment (ECHA, 2019).

The the major application area for arsenic compounds in the EU is the production of zinc together with the manufacture of glass (European Commission, 2018).

In this assessment, the share of arsenic by application was estimated based on the manufacturing and use mass flow of diarsenic trioxide in the EU, reported by European Chemicals Agency (2010). According to this study, , the main application of diarsenic trioxide in the EU is zinc production. Diarsenic trioxide is used in electrolysis for the manufacture of zinc metal. Its main purpose is the removal for impurities such as copper, cobalt, nickel, etc. Another important sector using diarsenic trioxide in the EU is special glass production. The chemicals industry mainly produces other arsenic compounds, as well as ultra-pure arsenic metal for the electronics industry. Moreover arsenic metal is used for alloys and in the electronics industry. However, the latter only plays a minor role in the use of arsenic in the EU (0.1%). The breakdown of arsenic by application in the EU can be seen in Figure 16.

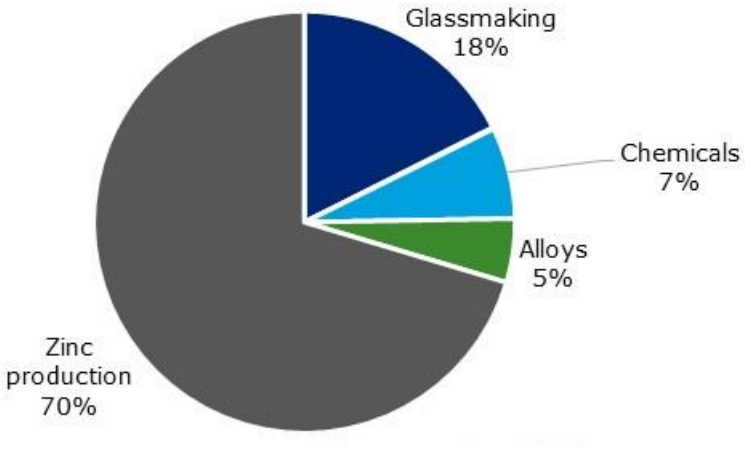


Figure 16: End uses of Arsenic[15]

Relevant industry sectors are described using the NACE sector codes (Eurostat, 2019b).

[15] JRC calculation based on ECHA (2010)

Table 7: Arsenic applications, 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2019b)

Applications	2-digit NACE sector	4-digit NACE sectors	Value added of NACE 2 sector (M€)
Zinc production (Electrowinning of zinc)	C24 – Manufacture of basic metals	C2443 – Lead, zinc and tin production	55,426
Glassmaking	C23 – Manufacture of non-metallic mineral products	C2319 – Manufacture and processing of other glass, including technical glassware	57,255
Chemicals (As compounds, ultra-pure arsenic metal)	C20 – Manufacture of chemicals and chemical products	C2013 – Manufacture of other inorganic basic chemicals; C2059 – Manufacture of other chemical products n.e.c.	105,514
Alloys	C24 - Manufacture of basic metals	C2443 – Lead, zinc and tin production; C2445 – Other non-ferrous metal production	55,426
Electronics (Circuit boards, GaAs wafers and semiconductors)	C26 – Manufacture of computer, electronic and optical products	C2611 – Manufacture of electronic components; C2612 – Manufacture of loaded electronic boards	65,703

2.3.3 Substitution

Depending on the application there are different possibilities of substituting arsenic. (European Commission, 2018b; ECHA, 2010; USGS, 2019)

- Zinc production: possible alternatives for diarsenic trioxide in the electrowinning or zinc are diantimony trioxide (Sb_2O_3) and antimony potassium tartrate (K2Sb2(C4H2O6)2).
- Alloys: as arsenic metal which is used for lead alloys is not classified carcinogenic, there is not a general pursue in the search for alternatives.
- Glass production: there is continuous research going on into replacing arsenic in special glass production, however, alternatives are currently not available, where very high quality glass is required.
    - There are no alternatives for arsenic in some optical filter glass, as they rely on the intrinsic properties for arsenic.
    - Use of alkali free glass in opto-electronic applications is very challenging.
    - Some glass-ceramic hobs are now arsenic-free, but producing clear glass hobs without arsenic remains a difficult challenge.
    - Alternative fining agents: sodium sulphate for lead crystal, antimony trioxide for lead crystal, sodium/potassium nitrates with antimony trioxides in special glasses, cerium oxide.
    - Alternative decolourising agents: antimony trioxide as decolourising agent for glass and as opacifier in ceramics and enamels, selenium for lead crystal, cerium oxide in special glass and as opacifier in ceramics and enamels.

- Semiconductors: Gallium-arsenide can be replaced by indium-phosphide, gallium-nitrate and silicon-germanium. (USGS, 2018b)
- Solar cells: Replacement of gallium-arsenide with silicon.
- Defence-related applications: So far no effective substitute for gallium-arsenide based integrated circuits exists.
- Copper foil: The study by the European Commission on Inorganic arsenic compounds (2018b) found an application of an alternative for arsenic in copper foils, the name was not been disclosed. At the time of the study it has been used for approx. 30% of the production showing similar physical properties, but different colours.
- Gold electroplating: no suitable alternatives considering technical and economic feasibility have been found.

2.4 Supply

2.4.1 EU supply chain

According to WMD (2019) the EU production of arsenic is solely based in Belgium, producing an estimated amount of 1,000 tonnes of diarsenic trioxide per year, averaged over 2012 to 2016. The Belgian production is equal to 732 tonnes of arsenic content. Imports from China (30%), Japan (2%) and other non EU countries make up the rest of 1,377 tonnes per year arsenic metal sourced on average between 2012 and 2016. These figures result in an import reliance of 32%. (Eurostat, 2019a; WMD, 2019). However, this estimation is incomplete for arsenic because there were no figures on the trade of diarsenic trioxide. Therefore, in this assessment, the EU supply risk, calculated mainly based on EU import and domestic production, was excluded.

The company Vital Materials Co. based in Belgium manufactures gallium arsenide substrates which are used as semiconductors in wireless communication applications for example. Another Belgian company KBM Affilips manufactures a wide range of master alloys, such as lead-arsenic, copper arsenic, or lead-arsenic-antimony alloys. Overall there are eight companies having registered arsenic use with ECHA in Belgium, France, Spain, Slovakia, Germany, and Luxembourg (ECHA, 2019; Vital Materials Co., 2019; KBM Affilips, 2019).

Only two companies produce diarsenic trioxide in the EU. Also the number of importers is very limited. ECHA's study concludes a very low level of complexity of the arsenic supply chain, as 88% of arsenic used in the EU is concentrated in two industry branches, zinc and glass production both being organised in effective industry associations. (ECHA, 2010)

2.4.2 Supply from primary materials

2.4.2.1 Geology, resources and reserves of Arsenic

Geological occurrence: Arsenic is an element stemming predominantly from natural sources occurring ubiquitously in the earth's crust with a concentration of 1,0-2,0 ppm which is why it is considered a rare element. (Lebensmittelchemisches Institut, 2010) Arsenic can occur in its elemental form, but usually does not occur in large deposits rather as a component in other minerals. It may be obtained as a by-product from copper, gold and lead smelter flue dust, as well as from roasting arsenopyrite, the most abundant ore mineral of arsenic. (USGS, 2019)

Global resources and reserves[16]*:* World reserves data are unavailable but are thought to be more than 20 times world production (700,000 t).

There are recoveries of orpiment (As_2S_3) and realgar (AsS) occurrences in China, Peru and the Philippines. China has stockpiled orpiment and realgar from gold mines for later recovery of arsenic. Arsenic occurrences are associated with copper-gold ores in Chile and gold deposits in Canada. It can also be recovered from enargite, a copper mineral. Diarsenic trioxide was produced at the hydrometallurgical complex of Guemassa, Morocco, from cobalt arsenide ore. (USGS, 2019)

EU resources and reserves[17]*:* For the EU there is only resource data available for Poland (see Table 8).

Table 8: Resource data for the EU compiled in the European Minerals Yearbook at Minerals4EU (2019)

Country	Reporting code	Commodity	Quantity	Unit	Grade	Code Resource Type
Poland	Nat. rep. code	Arsenic	10,000	t	4.35%	A+B+C1
Poland	Nat. rep. code	Arsenic	10,000	t	3.33%	C2+D
Poland	Nat. rep. code	Arsenic ore	230,000	t		A+B+C1
Poland	Nat. rep. code	Arsenic ore	300,000	t		C2+D

According to Minerals4EU (2019) there is exploration activity both in Portugal and in Poland. In Portugal there were 10 active exploration licences in 2013 for occurrences including arsenic with various other commodities. In 2013 in Poland there was one exploration licence active exploring an occurrence of arsenic with other minerals.

[16] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of arsenic in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template.[16], which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

[17] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for arsenic. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for arsenic, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for arsenic the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019).Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However a very solid estimation can be done by experts.

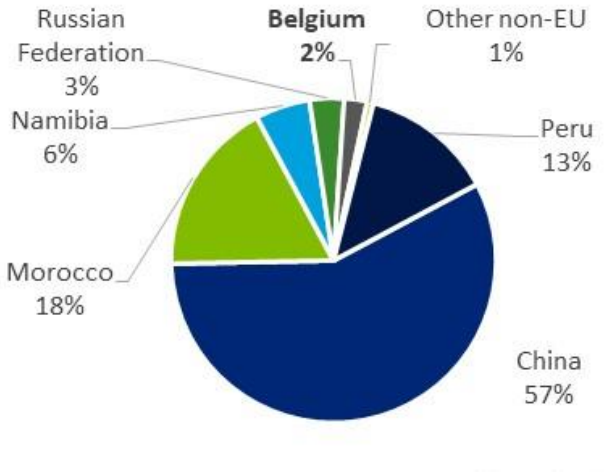
2.4.2.2 World and EU production

Arsenic is an element of the earth's crust and can be found in its elemental form, but commonly it is found as inorganic arsenic in the form of its sulphides. Additionally it can occur in form of its oxides and in arsenic alloys as metal arsenide and arsenate. The recovery of arsenic is mainly done by heating arsenopyrite (FeAsS) or loellingite ($FeAs_2$) under exclusion of air at 700°C in horizontal clay pipes. Thereby arsenic is sublimated and collected in cooled collectors and condensed.

However, the production of diarsenic trioxide as a by-product in the extraction, processing and purification of copper, lead, cobalt and gold is the most important method of producing arsenic. (Lebensmittelchemisches Institut, 2010)

The further reduction of diarsenic trioxide to arsenic metal was believed to have accounted for all world output of commercial-grade (99%-pure) arsenic metal. (USGS, 2018a)

WMD states the arsenic production as the amount of produced diarsenic trioxide, with an average global production rate of 28,800 tonnes between 2012 and 2016. In addition, BGS reported 4,400 tonnes per year of production from Peru on average 2012-2016, giving 33,000 tonnes per year of world average arsenic production between 2012 and2016.



World production: 33,200 tonnes

Figure 17: Global production of Diarsenic trioxide, average for the years 2012-2016. (WMD, 2019 and BGS, 2019)

2.4.3 Supply from secondary materials/recycling

There is no mentionable documented recycling of arsenic taking place. According to UNEP (2013) report "Recycling Rates of Metals" Old Scrap Ratio, Recycled Content and End-of-Life Recycling Rate are all below 1%.

2.4.4 Processing of Arsenic

To obtain pure arsenic metal the first step is the thermal reduction of the raw material diarsenic trioxide with coke or iron, producing arsenopyrite (FeAsS) or loellingite ($FeAs_2$). This is then heated in vacuum in horizontal sound tubes where elemental arsenic sublimates and returns to its solid state on the cold surface. In order to obtain arsenic metal with a purity greater 99.99999% necessary for semiconductor applications, multi-distilled diarsenic trichloride is reduced in hydrogen. (ISE, 2019)

2.5 Other considerations

2.5.1 Environmental and health and safety issues

Arsenic is naturally present as impurity in ores, fossil fuels, soil, plant material, etc. and may be released to the air by thermal processing or combustion of these materials. Occupational exposure to inorganic arsenic compounds may take place, for example, in the formation of the substances involving alloys with arsenic metal or in thermal processes where arsenic is present as unintentional impurity in raw materials.

Furthermore, arsenic compounds are present in dust formed by the processes. The number of workers potentially exposed to inorganic arsenic in the workplace is high. (European Commission, 2018)

Arsenic is an element of earth's crust and a component of many minerals. It can be released into the atmosphere by volcanic eruptions or industrial processes, such as mining, metallurgy and burning fossil fuels. People are also exposed to elevated levels of inorganic arsenic through drinking contaminated water, using contaminated water in food preparation and irrigation of food crops, industrial processes, eating contaminated food and smoking tobacco. Long-term exposure to inorganic arsenic, mainly through drinking-water and food, can lead to chronic arsenic poisoning. Skin lesions and skin cancer are the most characteristic effects. (WHO, 2019)

WHO (2019) provides guidelines for values of arsenic in drinking water and risk management recommendations. The EU has regulations in place limiting the amount of arsenic in water and food.

2.5.2 Socio-economic issues

The Environmental Justice Atlas (2019) reports several examples of mines/smelters with social issues related to arsenic production, either during operations or in the post-closure stage. Among these, Namibian Custom Smelter, Tsumeb, Namibia; Arsenic poisoning causing cancer around Hunan Realgar Mine in Shimen, Changde, China; Toroku mine, arsenic pollution, Miyazaki prefecture, Japan.

2.6 Comparison with previous EU assessments

Arsenic has not been assessed in previous criticality studies. The assessment has been conducted using the methodology for the 2017 list. Arsenic is evaluated at processed stage.

The trade figures for arsenic in Eurostat-Comext database was available for arsenic metal while for diarsenic trioxide the figures were not useable since it was a mix with another substance. Considering this lack of information, the supply risk value for arsenic was calculated based on the global supply risk of arsenic in the form of diarsenic trioxide.

The results of this assessment are shown in Table 9.

Table 9: Economic importance and supply risk results for Arsenic in the assessments of 2011, 2014, 2017, and 2020

Assessment	2011	2014	2017	2020	
Indicator	not assessed	not assessed	not assessed	EI	SR
Arsenic				2.56	1.12

2.7 Data sources

Data for consumption patterns in the EU are not available at the time of the assessment.

2.7.1 Data sources used in the factsheet

AGES (2019). Residues and Contaminants – Arsenic [Online]. Available at: https://www.ages.at/en/topics/residues-and-contaminants/arsenic/ (Accessed: 26.08.2019)

Environmental Justice Atlas [Online]. Available at: https://ejatlas.org/ (Accessed: 05.11.2019)

European Chemicals Agency (ECHA) (2010). Background document for Diarsenic trioxide. Available at: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&ved=2ahUKEwi_w4SdkdrlAhVFU1AKHY1uDsgQFjABegQIAxAC&url=https%3A%2F%2Fecha.europa.eu%2Fdocuments%2F10162%2F46eb55f6-b2ba-43e6-ad28-3064b89e93a5&usg=AOvVaw1YKVfJge_BqAQ9vkwlKyW1

European Chemicals Agency (ECHA) (2019). Arsenic - General information [Online]. Available at: https://echa.europa.eu/de/registration-dossier/-/registered-dossier/22366 (Accessed: 08.11.2019)

European Commission (2003). Press Release Database [Online]. Available at: https://europa.eu/rapid/press-release_IP-03-29_en.htm (Accessed 27.08.2019)

European Commission (2018a). Commission Staff Working Document, Impact Assessment. Proposal for a Directive of the European Parliament and of the Council amending Directive 2004/37 on the protection of workers from the risk related to exposure to carcinogens or mutagens at work. p. 133. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018SC0088

European Commission (2018b). Third study on collecting most recent information for a certain number of substances with the view to analyse the health, socio-economic and environmental impacts in connection with possible amendments of Directive 2004/37/EC. Final Report for inorganic arsenic compounds incl. arsenic acid and its salts. Available at: https://ec.europa.eu/social/main.jsp?catId=738&langId=en&pubId=8224&furtherPubs=yes

Eurostat (2019a). Comext International Trade [Online]. Available at: http://epp.eurostat.ec.europa.eu/newxtweb/mainxtnet.do (Accessed: 27.08.2019)

Eurostat (2019b). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E) [Online]. Available at: https://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2 (Accessed: 29.08.2019)

Federal Ministry Republic of Austria – Sustainability and Tourism (2019). World Mining Data 2019. Available at: https://www.world-mining-data.info/?World_Mining_Data___PDF-Files

ISE (2019). Arsen [Online]. Available at: https://institut-seltene-erden.de/seltene-erden-und-metalle/strategische-metalle-2/arsen/ (Accessed: 13.09.2019)

Kartopu, G. et al. (2019). Study of thin film poly-cristalline CdTe solar cells presenting high acceptor concentrations achieved by in-situ arsenic doping. Available at: https://www.scopus.com/record/display.uri?eid=2-s2.0-85062022921&origin=inward&txGid=a42658522247eab390230c4ab913bfcf

KBM Affilips B.V. (2019). Our product range [Online]. Available at: https://www.kbmaffilips.com/ (Accessed: 08.11.2019)

Lebensmittelchemisches Institut (2010). Arsen – Toxikologische Neubewertung eines Halbmetalls [Online]. Available at: https://www.lci-koeln.de/deutsch/veroeffentlichungen/lci-focus/arsen (Accessed: 29.08.2019)

Minerals4EU (2019). European Minerals Yearbook – Data for Arsenic [Online]. Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/pages/bycommodity.jsp?commodity=Arsenic (Accessed: 29.08.2019)

Mmta (2016). Metals – Arsenic [Online]. Available at: https://mmta.co.uk/metals/as/, (Accessed 27.08.2019)

OEC (2019). Arsenic [Online]. Available at: https://oec.world/en/profile/hs92/280480/ (Accessed: 27.08.2019)

OEDC (2019). Export restrictions on Industrial Raw Materials [Online]. Available at: https://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials (Accessed: 03.09.2019)

USGS (2017a). Historical Statistics for Mineral and Material Commodities in the United States. Available at: https://www.usgs.gov/centers/nmic/historical-statistics-mineral-and-material-commodities-united-states

USGS (2017b). Mineral Commodity Summaries. Available at: https://www.usgs.gov/centers/nmic/arsenic-statistics-and-information

USGS (2018a). 2016 Minerals Yearbook – Arsenic. Available at: https://www.usgs.gov/centers/nmic/arsenic-statistics-and-information

USGS (2018b). 2016 Minerals Yearbook – Gallium. Available at: https://www.usgs.gov/centers/nmic/arsenic-statistics-and-information

USGS (2019). Mineral Commodity Summaries. Available at: https://www.usgs.gov/centers/nmic/arsenic-statistics-and-information

Vital Materials Co. (2019). Gallium Arsenide (GaAs) Substrates [Online]. Available at: https://www.vitalchem.com/product/gallium-arsenide-wafer (Accessed: 08.11.2019)

WHO (2019). Fact sheets – Arsenic [Online]. Available at: https://www.who.int/news-room/fact-sheets/detail/arsenic (Accessed 28.08.2019)

II-VI INFRARED (2016). Gallium Arsenide (GaAs) [Online]. Available at: http://www.iiviinfrared.com/Optical-Materials/gaas.html (Accessed: 13.09.2019)

2.7.2 Data sources used in the criticality assessment

2.8 Acknowledgments

This factsheet was prepared by the JRC. The authors would like to thank XXX, the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this Factsheet.

3. BENTONITE

3.1 Overview

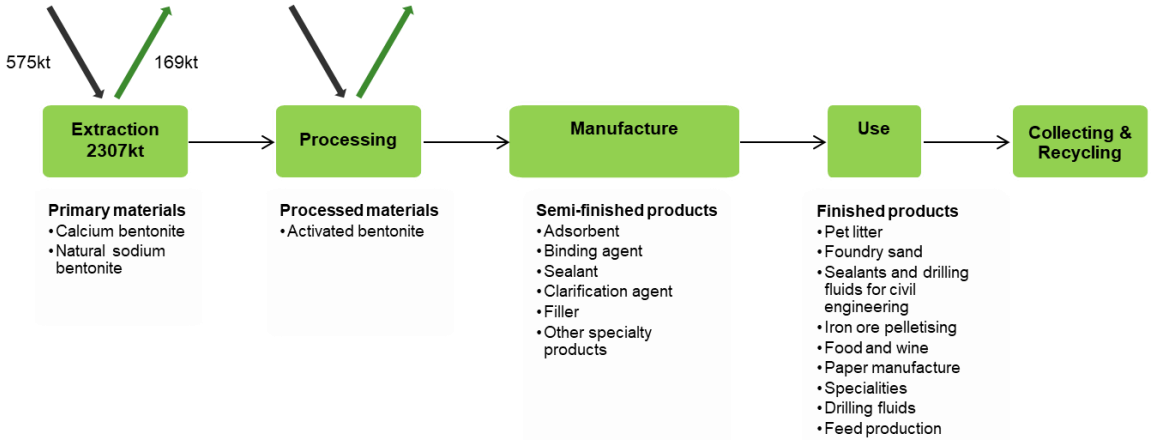
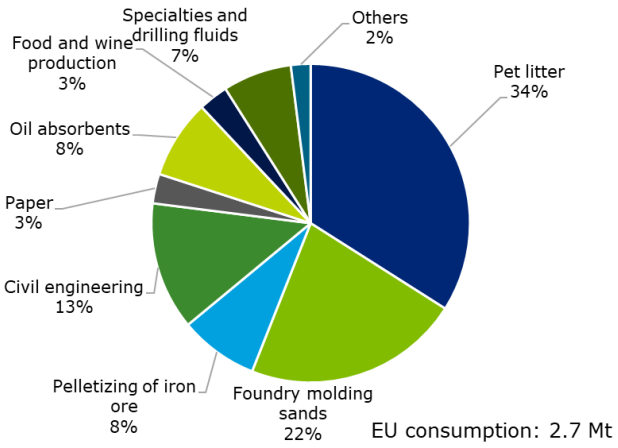
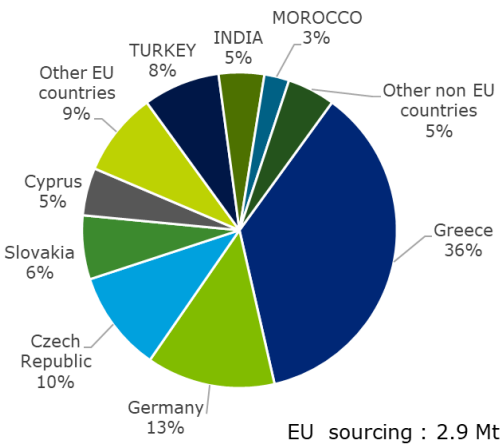


Figure 18: Simplified value chain for bentonite for the EU[18], averaged over 2012-2016

Bentonite is an absorbent aluminium phyllosilicate, composed predominantly of the clay mineral group smectite. Most bentonites are formed by the alteration of igneous material, either by sub-aqueous alteration of fine-grained volcanic ash or by in situ hydrothermal alteration of acid volcanic rocks. The smectite in most bentonites is the mineral montmorillonite, but occasionally other types of smectite are present. The two dominant types of bentonite are calcium bentonite and sodium bentonite which have different properties and uses. Bentonites have special properties such as hydration, swelling, water absorption, viscosity, thixotropy, ability to act as a bonding agent and significant cation exchange capacity. This makes them valuable materials for a wide range of uses and applications including pet litter, foundry sands and iron ore pelletizing, civil engineering applications, use as filler in various industries and others.





[18] JRC elaboration on multiple sources (see next sections)

Figure 19: EU end uses (IMA-Europe, 2018) and EU sourcing (WMD, 2019; ESTAT Comext, 2019) of bentonite (Average 2012-2016)

The EU is an important supplier of bentonite with approximately 15% of the global production. In this assessment Bentonite is analysed at the extraction stage, using the CN8 code 250810.

The EU consumption of bentonite is around 2.7 Mt, which are mostly sourced through domestic production, mainly from Greece, Germany, and Czechia. The EU is a net importer of bentonite, with Import reliance of 14.9% and Turkey, India and Morocco as main partner countries.

Bentonite is used in a diverse range of markets including pet litter, in foundry, construction and civil engineering, pelletising, paper, oil adsorbent, food and wine production, drilling fluids and many more.

Global reserves and resources figures are considered to be large. However, there are no global reserves figures, or country-specific figures published by any data provider. For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for bentonite.

The world annual production of bentonite is about 17 Mt of which 26% is produced in the Unites States and 21% in Mexico (WMD, 2019). The European production of bentonite is around 2.3 Mt (WMD, 2019). In the EU, bentonite is commonly recycled at end-of-life (50%), but the contribution of recycling to cover demand is estimated only at 19%.

3.2 Market analysis, trade and prices

3.2.1 Global market analysis and outlook

The future of bentonite is expected to vary for different end use sectors. For instance the pet litter application is expected to remain strong. Bentonite used in iron ore pelletising is influenced by trends the iron and steel market. Major iron and steel producers, such as China, have seen a shrinkage in this sector, which is expected to continue and it will influence the iron ore pelletising sector too. The future of bentonite used in foundry sands will follow the trend of key sectors utilising iron ore castings such as the automotive and heavy equipment manufacturing sectors. US comprises a major iron casting producer and the future of this industry is expected to remain positive due to ongoing technological innovation (e.g. the smart car) and the uptake from emerging economies. Trends in the construction sector largely affect bentonite sales too. Finally, the paper sector has been shrinking due to electronic exchange of information and therefore the sales of bentonite in this sector are expected to decrease further. For other end uses, it is difficult to speculate any future trends due to the variability of sales on bentonite seen from year to year and at regional level (USGS, 2015; Scogings, 2016; SCRREEN workshop 2019).

Table 10: Qualitative forecast of supply and demand of bentonite

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Bentonite		X	+	+	?	+	+	?

3.2.2 EU trade

The EU is a net importer of bentonite. With about 575 kt/y, import is three times higher than export in the period 2012-2016, according to Comext (Eurostat, 2019a). Export is about 169 kt/y.

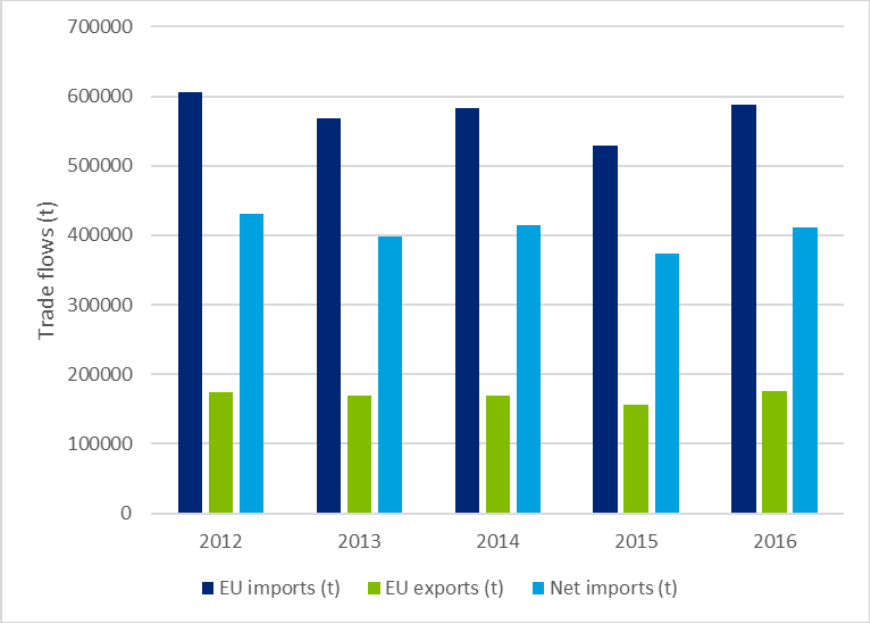


Figure 20: EU trade flows of bentonite (Eurostat, 2019a)

The main suppliers for the EU are Turkey (39%), India (23%), Morocco (13%), UK and United States (6% each).

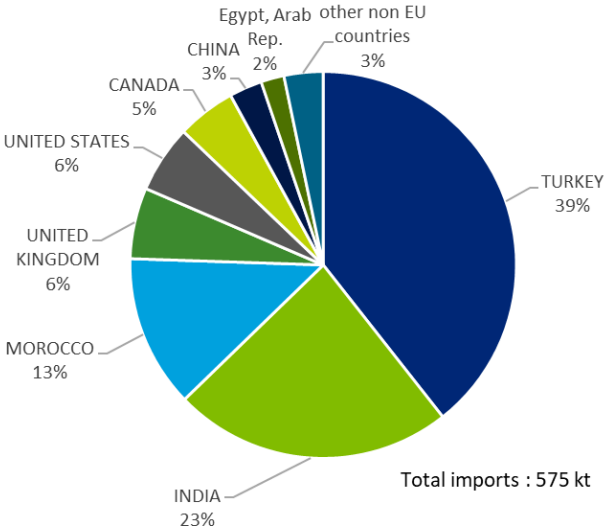


Figure 21: EU imports of bentonite, average 2012-2016 (Eurostat, 2019a)

According to Comext (Eurostat, 2019a), Europe imports about 20% of the bentonite used in the EU (about 2,9 Mt per year), mainly coming from Turkey (8%), India (5%), and Morocco (3%). The EU sourced about 80% of bentonite is sourced within the EU , mainly form Greece (36%), Germany (13%) and Czechia (7%).

3.2.3 Prices and price volatility

The price of bentonite depends on its end use and grade and can range from as low as approximately USD 30 per tonne for cat litter dried crude bentonite to USD 220 per tonne for foundry grade dried crude bentonite. Other grades, in particular for specialised applications, for instance in paper, wine refining, detergents, oil clarification markets command higher prices. (Industrial Minerals, 2016; Scogings, 2016; SCRREEN workshops, 2019).

3.3 EU demand

At global level, consumption patterns vary widely depending on the industry availability in a specific region and country demographics. For example cat litter consumption is higher in wealthier economies, such as North America, Europe and Japan. Bentonite use in iron ore pelletising is higher in countries that produce iron ore fines or have a strong steel industry, e.g. China, Russia and the United States (Scogings, 2016).

3.3.1 EU demand and consumption

The EU apparent consumption in the period 2012-2016 (5 year average) is estimated at 2.75 Mt/y, of which 2.3 Mt/y is domestic production, 0.58 Mt/y is the import from extra EU countries and 0.17 Mt/y is the export. The above figures suggest that the majority of the domestic production is consumed within Europe and it can satisfy the EU industry demand for bentonite, without major import reliance issues.

3.3.2 Uses and end-uses of bentonite in the EU

Bentonite is often named as the 'mineral of thousand uses'. It is used in a diverse range of markets including pet litter, foundry, construction and civil engineering, pelletising, paper, food and wine production, drilling fluids and many more. The EU market shares of the above mentioned applications are presented in Figure 22.

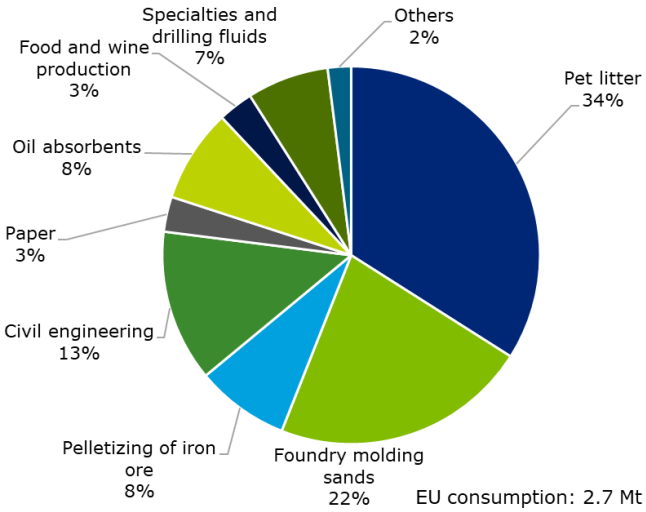


Figure 22: EU end uses of bentonite. Average 2012-2016. (IMA Europe, 2018)

In Europe, the pet litter market presents the greatest share. Bentonite is used due to its absorbing properties. The formation of clumps helps the removal of impurities, allowing the remaining product to be used for longer. Bentonite is used in foundry moulding sands as a bonding material for the production of iron, steel and non-ferrous casting. In civil engineering,

the bentonite thixotropic properties are important and it finds application in foundations, tunnelling, pipe jacking, and in horizontal directional drilling. It is also used in the construction and sealing of landfills. Bentonite finds use as a binding agent in the production of iron ore pellets, which comprises the feed material in blast furnaces for pig iron production or in the production of direct reduction iron (DRI). In food and wine, bentonite is used as a purification agent. Bentonite is important in paper making where it is used in pitch control, in de-inking during paper recycling and in the manufacture of carbonless copy paper. Bentonite finds application in numerous other specialised end uses, for example in the pharmaceutical and cosmetics markets, where it is used as a filler, in detergents, in paints and dyes, in catalysts and many more. In drilling fluids, bentonite comprises one of the key mud constituents for oil and water well drilling and it is used to seal the borehole walls, to lubricate the drill head and to remove drill cuttings. Bentonite also finds use in animal feed production, where it is used as a pelletising agent (IMA Europe, 2018). Several additional applications exist, but the ones mentioned in the figure above represent the key ones for the European market.

Relevant industry sectors are described using the NACE sector codes (Eurostat, 2019c).

Table 11: Bentonite applications (IMA-Europe, 2018), 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat 2019c)

Applications	**2-digit NACE sector**	**4-digit NACE sectors**	**Value added of NACE 2 sector (millions €)**
Pet litter	C23 - Manufacture of other non-metallic mineral products	C2399 - Manufacture of other non-metallic mineral products n.e.c.	57,255
Foundry molding sands	C24 - Manufacture of basic metals	C2452 - Casting of steel	55,426
Pelletising iron ore	C24 - Manufacture of basic metals	C2451 - Casting of iron	55,426
Civil engineering	C23 - Manufacture of other non-metallic mineral products	B0990 - Support activities for other mining and quarrying	57,255
Paper	C17 - Manufacture of paper and paper products	C1712 - Manufacture of paper and paperboard	38,910
Oil adsorbent	C20 - Manufacture of chemicals and chemical products		105,514
Food and wine production	C11 - Manufacture of beverages	C1102 Manufacture of wine from grapes	32,505
Specialties and drilling fluids	B09 - Mining support service activities	B0910 - Support activities for petroleum and natural gas extraction	3,400
Others	C20 - Manufacture of chemicals and chemical products		105,514

3.3.3 Substitution

Substitutes have been identified for applications in pet litter, foundry moulding sands, pelletising of iron ore and civil engineering uses.

Substitutes for bentonite used in pet litter include wood based litter and a range of other alternative pet litters. According to the literature, wood based pet litter and other alternative pet litters account for only 5% of the pet litter market, whilst 95% of the market depends on bentonite based products (Hall, 2016). Wood based pet litter comprises wood pellets (e.g. from pine) which are often produced from sawdust and recycled wood materials. Other alternative pet litter s include paper based, plant based or silica gel based products (Hall, 2016; Michaels, 2005).

Bentonite in foundry moulding sands acts as a binder. Several alternative binders are available for use, but bentonite is the most popular and alternatives are used only to satisfy specific needs or functions. Oils, such as linseed oil, other vegetable oils and marine oils may function as alternative binders in foundry moulding sands. Organic resins, such as phenolic resins are often used in resin shell sand casting, where good surface smoothness, fewer casting defects and good dimensional accuracy are a requirement. Phenolic resins however are much more expensive than bentonite. Some inorganic resins may also substitute bentonite, for example sodium silicate and phosphate (Engineered Casting Solutions, 2006).

In the pelletising of iron ore, bentonite is used as a binding agent and may be substituted by hydrated lime or organic binders. Bentonite is the most widely used binder in iron ore pelletizing. The use of bentonite is favourable in terms of physical, mechanical and metallurgical pellet qualities.

The use of hydrated lime as a binder finds application in the production of fluxed pellets. Hydrated lime was used as a binding agent for pellets in several plants as early as in the 1990s. Substitution of hydrated lime with bentonite however has significantly decreased the total energy requirements of the process, which provides direct cost savings (Kogel et al., 2006; Zhu et al., 2015). Organic binders provided good wet pellet strength; however, they have found limited application in industry. The use of boron together with organic binders have shown some promising results (Sunde, 2012; Sivrikaya and Arol, 2014).

Bentonite is used in civil engineering and related applications , for example in geosynthetics, in pilling, in the construction of cut-off walls (as a barrier), in excavation, boreholes and others. Polymer support fluids are used as alternatives to bentonite, but it is believed that bentonite support fluids are much more popular (Jafferis and Lam 2013; Lam and Jefferis 2014).

There are no quantified 'market sub-shares' for the identified substitutes of bentonite and the ones used are based on hypotheses made through expert consultation (SCRREEN workshops, 2019) and literature searches.

3.4 Supply

3.4.1 EU supply chain

The yearly European production of bentonite over 2012-2016 is around 2.3 Mt (WMD, 2019). Between 2012 and 2016, the EU production mainly took place in Greece, Germany, Czechia and Slovakia (WMD, 2019).

Europe is a net importer of bentonite and the main import countries are Turkey, India and Morocco. The import reliance of bentonite in EU-27 is estimated to be 15%. The only export

restriction to Europe is from Morocco, where an export tax of 2.5% applies since 1997 (OECD 2019d).

Major European bentonite exports go to Russia, Norway and Israel.

3.4.2 Supply from primary materials

3.4.2.1 Geology, resources and reserves of bentonite

Global reserves and resources figures are expected to be large, however there are no global reserves figures, or country-specific figures published.

3.4.2.2 World and EU mine production

World mine production of bentonite can be summarised: United States (4.3 Mt), China (3.6 Mt), Turkey (1.5 Mt), India (1.4 million tonnes) and Greece (1.1 Mt) are the major producing countries. Production from the United States and China accounts for 47% of the overall supply, equal to approximately 7,9 Mt per annum. Production of bentonite takes place in several other countries in a much smaller scale. In Europe, Greece in the largest producer but Germany (2% of global production), Czechia (2%), and Slovakia (1%) are also important producers. Overall 13 countries are recorded as bentonite producers in Europe.

Minerals Technologies Inc. (MTI) is the leading producer accounting for an estimated 15% of global bentonite production. MTI operates primarily in the United States (Wyoming and Alabama), but other mines and plants in Australia, China, Mexico, Turkey and elsewhere exist. Imerys is considered the second largest producer in the world with an estimated market share of 10-12%. Imerys owes mines and plants in Greece, Bulgaria, Hungary, Georgia, Morocco, South Africa and numerous other places. Clariant AG is an important producer of industrial grade bentonites, catalysts and specialised bentonite products. Finally the Taiko Group is reported as the largest producer of acid activated bentonites after Clariant (Scogings, 2016).

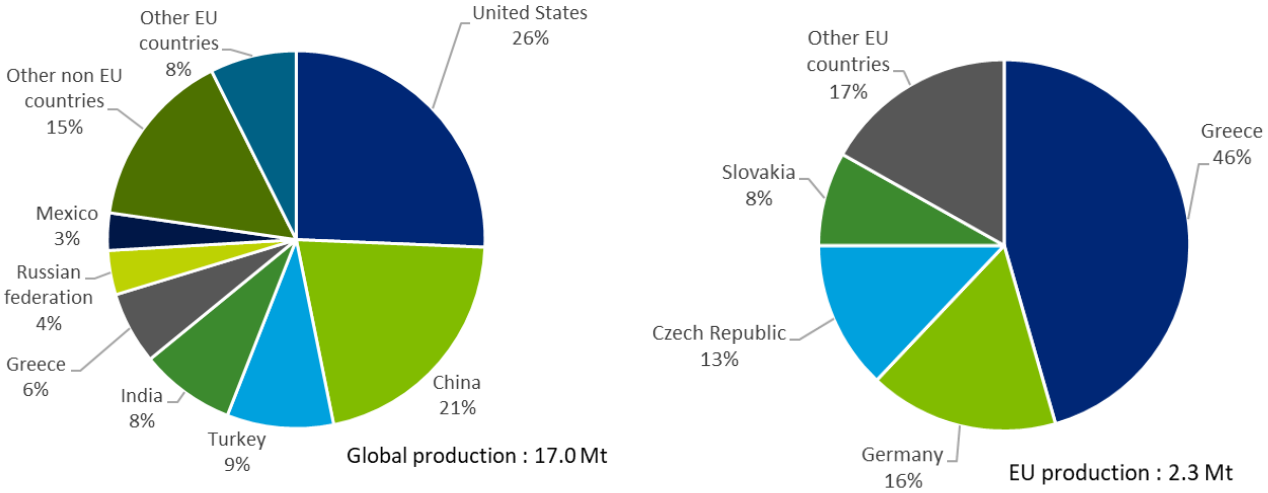


Figure 23: Global and EU mine production of bentonite in tonnes and percentage. Average 2012-2016 (WMD, 2019).

3.4.3 Supply from secondary materials/recycling

According to IMA-EUROPE (2018), 50% of bentonite in products is recycled at end-of-life. However, only for some applications, in particular Foundry molding sands (22%) and Civil engineering (13%), and to some extent paper (3%), recycling can contribute to partially cover demand. This corresponds to a EoL-RIR (End-of-Life Recycling Input Rate) of 19%.

Bentonite used in pet litter is not recovered. Pet litter commonly ends in the incinerated municipal waste stream and fly ash from that stream is often reused in various industries, for example the wall board industry. Bentonite used in the pelletising of iron ore is not recoverable and the majority of it ends up in the slag. Slag however often finds use in the cement industry and therefore part of the bentonite trapped in slag is used there. Bentonite is used in construction projects and often ends up in construction and demolition waste, which is widely recycled (IMA Europe, 2019).

3.5 Other considerations

3.5.1 Environmental and health and safety issues

No specific issues were identified during data collection and stakeholders consultation.

3.5.2 Socio-economic issues

No specific issues were identified during data collection and stakeholders consultation.

3.6 Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. The results of this and earlier assessments are shown in Table 5. Both supply risk and economic importance have slightly increased.

Table 12: Economic importance and supply risk results for bentonite in the assessments of 2011, 2014, 2017, 2020 (European Commission, 2011-2014-2017)

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Bentonite	5.48	0.34	4.61	0.37	2.1	0.3	2.85	0.5

Although it appears that the economic importance of bentonite has reduced between 2014 and 2017-20 this is a false impression created by a change in methodology. Since 2017, the value added criticality assessment corresponds to a 2-digit NACE sector rather than a 'megasector', which was used in the previous assessments.

3.7 Data sources

Market shares are based on the statistical data provided by the Industrial Minerals Association and the European Bentonite Association and they represent the European market (Industrial Minerals Association (IMA-Europe 2018). Production data for bentonite are from World Mining Data (WMD, 2019). Trade data was extracted from the Eurostat Easy Comext database (Eurostat, 2019a). Data on trade agreements are taken from the DG Trade webpages, which

include information on trade agreements between the EU and other countries (European Commission, 2019). Information on export restrictions are accessed by the OECD Export restrictions on Industrial Raw Materials database (OECD, 2019).

Production data for a limited number of countries also include quantities of other clays similar to bentonite, as shown in Table 13.

Table 13: Information on production data from certain countries

Country	Clays included in the production figure
Turkey	bentonite and sepiolite
South Africa	bentonite and attapulgite
Mexico	bentonite and fuller's earth
USA	bentonite and fuller's earth
India	bentonite and fuller's earth
Japan	bentonite and fuller's earth
Korea	bentonite and fuller's earth
Australia	bentonite and fuller's earth

For trade data the Combined Nomenclature (CN) code 250810-BENTONITE has been used.

All data were averaged over the five-year period 2012 to 2016.

Several assumptions are made in the assessment of substitutes, especially regarding the allocation of sub-shares. Hence the data used to calculate the substitution indexes are often of poor quality.

3.7.1 Data sources used in the factsheet

BGS (2019). World Mineral Production 2013-2017. [online] Keyworth, Nottingham British Geological Survey, Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.html http://www.bgs.ac.uk/mineralsuk/statistics/worldStatistics.html

Engineered casting solutions (2006). Guide to Casting and Molding Processes. [online] Available at: https://www.afsinc.org/files/methods.pdf.

European Commission (2011). Critical raw materials for the EU. [online] Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission (2014) Report on critical raw materials for the EU - Critical raw materials profiles.

European Commission (2019). DG Trade. Agreements [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/

Eurostat (2019a). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2019b). Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2019)c. Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

Hall, S. B. (2016). Cat litter [online] Available at: http://www.madehow.com/Volume-2/Cat-Litter.html

Industrial Minerals Association (IMA-Europe) (2019). Data and information on bentonite provided by IMA-Europe and the European Bentonite Association during stakeholder workshops and expert consultation within the 'Study on the review of the list of critical raw materials'.

Industrial Minerals Association (IMA-Europe) (2018). Recycling Industrial Minerals

Industrial Minerals Association (IMA-Europe) (2016). Bentonite factsheet [online] Available at: http://www.ima-europe.eu/about-industrial-minerals/industrial-minerals-ima-europe/bentonite

Industrial Minerals (2016). Industrial Minerals Pricing Database. [online] Available at: http://www.indmin.com/

Jefferis, S. A. and C. Lam (2013). Polymer support fluids: use and misuse of innovative fluids in geotechnical works. 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris.

Kogel, J. E., Trivedi, N.C., Barker, J.M., Krukowski, S.T. (2006). Industrial Minerals & Rocks. Commodities, Markets, and Uses. 7th Edition. SME.

Lam, C. and S. A. Jefferis (2014). The use of polymer solutions for deep excavations: lessons from Far Eastern experience. HKIE Transactions, 21(4), 262-271.

Michaels, M. (2005). Alternaitves to clumping clay kitty litters. [online] Available at: http://catmom.com/articles/natural.html

Minerals4EU (2019). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

OECD (2019). OECD Export restrictions on Industrial Raw Materials database. [online] Available at: http://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

Pohl, W. L. (2011). Economic Geology. Principles and Practice. UK: Wiley-Blackwell.

Scogings, A. (2016). Soaking it up: Bentonite's global reach Industrial Minerals, (June), 37-42.

Sivrikaya, O. and A. I. Arol (2014). Alterantive binders to bentonite for iron ore pelletizing - Part II: Effects on metallurgical and chemical properties HOLOS, 3(30).

Sunde, M. (2012). Organic binder as a substitute for bentonite in ilmenite pelletization. [online] Available at: www.diva-portal.org/smash/get/diva2:566311/FULLTEXT01.pdf

UN Statistics (2017). UN Comtrade Database [online] Available at: https://comtrade.un.org/data/

USGS (2015). Bentonite. 2015 Minerals Yearbook. [online] Available at: https://minerals.usgs.gov/minerals/pubs/commodity/clays/

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

Zhu, D., J. Pan, L. Lu and R. J. Holmes (2015). 15 - Iron ore pelletization. Iron Ore, Woodhead Publishing: 435-473.

3.7.2 Data sources used in the criticality assessment

BGS (2019). World Mineral Production 2013-2017. [online] Keyworth, Nottingham British Geological Survey, Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.html http://www.bgs.ac.uk/mineralsuk/statistics/worldStatistics.html

Engineered casting solutions (2006). Guide to Casting and Molding Processes. [online] Available at: https://www.afsinc.org/files/methods.pdf.

European Commission (2019). DG Trade. Agreements [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/

European Commission (2014). Report on Critical Raw Materials for the EU. [online] Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

Eurostat (2019a). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2019b). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

Federation of piling specialists (2006). Bentonite support fluids in civil engineering. [online] Available at: www.fps.org.uk

Hall, S. B. (2016). Cat litter [online] Available at: http://www.madehow.com/Volume-2/Cat-Litter.html

Industrial Minerals Association (IMA-Europe) (2019). Data and information on bentonite provided by IMA-Europe and the European Bentonite Association during stakeholder workshops and expert consultation within the 'Study on the review of the list of critical raw materials'.

Industrial Minerals (2016). Industrial Minerals Pricing Database. [online] Available at: http://www.indmin.com/

Industrial Minerals Association (IMA-Europe) (2013). Recycling Industrial Minerals [online] Available at: http://www.ima-europe.eu/sites/ima-europe.eu/files/publications/IMA%20Recycling%20Sheets%20FULL%20published%20on%204.10.2013_0.pdf

Jefferis, S. A. and C. Lam (2013). Polymer support fluids: use and misuse of innovative fluids in geotechnical works. 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris.

Kogel, J. E., Trivedi, N.C., Barker, J.M., Krukowski, S.T. (2006). Industrial Minerals & Rocks. Commodities, Markets, and Uses. 7th Edition. SME.

Lam, C. and S. A. Jefferis (2014). The use of polymer solutions for deep excavations: lessons from Far Eastern experience. HKIE Transactions, 21(4), 262-271.

Lu, L. (2015). Iron Ore. Mineralogy, Processing and Environmental Sustainability. Woodhead Publishing.

Michaels, M. (2005). Alternatives to clumping clay kitty litters. [online] Available at: http://catmom.com/articles/natural.html

OECD (2016). OECD Export restrictions on Industrial Raw Materials database. [online] Available at: http://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

Sivrikaya, O. and A. I. Arol (2014). Alterantive binders to bentonite for iron ore pelletizing - Part II: Effects on metallurgical and chemical properties HOLOS, 3(30).

Sunde, M. (2012). Organic binder as a substitute for bentonite in ilmenite pelletization. [online] Available at: www.diva-portal.org/smash/get/diva2:566311/FULLTEXT01.pdf

USGS (2016). Mineral Commodity Summary. Lime. [online] Available at: https://minerals.usgs.gov/minerals/pubs/commodity/lime/

Wikipedia (2016). Sand casting [online] Available at: https://en.wikipedia.org/wiki/Sand_casting

Zhu, D., J. Pan, L. Lu and R. J. Holmes (2015). 15 - Iron ore pelletization. Iron Ore, Woodhead Publishing: 435-473.

3.8 Acknowledgments

This factsheet was prepared by the JRC. The authors would like to thank Francesca Girardi (IMA Europe), the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this Factsheet.

4. CADMIUM

4.1 Overview

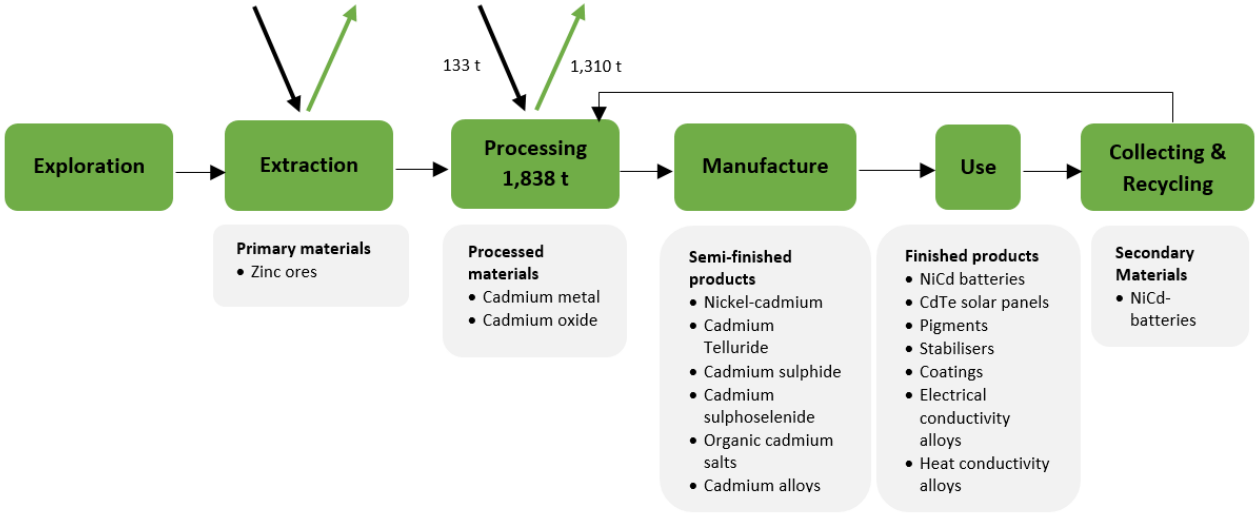


Figure 24: Simplified value chain for Cadmium for the EU, (average 2012-2016)[19]

Cadmium is an element with chemical symbol Cd and atomic number 48. It is a silver-white shiny metal with high ductility and malleability. Cadmium occurs in the earth's crust mainly in combination with zinc, which is why the main sources are zinc ores and concentrates. It is a rare element with a share of 0.3 ppm in earth's crust. (ISE, 2019; Lenntech, 2019)

Production figures are in cadmium content (WMD, 2019). For the evaluation of EU trade Eurostat Comext data was analysed, using CN8 code 28259060 "Cadmium Oxide". As production data is reported as cadmium content, trade data was converted to contained cadmium in order to ensure comparability.

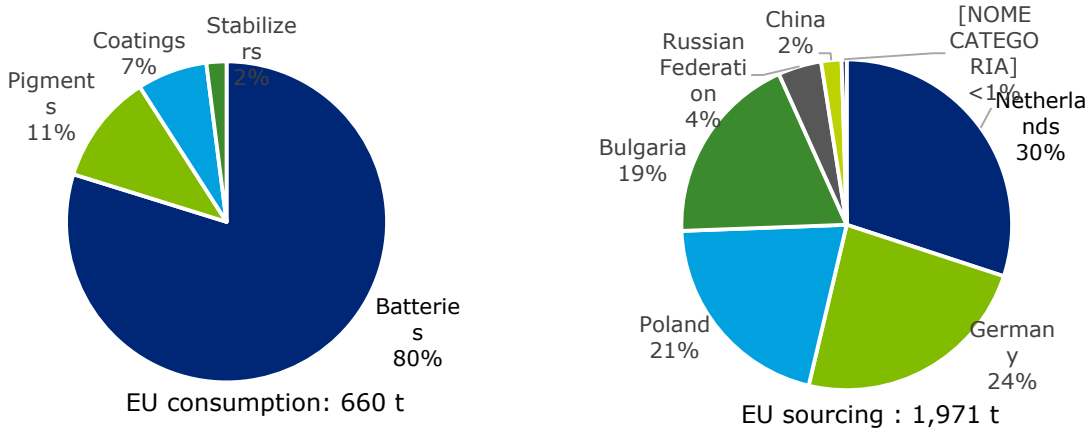


Figure 25: End uses and EU sourcing of Cadmium (ICdA, 2010; Eurostat, 2019a; WMD, 2019)

[19] JRC elaboration on multiple sources (see next sections)

The world market of cadmium in 2017 was worth USD 36.9 million, with a total supply of 25,685 tonnes. China is the main importer of cadmium with a market share of 34%, closely followed by India (28%). The largest cadmium exporters in 2017 were South Korea (25%), followed by Canada (9%), Kazakhstan (8%), and Japan (8%). (OEC, 2019; WMD, 2019)

The average apparent consumption of Cadmium in the EU was 660 t per year between 2012 and 2016. Almost all required cadmium is produced by EU countries. Four EU countries produce Cadmium: Netherlands (30% of EU sourcing), Germany (24%), Poland (21%), and Bulgaria (19%). Imports between 2012 and 2016 are rather low, at about 133 t per year, and mainly stem from Russia and China. (Eurostat, 2019a; WMD, 2019)

NiCd batteries are increasingly replaced by lithium-ion batteries, also nickel metal hybrid batteries are an alternative. However, NiCd batteries are preferable in applications where stability and reliability are crucial. Substitutes for cadmium coatings include zinc, aluminium, and tin, where the surface characteristics are not of major importance. Barium cadmium stabilisers in PVC can be replaced by barium zinc or calcium zinc stabilisers. For CdTe thin-film solar panels exist various alternatives, e.g. amorphous silicon panels. (USGS, 2019)

Nickel cadmium batteries may be a possibility of storing wind and solar energy in remote areas in the future. Moreover, cadmium is an important element for the production of thin-film solar panels. Thereby it is supporting the transition to renewable energy sources.

Cadmium is usually associated with zinc deposits, therefore, global figures for cadmium reserves and resources are not available. However, at least twelve countries in the EU have reported zinc resources, eight have reported zinc reserves, and it is very likely, that Cadmium is present in these mineralisations. (USGS, 2019; Minerals4EU, 2019)

Worldwide an average of 23,764 t per year was produced between 2012 and 2016. It is won almost exclusively as a by-product of zinc refining. Secondary sources for Cadmium are from the recycling of nickel-cadmium batteries which are almost 100% recyclable once they are collected. (ICdA,2010; WMD, 2019)

According to UNEP (2011) the overall recycling rate of Cadmium is 30% (SCRREEN workshops 2019).

Cadmium is toxic for humans, mainly affecting kidneys and the skeleton, and it is carcinogenic when inhaled. It is released to the atmosphere by the metals industry, processing cadmium containing metals (e.g. zinc production), as well as fossil fuel combustion. Cadmium can collect in bones and act as a source of exposure at a later point in life. Other forms of cadmium release into the environment are phosphorous fertilisers and sewage sludge. (UNEP, 2019)

4.2 Market analysis, trade and prices

4.2.1 Global market analysis and outlook

The total value of the cadmium market has been decreasing, while it was at USD 69.2 million in 2011 the average value between 2012 and 2016 decreased to USD 38.9 million with an absolute low in 2016 (USD 30.7 million). This is also reflected in the price trends (see Figure 28).

The main exporters in the period 2012-2016 were South Korea (21%), Japan (9%), and Mexico (8%). In 2017 South Korea remained number one exporter (25%), however, Canada (9%) and Kazakhstan (8%) gained importance and market shares (OEC 2019).

Considering trade and production numbers, China is the leading consumer of cadmium worldwide. In 2017 it imported 34% of available cadmium, followed by India with 28%. Especially Indian imports increased significantly, from 4% in 2012. Unlike imports by China that decreased from 49% in 2012. (OEC, 2019)

Most Cadmium is sold on long term contracts and only small amounts are freely available on the world market. (USGS, 2018)

Table 14: Qualitative forecast of supply and demand of Cadmium

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Cadmium		x	-	?	?	+	+	+

Cadmium consumption is declining, as NiCd batteries are increasingly replaced by lithium-ion batteries. However, there is growth potential in certain end uses (e.g. solar panels and solar energy storage). As Zinc production is believed to increase, so will the supply of cadmium and the excess production might need to be permanently stockpiled. (USGS, 2018)

4.2.2 EU trade

The EU is a net exporter of cadmium, exporting almost 12 times more cadmium than importing between 2012 and 2016. However, imported amounts were increasing in this period from 7 t in 2012 to 210 t in 2016. As opposed to EU's exports which decreased from 2,333 t to 998 t.

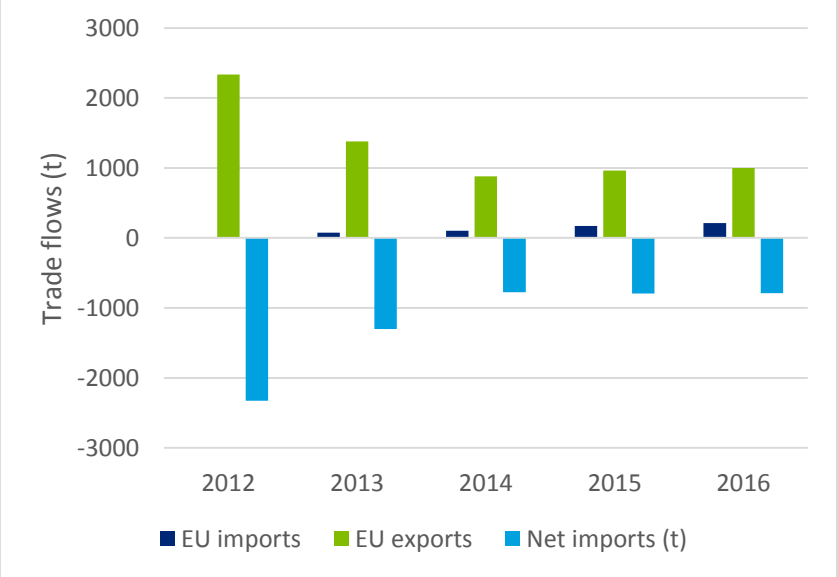


Figure 26: EU trade flows for Cadmium (Eurostat, 2019a)

In 2017 and 2018 numbers remain approximately at the same level. Import decreases from 277 t in 2017 to 241 t in 2018, whereas exports show a slight increase from 960 t in 2017 to 1033 t in 2018. (Eurostat, 2019a).

The EU produces most cadmium from domestic sources. The main external suppliers are Russia (63%), and China (30%). EU's cadmium exports are consumed by 38 countries. The largest consumer is India (35%), followed by China (15%), Japan, and the United Kingdom (11% and 10%).

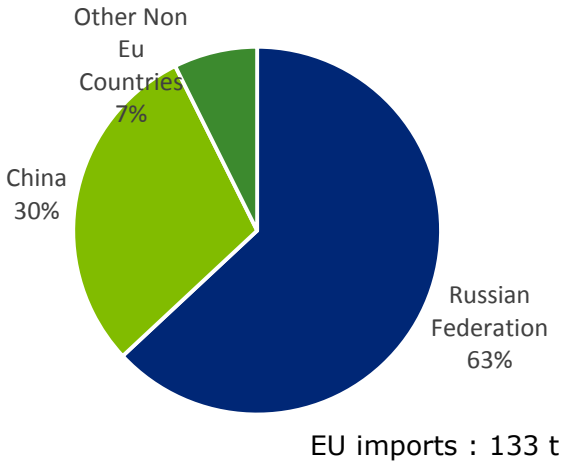


Figure 27: EU imports of Cadmium (Eurostat, 2019a)

OECD (2019) reports no export restrictions on cadmium metal or oxide. However, some countries have trade restrictions on

1. cadmium waste and scrap (Israel, Jamaica, Japan, Kyrgyzstan, Morocco, Sierra Leone, Tajikistan, Zambia, Zimbabwe)
2. slag, ash and residue containing cadmium (Israel) in place.

The EU has trade agreements with South Korea, Japan, Canada, Mexico, Peru, and Norway, all important cadmium suppliers. (European Commission, 2019)

4.2.3 Prices and price volatility

USGS records the unit value of cadmium (minimum 99.95% purity) since 1900. As the trend in Figure 28 shows, cadmium prices are strongly fluctuating, however, the overall trend is decreasing. Between 2012 and 2016 prices decreased from USD 2.03 per kilogram to USD 1.34 per kilogram. In 2017 and 2018 there was a slight recovery to USD 1.75 per kilogram and USD 2.90 per kilogram respectively.

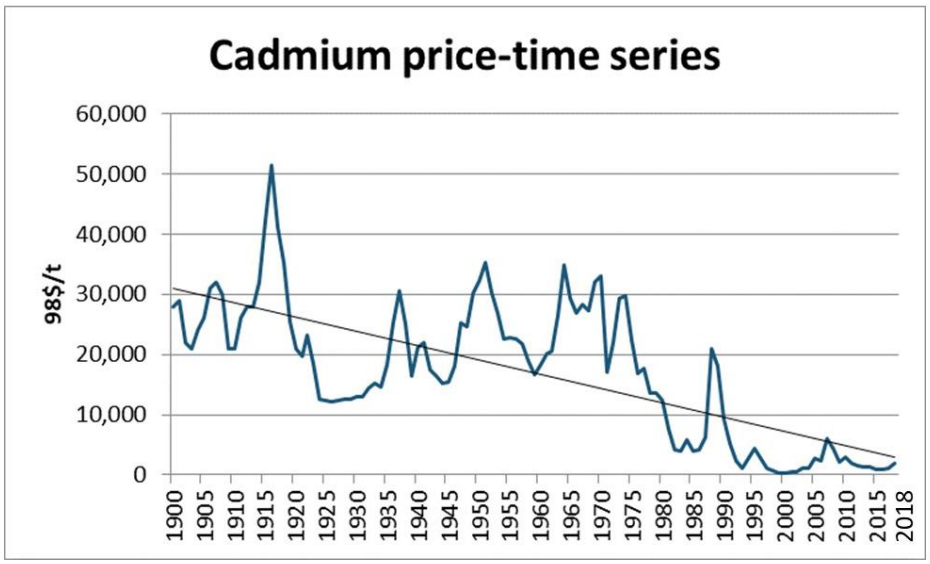


Figure 28: Prices of Cadmium (USD per tonne, converted to consumer price index of 1998) from 1900 to 2018 (USGS, 2017; USGS, 2019)



Figure 29: Prices of cadmium (USD per tonne) from 1979 to 2018 (Buchholtz 2019)

4.3 EU demand

The world global market of cadmium was worth USD 38.9 million on average between 2012 and 2016 with a total production of 23,764 t cadmium content.

4.3.1 EU demand and consumption

The EU had an apparent cadmium consumption of 660 t per year on average between 2012 and 2016. Apparent consumption is calculated as imports plus domestic production minus exports. Most of the cadmium demand is produced by EU countries and imports are rather small. Belgium is a large producer of cadmium compounds for coatings, pigments, batteries, etc. Flaurea Chemicals SA has developed a world leadership position in the manufacture of high-purity cadmium powder and oxide. Flaurea Chemicals is part of the Metals Chemistry Division of the French group AUREA. In 2017, total volume of cadmium processed and exported worldwide by Flaurea was 1,600 t, far less than the 2,500 t it processed in 2014. (AUREA was chosen by the Commercial Court of Tournai (Belgium) in July 2014, as the buyer of the assets of the "Floridienne Chemie" - renamed "Flaurea Chemicals", this company specialises in the treatment and recycling of zinc, cadmium and lead) (Eurometaux, 2019). Belgium imported an average of 11% of globally available cadmium in the period 2012-2016,

and is therefore the third largest consumer worldwide. It is followed by Sweden with 7%. (Eurostat, 2019; USGS, 2018; WMD, 2019)

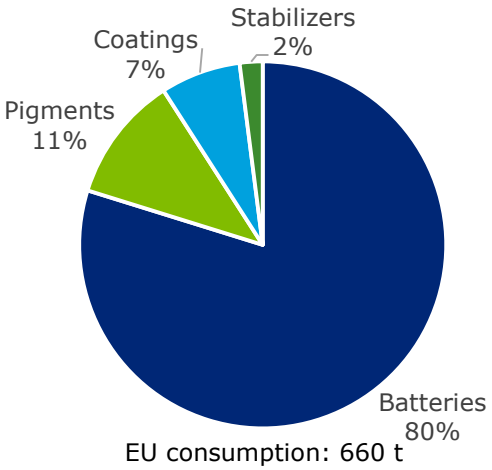


Figure 30: Global end uses of Cadmium (ICdA, 2010; SCRREEN workshops, 2019)

4.3.2 Uses and end-uses of Cadmium in the EU

Figure 30 presents the main uses of cadmium worldwide. Unfortunately, there is no data specifically for the consumption pattern of cadmium in the EU available.

Relevant industry sectors are described using the NACE sector codes (Eurostat, 2019b).

Table 15: Cadmium applications, 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2019b)

Applications	2-digit NACE sector	Value added of NACE 2 sector (M€)	4-digit NACE sectors
Batteries	C27 – Manufacture of electrical equipment	80,745	C2720 - Manufacture of batteries and accumulators
Pigments	C20 – Manufacture of chemicals and chemical products	105,514	C2030 – Manufacture of paints, varnishes and similar coatings, printing ink and mastics
Coatings	C25 – Manufacture of fabricated metal products, except machinery and equipment	148,351	C2561 – Treatment and coating of metals
Stabilisers	C20 – Manufacture of chemicals and chemical products	105,514	C2059 – Manufacture of other chemical products n.e.c.

The main application of cadmium is in nickel cadmium (NiCd) batteries. For this cadmium hydroxide is used as one of the electrodes. These batteries are applied both in consumer electronics (e.g. power tools), and in industrial applications (especially aeronautics and railway). However, it is important to mention, that the use of NiCd batteries in the EU is

restricted to industrial use – placing on the market of NiCd batteries in consumer goods is prohibited since 01 January 2017. Other regions did not set such restrictions but the NiCd batteries in consumer goods are more and more replaced by other batteries chemistries (Eurometaux, 2019). NiCd batteries are very reliable and stable, even under harsh weather conditions, which is why they may be an ideal solution for storing solar or wind energy. In China and India, cadmium is largely used in alloys for decorative castings (jewellery, ornaments) (Eurometaux, 2019).

Cadmium sulphide and cadmium sulphoselenide are used for the production of inorganic cadmium pigments, with a colour range from bright yellow (sulphide) to maroon (selenide). As cadmium provides resistance to high temperatures and pressures, these pigments are mainly used for plastics, ceramics, glasses, and enamels products that are processed under these conditions. The EU has restricted the use of cadmium pigments in most plastics to safety applications (Eurometaux, 2019). However, cadmium pigments are also used in artists' colours which has been grounds for concern due to their toxicity. Sweden suggested a ban of cadmium in artists' paints in the EU in 2013. Due to resistance by painters as there are no alternatives providing this colour spectrum and the limited effects on the environment this suggestion was declined.

Cadmium coatings are anticorrosive and used by aerospace industry and military on steel, aluminium, or other non-ferrous metal fasteners and moving parts. These coatings provide the best available combination of corrosion resistance, and a low friction coefficient. A substitution might compromise operational safety. Cadmium coatings can also be used in electrical or electronical applications, because they also provide low electrical resistivity.

The production of polyvinylchloride (PVC) utilises cadmium-bearing stabilisers to retard the degradation processes due to heat and ultraviolet light exposure. Cadmium is usually added in form of organic cadmium salts (e.g. cadmium laurate or cadmium stearate). However, also in this area of application the use of cadmium as PVC stabilisers was abandoned on a voluntary basis by the EU (Eurometaux, 2019).

Other minor uses include the production of cadmium telluride (CdTe) for thin-film solar panels, as well as cadmium alloys (electrical conductivity, heat conductivity, and electrical contact alloys) (ICdA, 2010; USGS, 2018).

Furthermore, cadmium is used for MCT (mercury cadmium telluride) for infrared technology and the new CZT (cadmium-zinc-telluride) semiconductor for gamma- and x-ray detection (radiation mapping, nuclear medical imaging, astrophysics and homeland security) (Fenixam, 2019).

4.3.3 Substitution

In small consumer electronics NiCd batteries have been increasingly substituted by lithium-ion batteries. This development is expected to continue, as production costs for lithium-ion batteries decrease and their storage capacity increases. However, NiCd batteries cannot be substituted in applications, where reliability and stability is of major importance. This is mainly in industrial applications, such as railway batteries for starting, braking, etc.

Another alternative for NiCd batteries are nickel-metal hydride batteries. This type of batteries has a higher capacity than NiCd batteries and it is more environmentally friendly, as it does not contain as many toxins. However, nickel-metal hydride batteries do have major drawbacks, such as limited service life, sensitivity to overcharge, high self-discharge, etc.

Cadmium in pigments can be replaced by cerium sulphide, which is used mainly in the production of plastics. There are no alternatives for cadmium in artists' paints providing the same colour spectrum.

Coatings using cadmium can only be replaced where the surface characteristics provided by cadmium (corrosion resistance, low friction coefficient, electric conductivity) are not of critical importance. Alternatives are zinc, zinc-nickel, aluminium, or tin coatings.

Substitutes for cadmium as a stabiliser in PVC production are barium zinc, or calcium zinc stabilisers. However, they are not very common an in the EU-PVC-industry, cadmium was completely replaced by Ba-Zn and Ca-Zn alternatives since 2007. (Eurometaux, 2019) (Cadex, 2018; USGS, 2018; USGS, 2019)

4.4 Supply

4.4.1 EU supply chain

The EU sources 94% of cadmium used from domestic producers. Four EU countries produce cadmium: the Netherlands (32%), Germany (26%), Poland (22%), and Bulgaria (20%). They produced an average of 1,838 t per year between 2012 and 2016. Outside sources are mainly Russia (63% of imports), and China (30% of imports). The EU imports about 133 t of cadmium per year, averaged over 2012-2016.

Belgium is the largest consumer of cadmium in the EU with the company Flaurea Chemicals SA producing cadmium compounds for pigments, batteries, etc. (in 2016 and 2017 about 800 t per year) (Eurometaux, 2019). In 2016, Belgium imported 2,890 t of cadmium, mostly from France, Mexico, the Netherlands, and Poland (USGS 2016).
Belgium's main supplier (apart from EU sources) is China and in 2014 large amounts were imported from the United Kingdom.

The EU exported an average of 1,310 t of Cadmium per year in the period of 2012-2016 to 38 different countries. The main consumer of EU's cadmium is India (35%), followed by China (15%) (Eurostat, 2019; WMD, 2019).

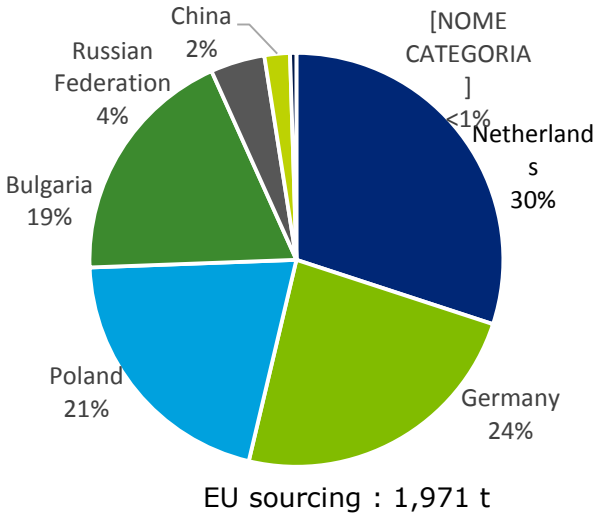


Figure 31: EU sourcing (domestic production + imports) of Cadmium. Average values 2012-2016 (Eurostat, 2019; WMD, 2019)

4.4.2 Supply from primary materials

4.4.2.1 Geology, resources and reserves of Cadmium

Geological occurrence: Cadmium is a very rare element with an occurrence of 0.3 ppm in earth's crust. It can occur in its elemental form, but so far only five locations are known where elemental cadmium has been found.

- Russia: River Khann'ya, Jana river basin, Billeekh intrusion
- US: Goldstrike mines in Lynn (Eureka County, Nevada)
- Kazakhstan: Burabaiskii massif

There are more than 20 different cadmium minerals, including greenockite (CdS), and Otavite ($CdCO_3$). These ores are not of economic importance due to their rarity. However, they usually occur together with zinc ores such as sphalerite (ZnS) and smithsonite ($ZnCO_3$). Moreover, cadmium can partly replace zinc in the crystal lattice of sphalerite as both have similar chemical properties. It can also be found as an impurity in lead and copper ores. (ICdA, 2010; ISE, 2019; USGS, 2019)

Global resources and reserves[20]*:* Global cadmium resources and reserves are not reported separately, as cadmium is solely produced as a by-product from zinc, copper, or lead refining.

[20] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of cadmium in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template.[20], which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

Typically zinc concentrates contain an average of 0.2% cadmium and 52% zinc. (Eurometaux, 2019)

According to USGS worldwide zinc reserves are estimated at 230 million t, and there are about 1.9 billion t of zinc resources. It is more than likely that these zinc reserves and resources contain cadmium that can be recovered as a by-product.

EU resources and reserves[21]*:*

At the time of the Minerals4EU (2019) assessment only France reported cadmium resources with 520 t of cadmium content. However, Germany and Bulgaria are believed to have resources as well. There were in total three exploration projects ongoing, one in Portugal and two in Slovakia, that are potential sources for cadmium.
Due to low demand for cadmium, only four EU zinc plants recover cadmium from zinc concentrates. They represent 37% of EU zinc refining. The other plants extract a cadmium concentrate which is stabilised for safe and environmentally approved disposal. This implies that only one third of all cadmium mined in the EU or entering the EU is recovered for sales and use (Eurometaux, 2019).

Table 16: Resource data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2019)

Country	Reporting code	Quantity	Unit	Grade	Code Resource Type
France	-	520	t (metal content)	-	Historic Resource Estimates

In the EU eight countries[22] have reported zinc reserves and twelve[23] zinc resources. These deposits are likely to contain cadmium. (Minerals4EU, 2019)

4.4.2.2World and EU refinery production

Worldwide 20 countries produce cadmium, all as a by-product mainly from zinc refining, but also from copper and lead production. Between 2012 and 2016 an average of 23,764 t of cadmium was produced per year. 8% of global supply are produced by EU countries (1,819 t per year). In the EU the Netherlands, Germany, Poland, and Bulgaria recover Cadmium. In 2017 production increased significantly 659 t. (WMD, 2019)

[21] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for cadmium. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for cadmium, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for cadmium the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019).Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However a very solid estimation can be done by experts.

[22] Finland, Greece, Ireland, Italy, Poland, Portugal, Slovakia and Sweden

[23] Czech Republic, Finland, France, Greece, Hungary, Ireland, Italy, Poland, Portugal, Slovakia, Spain, Sweden

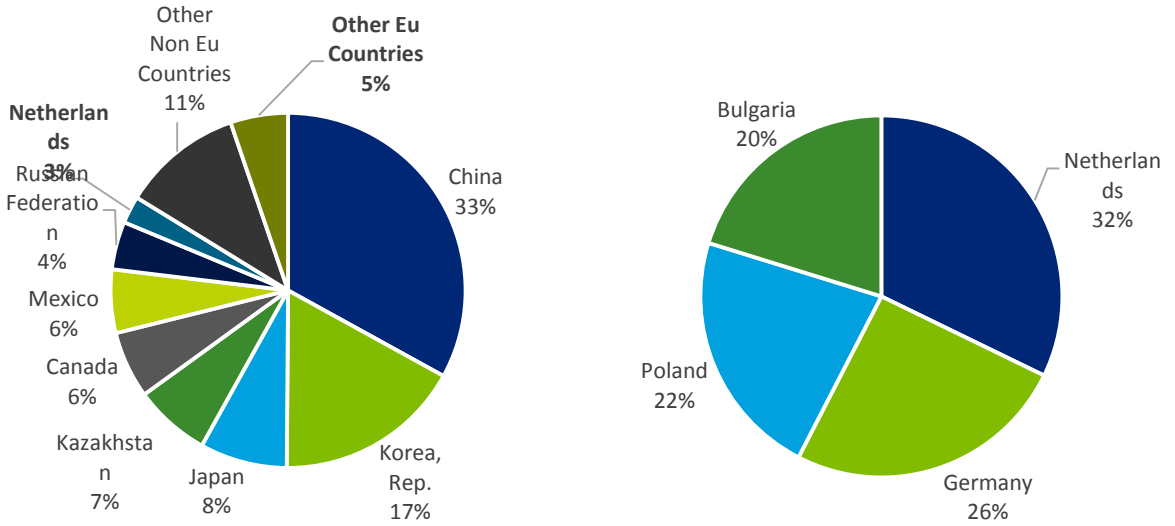


Figure 32: Global and EU production of Cadmium in t and percentage. Average for the years 2012-2016. (WMD, 2019)

4.4.3 Supply from secondary materials/recycling

Cadmium has a rather high recycling rate of about 30% according to UNEP (2011)(SCRREEN workshops 2019). Mainly NiCd batteries are recycled. There are initiatives in Europe, North America, and Japan to collect NiCd batteries. Worldwide nine plants for NiCd recycling have a total capacity of 20,000 million t of industrial and consumer batteries and their manufacturing scraps. In the EU, there are six plants that recycle collected NiCd batteries. Over the past 5 years (reference year 2019), an average of 6,000 t per year NiCd batteries of EU origin were offered for recycling (Eurometaux, 2019). This means there is enough capacity to recycle all NiCd batteries if they were collected. The batteries are virtually 100% recyclable. Recycling of cadmium containing products is not only important to provide further raw material sources, but also to keep it out of the waste streams due to its toxicity.

4.4.4 Processing of Cadmium

The production of cadmium depends on the method used for zinc refining. Zinc can either be produced using the so called dry zinc extraction, or the wet zinc extraction.

In the dry zinc extraction cadmium and zinc are reduced. As cadmium has a lower boiling point it evaporates before the zinc components. It then reacts with oxygen to cadmium oxide and can be distilled. Fractional distillation is used to increase cadmium recovery.

Wet zinc extraction reduces and precipitates dissolved cadmium ions with zinc dust. It is then oxidised with oxygen and dissolved in sulphuric acid. The resulting cadmium sulphate is electrolysed with aluminium anodes and lead cathodes producing particularly pure cadmium. (ISE, 2019)

4.5 Other considerations

4.5.1 Environmental and health and safety issues

Cadmium and its compounds are classified from harmful to toxic and it is assumed to be carcinogenic. The inhalation of cadmium dust causes harm to lung, kidneys and liver. Most reported toxicity is on kidney dysfunction and failure and when inhalation is the major source of exposure, also lungs are attacked (Eurometaux, 2019).

Cadmium can be released into the atmosphere by industry activities (electricity generation from waste and fossil fuel combustion, steel blast furnaces and metal refining).
Also volcanic activity releases cadmium into the air. Soil and water is contaminated with cadmium by industry waste streams, or fertiliser production and application. Cadmium in soils can be collected by plants which is a potential danger for animals. Especially earth worms and other essential soil organisms are very sensitive to cadmium poisoning and can die at low concentrations. This can threaten the entire soil ecosystem.
Human uptake of cadmium occurs usually via food ingestion, e.g. mussels, shellfish, fish, etc. that bio accumulate cadmium, but also liver from animals that fed on cadmium contaminated plants, or mushrooms (ISE, 2019; Lenntech, 2019).

According to the Regulation (EC) 1907/2006 (REACH), cadmium cannot be placed on the market or used as a substance, as constituent of another substance or in mixtures for supply to the general public when the individual concentration in the substance or mixture is equal to or greater than 0,1%. The packaging must be marked visibly, legible and indelibly "Restricted to professional users"[24]. Cadmium cannot be used in mixtures and articles produced from 16 listed synthetic organic polymers and mixtures and articles produced from listed plastic materials cannot be placed on the market if the concentration of cadmium expressed as Cd metal is equal to or greater than 0,01% by weight of the plastic material. Cadmium cannot be used or placed on the market in paint with codes [3208] [3209] in a concentration expressed as Cd metal equal to or greater than 0,01% by weight. If the zinc content of such paints exceeds 10% by weight of the paint, the concentration of cadmium expressed as Cd metal cannot be equal to or greater than 0,1% by weight. Painted articles cannot be placed on the market if the concentration of cadmium (expressed as Cd metal) is equal to or greater than 0,1% by weight of the paint on the painted article. Cadmium cannot be used for cadmium plating metallic articles or components of the articles used in listed secors or applications and placing on the market of cadmium-plated articles or compionents of such articles used in the listed sectors or applications is prohibited. Placing on the market of articles manufactured in some of the listed sectors is prohibited. Cadmium cannot be used in brazing fillers in concentration equal to or greater than 0,01% by weight and brazing fillers cannot be placed on the market if the concentration of cadmium expressed as Cd metal is equal to or greater than 0,01% by weight[25]. Cadmium and its compounds cannot be placed on the market after 1/1/2020 in clothing or related accessories, in textiles other than clothing which under normal or reasonably foreseeable conditions of use come into contact with human skin to an extent similar to clothing, or footwear, if the clothing etc. is for use by consumers and cadmium is present in a concentration measured in homogeneous material equal to or greater than 1 mg.kg after extration expressed as Cd metal that can be extracted from the material[26].

[24] Annex XVII entry 28 and Appendix 2 of Regulation (EC) 1907/2006 (REACH)
[25] Annex XVII entry 23 of Regulation (EC) 1907/2006 (REACH)
[26] Annex XVII entry 72 of Regulation (EC) 1907/2006 (REACH)

4.5.2 Socio-economic issues

The Environmental Justice Atlas (2019) reports examples of social issues related to cadmium production. Among these Melody Chemical plant in Hengdong, Hunan, China where cadmium content exceeds the standard more than 20 times; in Shangba Village Cadmium and Lead Pollution in Wengyuan, Guangdong, China cadmium in the soil was 12 times higher. In Toyama prefecture, Japan, the outbreak of itai-itai disease, painful chronic cadmium poisoning, took place along the Jinzū River for many decades. A refinery run by the Toho Zinc Co., Ltd., in Japan which was established in 1937, discharged cadmium into the air and the river. In 1991, an agreement was reached regarding refinery emission and discharge as well as compensation. This arrangement continues today.

4.6 Comparison with previous EU assessments

Cadmium has been evaluated for the first time in this criticality assessment.

The results of this assessment are shown in Table 17.

Table 17: Economic importance and supply risk results for Cadmium in the assessment of 2011, 2014, 2017, 2020

Assessment	2011		2014		2017		2020	
Indicator	not assessed		not assessed		not assessed		EI	SR
Cadmium							4.16	0.34

4.7 Data sources

There are many publically available sources providing information on cadmium. However, it was not possible to find EU specific information on consumption patterns.

4.7.1 Data sources used in the factsheet

Buchholz P., Wellmer F.W., Bastian D., Liedtke M. (2019) Leaning against the wind: Low price benchmarks for acting anticyclically in the metal markets. Mineral Economics. https://doi.org/10.1007/s13563-019-00199-y

Cadex Electronics Inc. (2018). Battery University [Online]. Available at: https://batteryuniversity.com/learn/article/nickel_based_batteries (Accessed: 18.09.2019)

Environmental Justice Atlas [Online]. Available at: https://ejatlas.org/ (Accessed: 05.11.2019)

Eurometaux (2019). Ad hoc Working Group feedback. Expert consultation. Mr. Mik Gilles (ICdA)

European Commission (2019). Negotiations and agreements [Online]. Available at: https://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/ (Accessed 12.09.2019)

Eurostat (2019a). Comext – International Trade [Online]. Available at: http://epp.eurostat.ec.europa.eu/newxtweb/ (Accessed: 07.09.2019)

Eurostat (2019b). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E) [Online]. Available at: https://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2 (Accessed: 07.09.2019)

Fenixam (2019). Fenix Advanced Materials. Expert feedback. Mr. Dan Oliric Manaig

International Cadmium Association (ICdA) (2010). Cadmium – Working towards a sustainable future [Online]. Available at: https://www.cadmium.org/home (Accessed: 16.09.2019)

Institut für seltene Erden und strategische Metalle (ISE) (2019). Cadmium [Online]. Available at: https://institut-seltene-erden.de/seltene-erden-und-metalle/strategische-metalle-2/kadmium/ (Accessed: 16.09.2019)

Lenntech (2019). Periodic Table – Cadmium [Online]. Available at: https://www.lenntech.com/periodic/elements/cd.htm (Accessed: 17.09.2019)

Minerals4EU (2019). European Minerals Yearbook [Online]. Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook (Accessed: 17.09.2019)

OECD (2019). Export restrictions on Industrial Raw Materials [Online]. Available at: https://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/ (Accessed: 12.09.2019)

SCRREEN workshop (2019) 'Validation workshop on Critical Raw Materials, 10-12 September 2019, Thon Hotel Brussels City Centre'. Brussels.

UNEP (2011). Recycling Rates of Metals – A Status Report. Available at: https://www.resourcepanel.org/reports/recycling-rates-metals

UNEP (2019). Emerging issues – Lead and cadmium [Online]. Available at: https://www.unenvironment.org/explore-topics/chemicals-waste/what-we-do/emerging-issues/lead-and-cadmium (Accessed: 17.09.2019)

USGS (2016). 2016 Minerals Yearbook – Cadmium [Advance Release]. Available at: https://s3-us-west-2.amazonaws.com/prd-wret/assets/palladium/production/mineral-pubs/cadmium/myb1-2016-cadmi.pdf

USGS (2017). Historical Statistics for Mineral and Material Commodities in the United States – Cadmium. Available at: https://www.usgs.gov/centers/nmic/historical-statistics-mineral-and-material-commodities-united-states

USGS (2018). 2015 Minerals Yearbook – Cadmium [Advance Release]. Available at: https://www.usgs.gov/centers/nmic/cadmium-statistics-and-information

USGS (2019). Mineral Commodity Summaries – Cadmium. Available at: https://www.usgs.gov/centers/nmic/cadmium-statistics-and-information

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

4.7.2 Data sources used in the criticality assessment

European Commission (2019). Negotiations and agreements [Online]. Available at: https://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/ (Accessed 12.09.2019)

Eurostat (2019a). Comext – International Trade [Online]. Available at: http://epp.eurostat.ec.europa.eu/newxtweb/ (Accessed: 07.09.2019)

Graedel, T.E. (2015). On the materials basis of modern society - supplementary file; Proc Natl Acad Sci USA. 2015 May 19; 112(20): 6295–6300. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4443350/

International Cadmium Association (ICdA) (2010). Cadmium – Working towards a sustainable future [Online]. Available at: https://www.cadmium.org/home (Accessed: 16.09.2019)

James, B. (2018). US DoE; 2018 Cost Projections of PEM Fuel Cell Systems for Automobiles and Medium -Duty Vehicles. Available at: https://www.energy.gov/sites/prod/files/2018/04/f51/fcto_webinarslides_2018_costs_pem_fc_autos_trucks_042518.pdf

Nassar, N.T. (2015). By-product metals are technologically essential but have problematic supply; Science Advances 03 Apr 2015: Vol. 1, no. 3, e1400180. Available at: https://advances.sciencemag.org/content/1/3/e1400180

OECD (2019). Export restrictions on Industrial Raw Materials [Online]. Available at: https://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/ (Accessed: 12.09.2019)

TURI (2011). Toxics Use Reduction Institute. Alternatives to cadmium. Available at: https://www.turi.org/TURI_Publications/TURI_Chemical_Fact_Sheets/Cadmium_and_Cadmium_Compounds_Fact_Sheet/Cadmium_and_Cadmium_Compounds_Facts/Alternatives

UNEP (2011). Recycling Rates of Metals – A Status Report. Available at: https://www.resourcepanel.org/reports/recycling-rates-metals

USGS (2017). Historical Statistics for Mineral and Material Commodities in the United States – Cadmium. Available at: https://www.usgs.gov/centers/nmic/historical-statistics-mineral-and-material-commodities-united-states

USGS (2018). 2015 Minerals Yearbook – Cadmium [Advance Release]. Available at: https://www.usgs.gov/centers/nmic/cadmium-statistics-and-information

USGS (2019). Mineral Commodity Summaries – Cadmium. Available at: https://www.usgs.gov/centers/nmic/cadmium-statistics-and-information

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels.

4.8 Acknowledgments

This factsheet was prepared by the JRC in collaboration with Ms. Marie-Theres Kügerl (Resources Innovation Center Leoben). The authors would like to thank the Ad Hoc Working

Group on Critical Raw Materials, in particular Eurometaux, as well as experts participating in SCRREEN workshops for their valuable contribution and feedback.

5. CHROMIUM

5.1 Overview

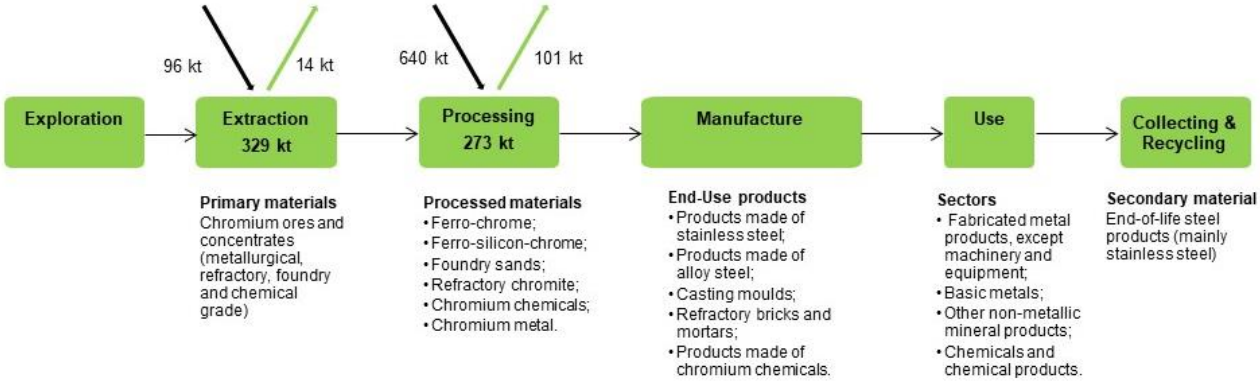


Figure 33: Simplified value chain for chromium for the EU, average 2012-2016[27]

Chromium (Cr, atomic number 24) is a lustrous, silvery-white, corrosion-resistant, hard metal. Chromium is obtained by mining chromite, a mineral of chromium and iron. The main product of chromite ore refining is ferrochrome, which is an essential component in the manufacturing of stainless steel, a key material in a variety of industries and end-uses. Chromium provides the corrosive resistance properties to stainless steel. In general, chromium presence as an alloying element to steels and non-ferrous metals enhances strength, and resistance to corrosion, temperature and wear. Other important properties are the high melting point, low coefficient of expansion and very high thermal conductivity which allows the use of chromite in foundry sands and refractory materials. Also, the wear resistance, hardness, low coefficient of friction and brightness of chromium are employed to the electrodeposition of chromium plating.

Chromium is assessed at the extraction stage in the form of chromium ores and concentrates (also referred to as "chromite" or "chromium ore"), and at the processing/refining stage, in the form of chromium ferroalloys (also referred to as "ferrochrome" or "ferrochromium"). Quantities are expressed in tonnes of chromium content and all figures are averaged over 2012–2016 data, unless otherwise specified.

[27] JRC elaboration on multiple sources (see next sections)

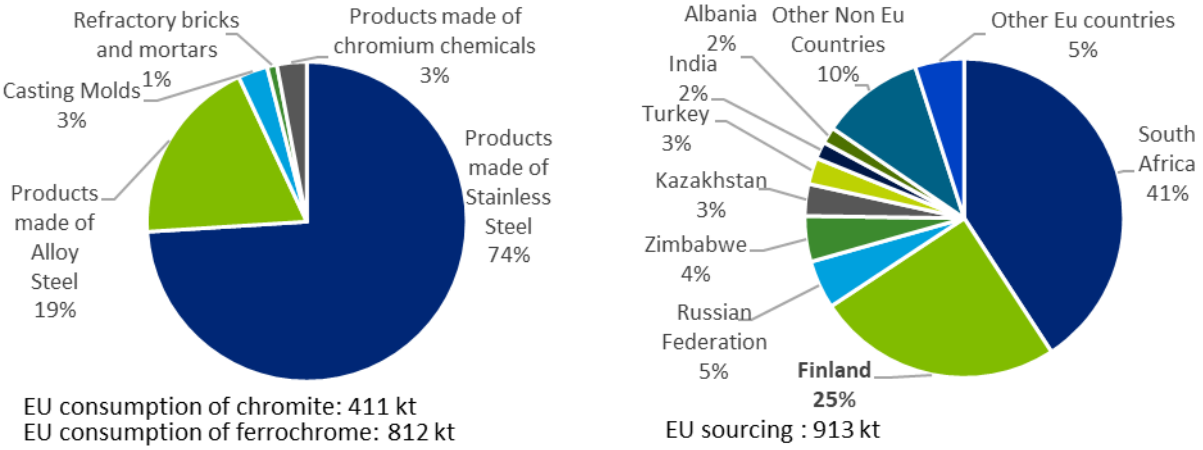


Figure 34: EU end uses of chromium and EU sourcing of ferrochrome

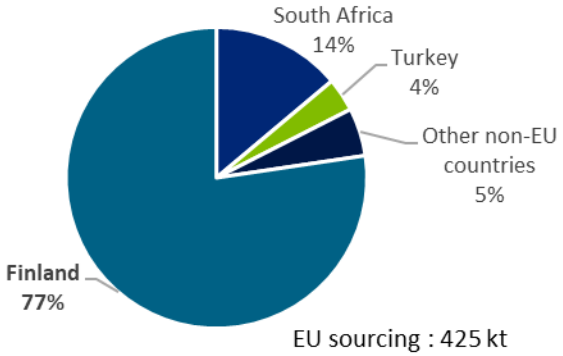


Figure 35: EU sourcing of chromite

The trade code used in the assessment for the mining stage (chromite) is the HS 261000 "Chromium ores and concentrates", with an assumed average Cr_2O_3 content of 45%. For the refining stage (ferrochrome) the following trade codes are used: HS 720241 "Ferro-chromium, containing by weight > 4% of carbon"; HS 720249 "Ferro-chromium, containing by weight <= 4% of carbon"; HS 720250 "Ferro-silicon-chromium". Ferrochrome is considered with an average chromium content of 56%. Trade flows and production statistics were converted to chromium content using the above generic coefficients.

The world production of chromite and ferrochrome is moderately concentrated in terms of producing countries (South Africa 46% of chromite and China 37% of ferrochrome). The chromium market follows closely the trends in the stainless-steel industry, which accounts for around 74% of world chromium consumption. China has doubled its ferrochrome capacity to 4,698 t (ICDA 2019) in the past few years (2012-2016) , and it has captured the highest share of the ferrochrome supply market worldwide, overtaking South Africa.

Prices of chromium commodities are strongly linked to stainless steel demand. Following a sharp increase in 2007 to historically high prices, chromium prices were affected strongly by the global economic recession, but recovered fast due to increasing demand from China. Since then, prices demonstrate temporal cyclicity, linked to the balance between supply and demand. In 2017, the average price was 2.9 USD per kg of Cr content for high-carbon ferrochrome, and 9,117 USD per tonne of chromium metal (BGR 2019).

The EU annual average consumption of chromite is around 411 kt of contained chromium, which is mainly sourced through domestic production in Finland (329 kt) and imports from South Africa (96 kt). The import reliance for chromium ores and concentrates is 20%.

The EU annual average consumption of ferrochrome is about 812 kt on a contained-chromium basis. Finland (25%), Sweden (4%) and Germany (1%) are the contributors to domestic production with 273 t in chromium content, while South Africa is the top supplier to the EU, with 373 kt of exports in chromium content. The import reliance for ferrochrome is 66%.

Chromium is mostly used in the production of stainless steel and alloyed steel. Of the total mine output of chromite, 96% is used to produce ferrochrome. About 73% of the ferrochrome supply is processed into stainless steel and the remaining 27% into speciality steel alloys. Minor applications can be found in the refractory and foundry industry, as well as in leather tanning, metal finishing, superalloys, wood preservatives and pigments. No suitable substitutes are currently available for the major uses of chromium.

Chromium is an essential material for low-carbon technologies using chromium-bearing steels such as in high-strength steel for lighter vehicles, as well as for low-carbon energy generation due to its high corrosion- and temperature-resistance.

World resources and reserves of chromite, the only commercial source of chromium, are estimated at 12 billion tonnes of resources and 584 million tonnes of reserves of shipping-grade chromite.
Resources and reserves are abundant, but highly concentrated. South Africa, Zimbabwe and Kazakhstan host the largest chromium deposits in the world (95% of the global resources), while South Africa, Kazakhstan and India account for 90% of the world reserves. In the EU, a very large deposit (Kemi) is located in Finland with JORC-compliant resources and reserves; the latter are estimated to 28 million tonnes of shipping-grade chromite.

The global chromium ore production was 13 Mt of Cr_2O_3 content, or nearly 8.8 Mt in Cr content, as an average over 2012-2016. South Africa, the world's largest source of chromite, accounted for 46% of global supply, and three other countries contributed 39% to the worldwide production of chromite, i.e. Kazakhstan (16%) Turkey (13%), and India (10%). In the EU, Finland is the sole producer of chromium ore with an annual average production of about 329 kt in Cr content over the 2012-2016 period.

During the same period, the average world production of ferrochrome was about 6.2 Mt in Cr content per year. China (37% of the global output), South Africa (28%), and Kazakhstan (14%) were the major producers. In the EU, industrial capacity of 800 kt for ferrochrome production exists in Finland, Sweden and Germany, with an annual average output of about 273 kt in Cr content over the 2012-2016 period.

The post-consumer functional recycling of stainless steel is well established, contributing to chromium supply from secondary sources. According to data provided by the MSA study of chromium, in 2013 the end-of-life recycling input rate (EOL-RIR) in the EU was 21%.

Many hexavalent chromium compounds, mainly used in surface treatment processes, are harmful to health and the environment for their carcinogenic and mutagenic properties. From September 2017, stringent requirements are imposed on their use through the REACH Regulation, i.e. there is an EU-wide ban to place on the market or use Cr (VI) substances in production unless special authorisation is granted to use the substance for a specific process.

5.2 Market analysis, trade and prices

5.2.1 Global market

The world production of chromium ore is dominated by South Africa, which in 2017 accounted for nearly half of the world's chromium ore output (WMD, 2019), two-thirds of which was exported (UN Comtrade 2019). South Africa is the top global exporter of chromium ore, while China is by far the major importer accounting for about 80% of the world's imports by value (Figure 36) South Africa's high share of the total supply of chromite on world markets is maintained due to the increasing availability of the Upper Group 2 Reef (UG2) concentrates produced as a by-product of PGM operations in South Africa (Roskill 2014) (Roskill 2018). The market value of the annual chromite production is estimated at USD 4.4 billion[28] in 2015.

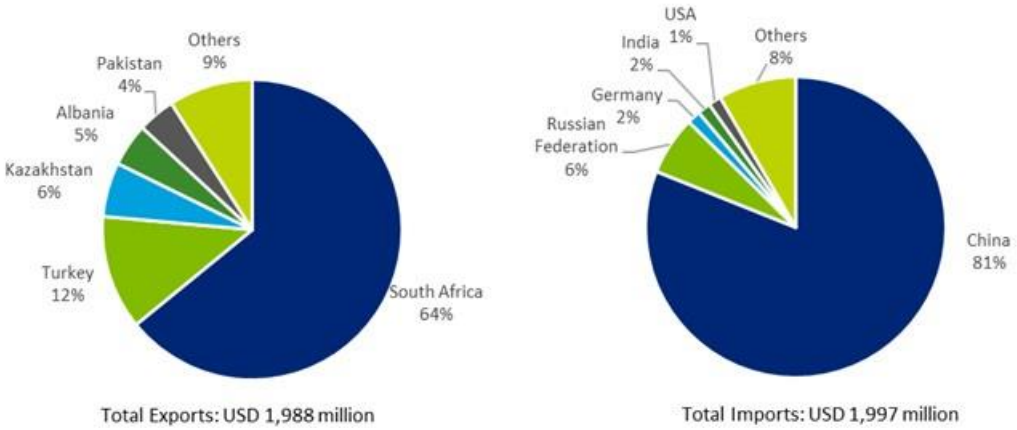


Figure 36: Top-5 exporting (left) and importing (right) countries of chromite in 2016 by value. (UN Comtrade 2019)

After 2012, China overtook South Africa to become the world's largest ferrochrome producer. Three of the four leading chromite producers, i.e. South Africa, Kazakhstan and India, are also among the four largest ferrochrome producers. These four countries accounted for 87% of world production in 2018 (ICDA 2019). South Africa is the world's top exporter of ferrochrome. Even though China is the top producer worldwide of ferrochrome consuming the surplus of chromium ores and concentrates produced in other regions, it is also the leading global importer of ferrochrome (see Figure 37) China has led the growth in developing ferrochrome capacity over the past two decades, due to increasing demand from the domestic stainless steel industry. Between 2000 and 2018, the Chinese output of chromium ferroalloys rose at an annual compound rate (CAGR) of 14.5%, from a gross weight of 445 kt in 2000 (7% of the world total) to 5,960 kt in 2018 (40% of the world total), while the CAGR in the rest of the world has been only 2.5% in the same period (background data from BGS (2019) and ICDA (2019). The growth in Chinese ferrochrome production has been based on imported raw materials, mainly from South Africa (Roskill 2014). The market value of the annual ferrochrome production is estimated at USD 22.2 billion[29] in 2017.

[28] Estimated as: 29.7 million tonnes (total production of chromium concentrates in 2015 as reported by (ICDA 2019)) X USD 148.3 per tonne (average price in 2015 of chromite metallurgical grade, friable lumpy, 40 % Cr_2O_3, South African, northwest, ex works, as reported by (BGR 2019))

[29] Estimated as 13.7 million tonnes (total production of chromium ferroalloys in 2017 according to (ICDA 2019)) X 56% average Cr content X USD 2.9 per kg of Cr content (average price in 2017 of high-carbon ferrochrome as reported by (BGR 2019))

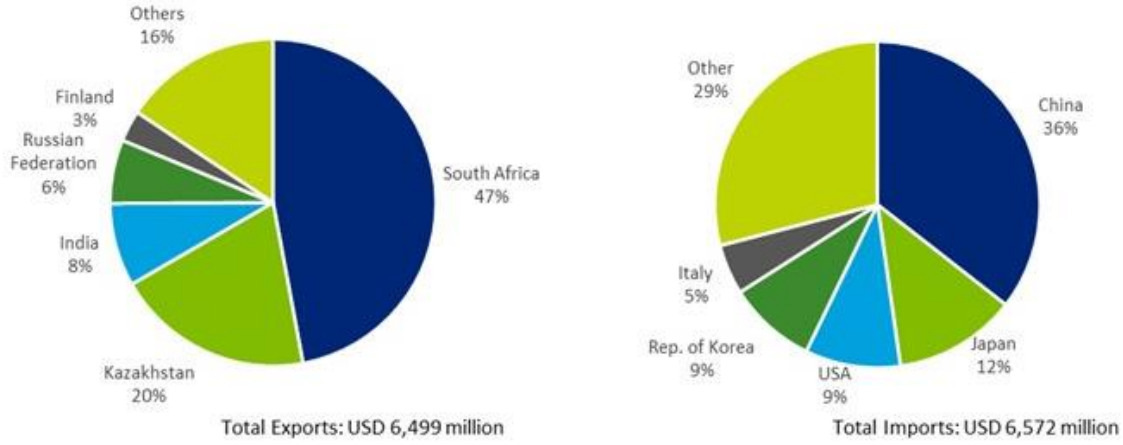


Figure 37: Top-5 exporting (left) and importing (right) of chromium ferroalloys in 2016 by value. (UN Comtrade 2019)

Russia is the leading source of chromium metal on international markets (see Figure 38). In 2018 it accounted for 32% of global exports by gross weight, followed by China (17%), UK (16%) and France (14%). Netherlands is the top destination country for imports of chromium metal, which is subsequently exported to other EU countries. USA and Germany are the main destinations of chromium metal imports for consumption, accounting for 18% and 15% respectively of world imports (ICDA 2019).

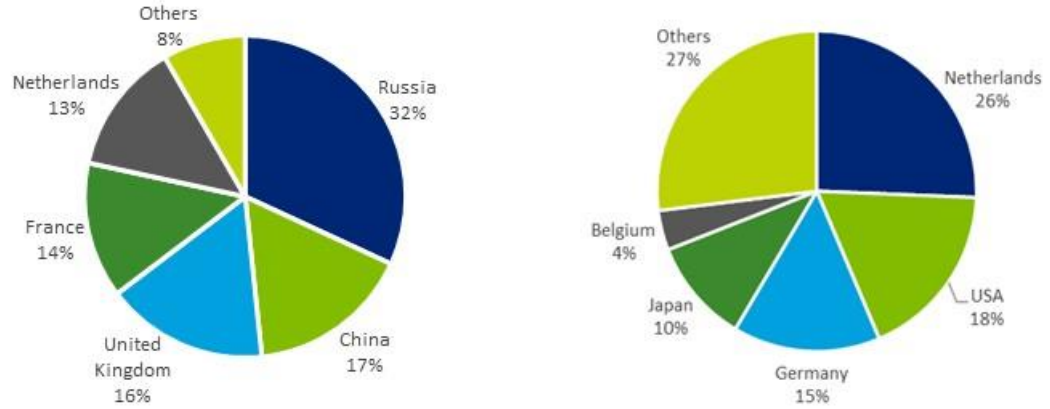


Figure 38: Top-5 exporting (left) and importing (right) of chrome metal in 2018 by gross weight. Background Data from (ICDA 2019)

As regards the most important export restrictions in place in 2017, India, which had a share of 13% of chromium ores and concentrates production in 2016, removed its export tax of 30% in March 2016. For ferrochrome, China imposes an export tax of 20% for ferrochrome containing less than 4% C (HS 720249), and an export tax of 15% for ferrochrome containing more than 4% C (HS 720241) and ferrosilicon-chrome (HS 720250); for these two commodities the tax decreased from 20% in 2017 (OECD 2019).

5.2.2 Outlook for supply and demand

The consumption of chromium closely follows the trends in demand for steel, and stainless steel in particular (USGS 2018a). Global stainless steel consumption has increased from 1980 to 2018 at a CAGR of 5.4% (ISSF 2019b). Demand for stainless steel, the primary chromium

application, will continue to grow, although at a slower rate compared to the previous decade. The expected rise in stainless steel production in the next decade is estimated at around 4% annually, driven by Chinese demand (BRGM 2017).

According to industry experts, the projected lower growth rate of the ferrochrome demand in comparison to the last years is mainly due to the slowing down of the Chinese economy, to the anticipated increased use of scrap in the Chinese stainless steel production, and to plant closures because of the increasingly stringent environmental regulations in China. Despite the moderate increase in demand for ferrochrome, an increasing oversupply in the ferrochrome industry over the next five years is expected as a result of expansions in smelting capacity, coming mainly from Zimbabwe, which will outpace significantly the growth of demand (Fastmarkets MB 2018)(Roskill 2018).

Table 18: Qualitative forecast of supply and demand of chromium

Material	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Chromium		x	+	+	?	+	+	?

5.2.3 EU trade

EU imports outweigh exports for chromium ores and concentrates. Trade statistics reported by Eurostat show that imports of chromite decreased from 2012 to 2016 by 18% (see Figure 39). The annual average EU imports amount to about 96 kt in chromium content during the 2012-2016 period. South Africa is the leading exporter to the EU with a share of 62% of total imports. Turkey is the second-ranked contributor to EU imports with a share of 16% (see Figure 41).

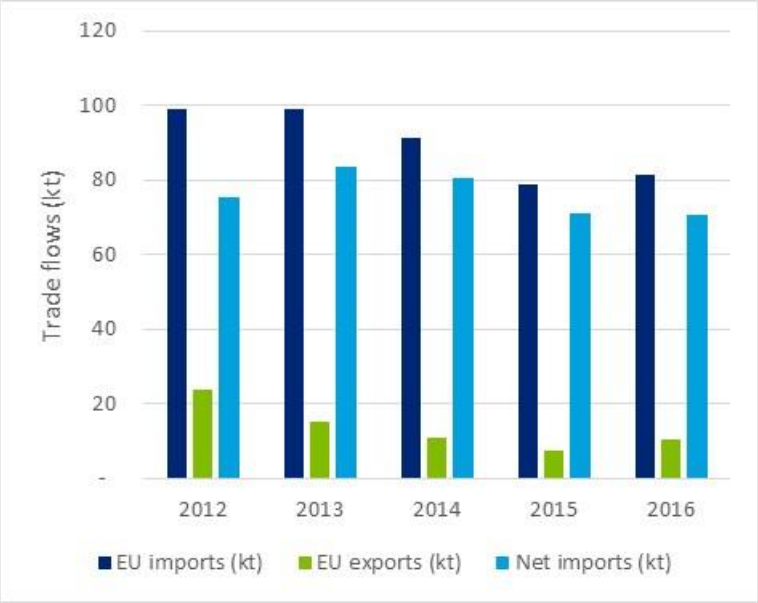


Figure 39: EU trade flows for chromium ores and concentrates (Eurostat 2019b)

The EU is also a net importer for ferrochrome. Imports of ferrochrome averaged to 640 kt in chromium content per year for the period 2012-2016, also mostly originating from South Africa, i.e. 58% of the total EU imports (see Figure 41). However, imports of ferrochrome declined substantially from 2012 to 2016 by 28% (see Figure 40). As the exports have remained relatively stable in this period, net imports have decreased considerably by 36%, from 691 kt in 2012 to 439 kt in 2016. The sharp increase of domestic production of ferrochrome in 2013, followed by a modest rise on a year-to-year basis for the following years can explain to a large extent the declining trend in imports; in absolute terms, the EU output has doubled from 2012 to 2016 by about 150 kt (in Cr content).

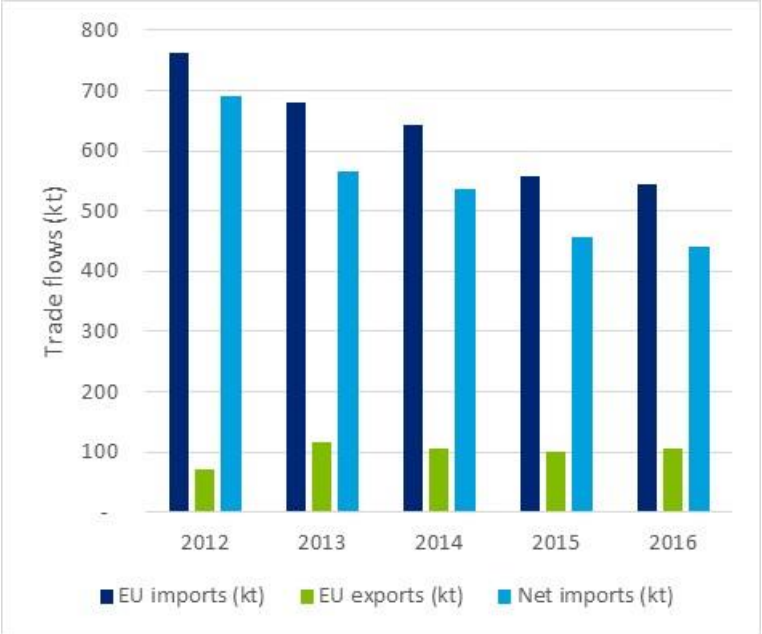


Figure 40: EU trade flows for ferrochrome (Eurostat 2019b)

Figure 41 presents the countries of origin for EU imports of chromite and ferrochrome.

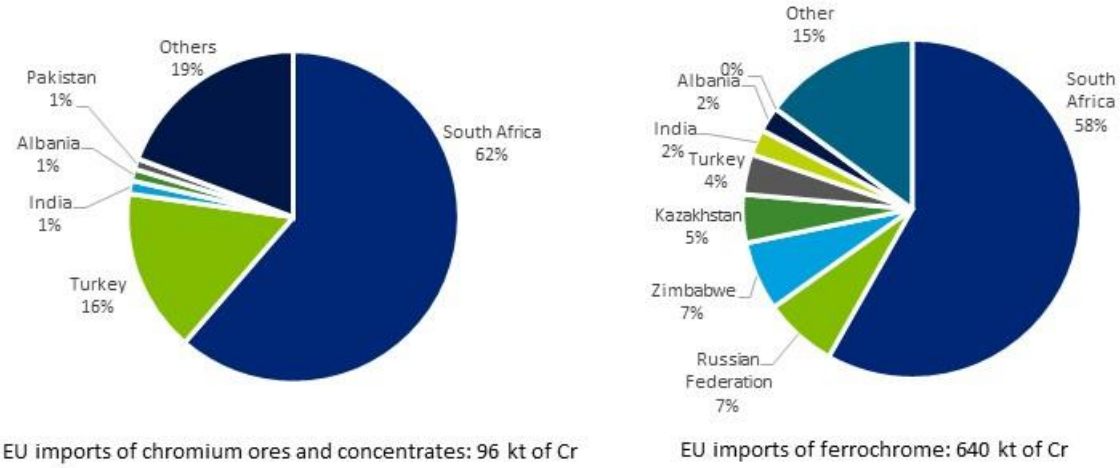


Figure 41: EU imports of chromium ores and concentrates (left) and ferrochrome (right). Average 2012-2016 (in Cr content) (Eurostat 2019b)

A trade agreement of the EU with South Africa is in place (European Commission 2019). In 2017, there were no export taxes, quotas or export prohibition in place between the EU and its suppliers for chromium ores and concentrates and ferrochrome, except China which accounts only for about 3% of the EU imports of ferrochrome (OECD 2019).

5.2.4 Prices and price volatility

Chromium is traded in the form of chromium ores and concentrates, ferrochrome, chromium metal and chromium chemicals (Roskill 2014). Chromium is not traded on any commodity exchange, and direct negotiations between buyers and sellers establish prices. Trade journals publish ranges of composite prices based on interviews with buyers and sellers (USGS 2018a) (BRGM 2017). In contracts of ferrochrome, volumes are negotiated on an annual basis and prices quarterly. Ferrochrome is also traded on the spot market (Roskill 2014).

Chromium ores and concentrates are priced in terms of gross weight and the price depends on specifications, i.e. metal content, impurities and ore type (e.g. lumpy, friable, concentrates). Trends in chromium ores and concentrates prices follow those of ferrochrome, which accounts for 96% of chromite consumption. Non-metallurgical grades attract a price premium in comparison to metallurgical-grade chromite because of their higher chromium content and the higher degree of processing required. Prices for refractory-grade chromite are generally higher than chemical-grade and foundry-grade chromite (Roskill 2014).

Ferrochrome prices follow the trends in the stainless steel industry with a time-lag. The volatility in year-on-year changes in demand and rates for ferroalloys reflects the periods of de-stocking and re-stocking by the stainless steel industry (Roskill 2014). Prices of low-carbon ferrochrome consumed in special steels command premiums of up to 70-80% over those of charge chrome, because of their higher purity.

Ferrochrome prices escalated to historical highs from 2007 up to the first months of 2008, reflecting the strong growth in stainless steel production. The onset of the global recession at the end of 2008 led to a significant fall in the stainless steel output, which in combination with de-stocking caused a sharp drop to ferrochrome prices. In 2010 prices rebounded driven by a remarkable rise in the Chinese production of stainless steel. The recovery was not sustained in 2012-2013 as world demand for stainless steel in the rest of the world remained stable, supply from South Africa and China increased, and Chinese producers covered a higher percentage of the domestic market (Roskill 2014).

Within 2015, chrome prices collapsed because of a downturn in the Chinese economy, contracting the demand for stainless steel, and at the beginning of 2016, chrome prices reached a six-year low, which had significant implications for South African industry, where ferrochrome smelters closed and mines undertook care and maintenance programs. The resulting decrease in chrome supply was substantial and created a market deficit in the second half of 2016 when stainless steel demand revived in China. The shortage initiated a sharp recovery in prices which reached the levels before the global economic downturn, which in turn triggered a supply surge from producers in South Africa based on idled ferrochrome capacity and other countries such as India and Kazakhstan. In 2017, prices followed the cyclical and temporary balances of supply and demand, affected mainly by increased Chinese smelting supply, electricity tariffs in South Africa, fluctuating stainless steel demand, and industry stockpiling (KPMG 2018)(Saxby 2017).

According to the DERA price volatility monitoring of December 2017 (BGR 2019), the average price of ferrochrome (6-8% C, basis 60% Cr, max 1.5% Si, major European destinations) in the period 2012-2016 was USD 2.2 per kg of chromium. In 2017, the annual average price of

ferrochrome's grade mentioned above surged to USD 2.9 per kg of chromium, i.e. a price increase of 32 % in comparison to the average of 2012-2016. The average price of chromium metal (min. 99 %, aluminothermic, in warehouse) was USD 7,952 per tonne in 2012-2016. In 2017 the annual average price reached USD 9,117 per tonne, i.e. a price increase of about 15% in comparison to the average of 2012-2016.

The United States Geological Survey regularly publishes assessments of the unit value of apparent chromium consumption in the US. Figure 42 shows the long-term trend in the unit value of chromium in the US as an indication of the global trends of price volatility.

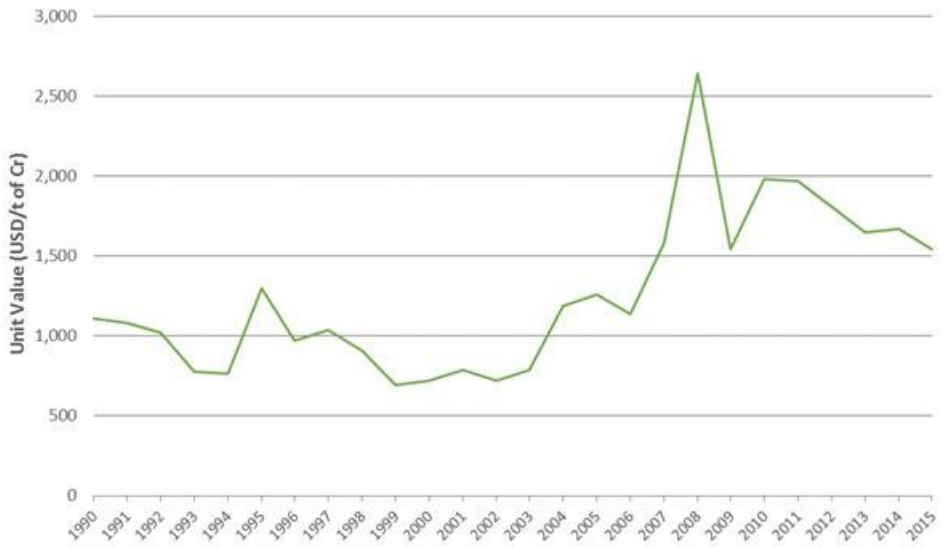


Figure 42. Unit value[30] of chromium in the United States (indexed to the 1998 unit value), yearly average (in USD/tonne of contained chromium). (USGS 2017)

Trade statistics may provide an alternative source for prices and values of chromium raw materials. Figure 43 and Figure 44 present the imports unit value in the EU of various chromium commodities from 2010 to 2017. It is noted that the unit value of imports for all chromium commodities demonstrated an uptick in 2017.

[30] The unit value of chromium in the US is defined as the estimated value of apparent consumption of chromium commodities (based on the reported values of imports, exports and production) of 1 tonne of chromium content. The unit value is adjusted in constant 1998 U.S. dollars.



Figure 43. Unit value[31] of EU imports of chromium ores and concentrates (left) and ferrochrome (right), yearly average (in EUR per tonne of gross weight). (Eurostat 2019b)

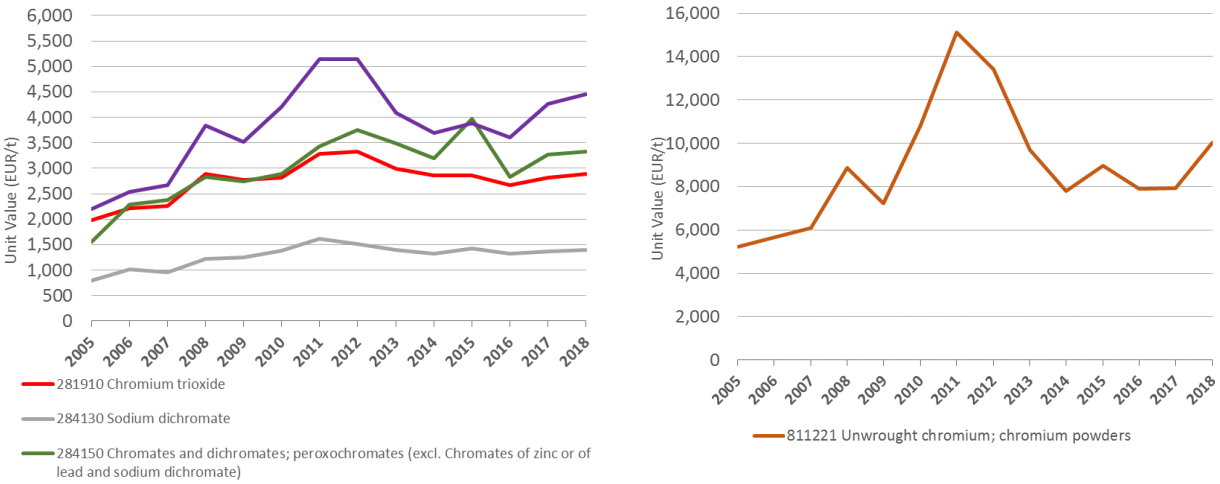


Figure 44. Unit value[32] of EU imports of chromium chemicals (left) and chromium metal (right, yearly average (in EUR per tonne of gross weight). (Eurostat 2019b)

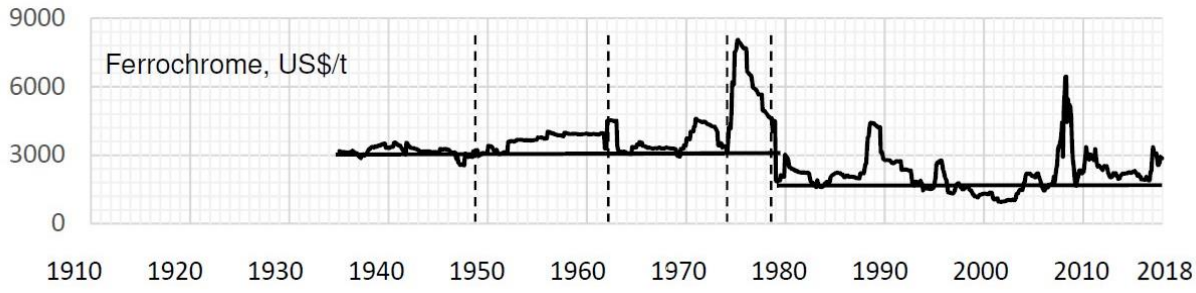


Figure 45: Prices of Ferrochrome from 1935 to 2018 (Buchholtz, 2019)

[31] Inflation adjusted with the Harmonised Index of Consumer Prices (HICP). Base 2015 = 100

[32] Inflation adjusted with the Harmonised Index of Consumer Prices (HICP). Base 2015 = 100

5.3 EU demand

5.3.1 EU consumption

As an average for the period 2012-2016, the EU consumed about 411 kt of chromium contained in chromite, and 812 kt of chromium contained in ferrochrome for the production of stainless steel and alloy steels. In terms of volume in the same period 2012-2016, the average apparent consumption of chromite is about 1,100 kt, and ferrochrome around 1,500 kt (background data from (Eurostat 2019b), (BGS 2019), (WMD, 2019)).

As a percentage of apparent consumption, the import reliance for chromite is 23% and for ferrochrome 66%.

5.3.2 Uses and end-uses of chromium in the EU

The end uses of chromium products in the EU are demonstrated in Figure 46.

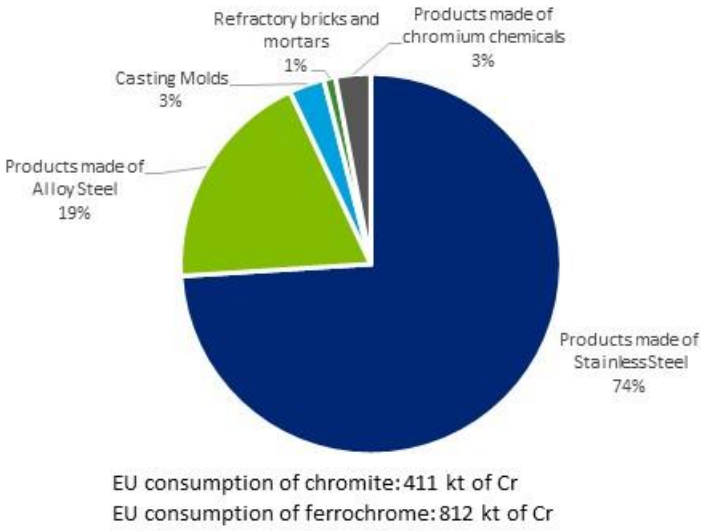


Figure 46: EU end uses of chromium in 2013 (BIO Intelligence Service 2015) (SCRREEN workshops 2019), and EU consumption of chromite and ferrochrome. Average 2012-2016

The applications of chromium are multiple, in the metals industry, refractories and chemicals. In particular:

- *Products made of Stainless Steel*: Chromium is by far the most important alloying element in stainless steel production. When added in sufficient quantity to steel, chromium spontaneously forms a thin and stable layer of chromium oxide on the steel surface, which renders steel inert to a chemical reaction, thus making it shiny and highly resistant against corrosion and oxidation, i.e. stainless. The minimum chromium content required for the formation of the protective (passive) layer is 10.5%; the strength of the layer, hence corrosion resistance, increases with increasing chromium content. Stainless steels are extremely versatile engineering materials, which are selected primarily for their corrosion and heat-resistant

properties. The chromium content of stainless steels ranges from 12.5% to 26% (EUROFER 2019). Ferrochrome, the main product of chromium ore refining, is the ferroalloy that provides chromium to steel production. About 73% of the ferrochrome production is transformed into stainless steel. The finished products manufactured by stainless steel are suitable for a vast range of diverse uses in industry, architecture, transport, and kitchenware and other applications, covering all end-use sectors (ISSF 2019a). In 2018, according to the International Stainless Steel Forum, 38% of stainless steel was consumed in the fabrication of metal products, 29% in mechanical engineering, 12% in construction, 8% in motor vehicles and parts, 8% in electrical machinery and 5% in other transport applications (ISSF 2019b);

• *Products made of Alloy Steel*: The remainder of the ferrochrome production (27%) is consumed in speciality steel alloys which are employed in industrial applications where enhanced properties are required (e.g. tools, injection moulds, camshafts, dies, bearings and mill rollers). Chromium added to steel improves wear resistance, enhances corrosion and oxidation resistance, increases hardenability, and promotes strength at elevated temperatures (European Commission 2017)(USGS 2018b);

• Refractories: Refractory-grade chromite is used to manufacture refractory bricks and mortars, mainly basic refractories in combination with magnesite, i.e. mag-chrome which contain (<30% Cr_2O_3) and chrome-mag (>30% Cr_2O_3). Chromite-bearing refractories are preferred in pyrometallurgical extraction processes for copper, nickel and platinum. In the cement and glass industries chromite refractories are being phased out due to concerns regarding hexavalent chromium (Roskill 2014);

•*Casting moulds*: Foundry sands from foundry-grade chromite are used to make casting moulds for the production of ferrous and non-ferrous castings. Chromite belongs to speciality sands (i.e. other than conventional silica sands), especially used in the production of large steel castings (> 4 t) where selective chilling, good surface finish and dimensional accuracy are required (Roskill 2014);

• *Products made of chromium chemicals*: Chromium chemical compounds have various applications.
Leather tanning is the largest market for chromium chemicals which accounted for 27% of the total consumption of chromium chemicals in 2012 (Roskill 2014). It is estimated that 80 % to 90 % of all the leather produced is tanned using chromium (III) salts, mainly in the form of chromium sulphate. Hexavalent chromium (Cr (VI)), in contrast, is not used in the tanning process as has no tanning effect. The possible formation of chromate in leather during its manufacture depends on the synergetic effects of several components (Black et al. 2013).
Moreover, chromium chemicals, in the form of acidic chromate or dichromate solutions, are employed by the metal finishing industry for the applications of coatings to other metals. Main applications include decorative chromium plating of everyday consumer durables and hard chromium plating for engineering requirements. Other metal plating applications in which chromium chemicals are involved are anodising and chromating. Metal finishing consumed 23% of chromium chemical compounds in 2012 (Roskill 2014).
Also, the production of chromium metal by chromium (III) oxide is an important niche application of chromium chemicals (BIO Intelligence Service 2015), that represented 13% of the total consumption of chromium chemical compounds in 2012 (Roskill 2014). Chromium metal is used as an alloying element to specific grades of superalloys (USGS 2018a). Due to their unique high-temperature and corrosion-resistance properties, superalloys are employed in critical applications in the aerospace, nuclear and energy sector (e.g. gas turbines). Chromium metal is also used in aircraft motor system as it resists high temperatures and very

extreme conditions, and in certain widely used aluminium alloys as an alloying element (USGS 2018a).
Furthermore, chromium chemicals are employed in colouring pigments (12% of the total chemical consumption in 2012) based on either chromium oxide or sodium dichromate; chrome oxide greens are the most widely-used chromium pigments. The pigments provide bright colour and opacity to coatings and increased durability and resistance to chemical corrosion (Roskill 2014). Finally, other uses of chromium chemicals include wood preservatives (9% of the total consumption of chromium chemicals), colouring agents in glass and ceramics (6% of the total chromium chemicals consumption) and other minor uses (10% of total chromium chemicals consumption) (Roskill 2014).

Relevant industry sectors are described using the NACE sector codes (Eurostat 2019a) provided in Table 19.

Table 19: Chromium applications, 2-digit and examples of associated 4-digit NACE sectors, and value-added per sector (Eurostat 2019a)

Applications	2-digit NACE sector	Value-added of NACE 2 sector (M€)	Examples of 4-digit NACE sectors
Products made of Stainless Steel	C25 - Manufacture of fabricated metal products, except machinery and equipment	148,351	C2571- Manufacture of cutlery; C2591 - Manufacture of steel drums and similar containers; C2599- Manufacture of other fabricated metal products n.e.c.
Products made of Alloy Steel	C25 - Manufacture of fabricated metal products, except machinery and equipment	148,351	C2599- Manufacture of other fabricated metal products n.e.c.
Casting Moulds	C24 - Manufacture of basic metals	55,426	C2420- Other non-ferrous metal production; C2432- Casting of other non-ferrous metals
Refractory bricks and mortars	C23 - Manufacture of other non-metallic mineral products	57,255	C2391- Manufacture of refractory products; C2395- Manufacture of mortars
Products made of chromium chemicals	C20 - Manufacture of chemicals and chemical products	105,514	C2011- Manufacture of dyes and pigments; C2029- Manufacture of other chemical products n.e.c.

5.3.3 Substitution

No good substitutes are currently available for the significant uses of chromium (Graedel et al. 2015). In particular, no suitable substitute is known that can provide the corrosion and oxidation resistance to metals (e.g. stainless steel) as chromium does (Johnson, Schewel, and Graedel 2006) (BRGM 2017). In superalloys, it is only possible to reduce the Cr content, but not to eliminate it in order to maintain the anti-corrosion properties, e.g. Cr is used in Ni-based superalloy structural gas turbines components and overlay coatings (CRM experts 2019).

Concerning the steel end uses, manganese, molybdenum, and nickel are considered as potential substitutes of chromium in steel alloys used in construction, and galvanised steel in steel-reinforced concrete. Aluminium is an adequate substitute for steel used in transport applications, in domestic appliances and miscellaneous metal goods. Brass can be a substitute

in some stainless steel fasteners and tungsten carbide in high-speed steels. There is no substitute at all for food processing equipment and transport of chemicals or food by truck, rail, or ship, or for the hulls of container ships or bulk carriers (Graedel et al. 2015).
In plating applications, electrolytic hard chrome plating can be replaced by thermally sprayed carbide powders, cobalt-based hardfacing alloys, plasma spraying of cermets, and electrolytic nickel-based coatings for internal surfaces (Roskill 2014). For automotive plating, potential substitutes are tin-nickel, silicon-based coatings, and organic polymer coatings, while a tin-nickel alloy is an adequate substitute for plating in electronics (Graedel et al. 2015). The FP7 project HardAlt investigated the substitution of hexavalent chromium in hard coatings with nickel-phosphorous based coatings (CORDIS 2019). Nevertheless, decorative and hard chromium plating has advantages over alternative metal finishes due to lower cost, aesthetics, corrosion resistance and multi-substrate capability (Roskill 2014).

On a scale of 0 to 100[33], chromium's substitutes performance has been assessed as 76 by (Graedel et al. 2015).

5.4 Supply

5.4.1 EU supply chain

The chromium flows through the EU economy are demonstrated in Figure 47.

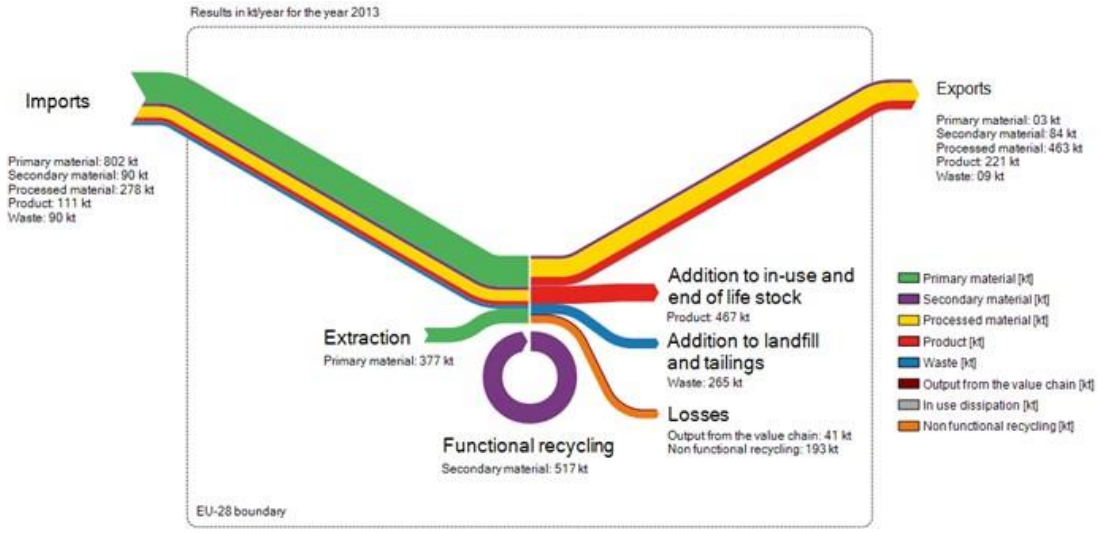


Figure 47: Simplified MSA of chromium flows in the EU. 2013. (BIO Intelligence Service 2015)

5.4.1.1 EU sourcing of chromite

In the EU, Chromium ores and concentrates are currently produced only in Finland. A minor production in Greece ended in 2012 according to production statistics from WMD (2019). In the 2012-2016 period, domestic production averaged 1,855 kt of mined ore (GTK 2019a), or 906 kt of chromium concentrate (ICDA 2019), or 480 kt in C_2O_3 content (GTK 2019a). The equivalent chromium content is estimated at 329 kt, which accounts for 77% of EU supply (see Figure 48).

[33] On this scale, zero indicates that exemplary substitutes exist for all major uses and 100 indicates that no substitute with even adequate performance exists for any of the major uses.

Outokumpu's Kemi mine in Finland is the only operating chromite mine in the EU. The mine started production in 1968 as an open pit, and currently, all mining is underground. Ore is concentrated into upgraded lumpy ore, and fine concentrate, which are raw materials for Outokumpu's ferrochrome works in Tornio (Outokumpu 2015)(USGS 2018a). The annual output of Finland has increased from 499 kt of chromium concentrates in 2012 to 972 kt of chromium concentrates in 2017, after a major expansion in production in 2013 (ICDA 2019).

Imports from South Africa cover 16% of the EU sourcing for chromium ores and concentrates. As a percentage of apparent consumption, the import reliance is 20%.

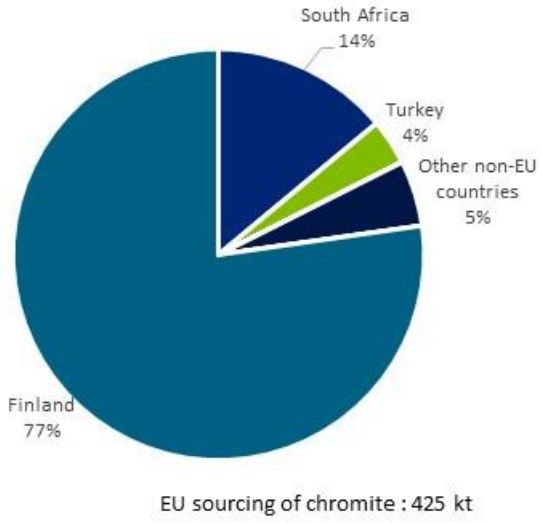


Figure 48: EU sourcing (domestic production+imports) of chromium ores and concentrates, average 2012-2016 (in Cr content). Background data from (WMD, 2019) (GTK 2019a) (Eurostat 2019b).

5.4.1.2 EU sourcing of ferrochrome

Ferrochrome is currently produced in Finland, Sweden and Germany by three companies. Total EU production amounted to 493 kt of ferrochrome (estimated to 273 Kt in chromium content) on average in the 2012-2016 period covering 30% of EU supply, while imports of ferrochrome reached 640 kt in chromium content. South Africa is the leading EU supplier with a 41% share of EU sourcing (see Figure 49). A small ferrochrome production in Romania terminated in 2010 (BGS 2019).

At the integrated stainless steel plant of Tornio in Finland, operated by Outokumpu, ferrochrome production is taking place on-site with molten ferrochrome transferred and charged directly to the steel melting shop. Three smelting furnaces are operated with a capacity of 530 kt per annum after a significant expansion in 2013 (Outokumpu 2015). Outokumpu is the only fully integrated producer of chromite, ferrochrome and stainless steel worldwide (Roskill 2014). Average production over 2012-2016 amounted to 406 kt of high-carbon ferrochrome. In 2018, the ferrochrome output reached a record level of 493 kt (ICDA 2019).

In Sweden, Vargön Alloys AB produces high-carbon ferrochrome and charge chrome with an annual production capacity of about 240 kt (Vargön Alloys AB 2019). The average ferrochrome production in 2012-2016 was 64 kt, while in 2018 production amounted to 100 kt of ferrochrome.

In Germany, Afarak Elektrowerk Weisweiler GmbH operates a smelting plant producing special grades of low-carbon ferrochrome and ultra-low-carbon ferrochrome (Afarak EWW 2019). Production capacity is 30 kt per annum (Roskill 2014). The average output in years 2012-2016 amounted to about 23 kt of ferrochrome (ICDA 2019).

South Africa is the principal non-EU supplier accounting for 41% of the EU sourcing for ferrochrome. As a percentage of apparent consumption, the import reliance is 66%.

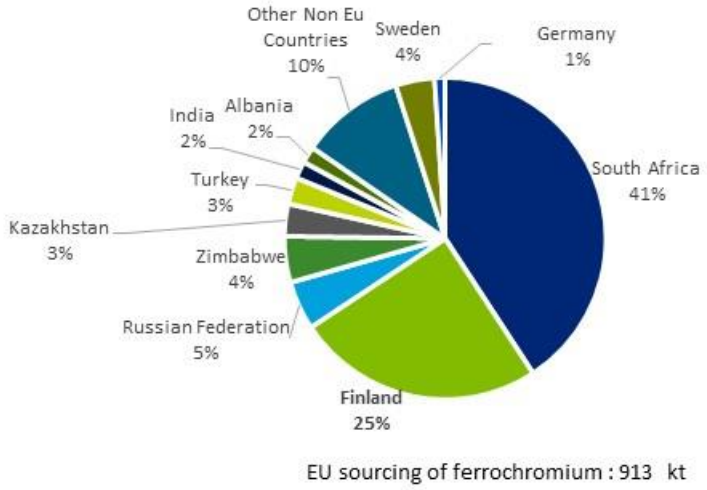


Figure 49: EU sourcing (domestic production+imports) of ferrochrome, average 2012-2016 (in Cr content). Background data from (BGS 2019)(Eurostat 2019b).

5.4.1.3 Chrome metal and chromium chemicals supply

Products made of chromium chemicals represent a minor volume of all chromium contained in finished products manufactured in the EU. However, these are key strategic products for the European industry, due to their use in the aviation and energy sectors.

Chromium metal is produced in France and Germany. In France, DCX Chrome operates a plant in Marly with an annual production capacity of 12 kt. It is reported as the world leader in the production of high-purity, aluminothermic chrome metal with applications in superalloys, special steels, hard-facing materials, weldings, powder metallurgy and aluminium alloys (BRGM, 2017)(DCX Chrome, 2019). GfE in Nürnberg, Germany, produces chromium granules, powders and lumps, and chromium alloys via an aluminothermic process. According to the US Geological Survey, capacity for chromium metal in Germany is 1 kt per year (GfE, 2020) (USGS, 2019).

Alventa SA in Poland produces chromium chemicals, i.e. basic chromium sulphate for leather tanning (chromal), and chrome oxide green (Alventa SA, 2019). Capacity for chromium chemicals in Poland is reported as 7 kt per year in Cr content in 2017 (USGS, 2019b). Cromital SPA in Ostellato, Italy, produces basic chromium sulphate for the tanning industry as well as chromic acid (chromium trioxide) and Cr (III) compounds for metal finishing and electroplating operations (Cromital, 2020). The production capacity of chromium chemicals in Italy is reported as 5 kt in contained chromium per year in 2017 (USGS, 2019b). Lanxess in Krefeld, Germany, produces chromium oxide for pigments from imported sodium dichromate (Lanxess, 2020) (Roskill, 2014). The annual production capacity in Germany is 1 kt in 2017 (in Cr

content) (USGS, 2019b). Finally, Spain is also among the EU countries with production capacity to produce chromium chemicals in 2017 (1 kt in Cr content) (USGS, 2019b).

5.4.2 Supply from primary materials

5.4.2.1 Geology, resources and reserves of chromium

Geological occurrence: Chromium is quite abundant in the Earth's crust. According to (R. L. Rudnick and Gao 2014), the average concentration of chromium in Earth's crust is 135 ppm, and in the upper crust 92 ppm. Chromium ore (chromite) is found mainly in ultramafic igneous rocks as a chromium spinel, a group of minerals with a highly variable chemical composition. The generic formula of chromium spinels is $(Fe,Mg)(Cr,Al)_2O_4$, a solid solution between chromite ($FeCr_2O_4$) and magnesio-chromite ($MgCr_2O_4$). 'Chromite' is used as a general term to describe chromium-bearing spinel minerals. Large variations in the total and relative amounts of Cr, Fe, Al and Mg in the lattice occur in different deposits. These affect the ore grade not only in terms of the Cr_2O_3 content but also in the reducibility of the ore and the chromium content of ferrochrome (ICDA 2011a). Commercial chromites contain between 40% and 60% of Cr_2O_3 content with an average of about 45% (BRGM 2017). In this factsheet, the terms "chromite" and "chromium ore" are considered interchangeable.

Commercial chromite deposits are found mainly in two types: stratiform (bedded) in basin-like intrusions, often multiple seams through repeated igneous injections, and the more irregular podiform (pod-shaped) deposits (ICDA 2011a). The Bushveld Complex in South Africa and the Great Dyke of Zimbabwe stratiform deposits contain the majority of the current global chromite resources. Other significant deposits of the stratiform type occur in Finland (Kemi deposit), India and Madagascar. The podiform deposits are relatively small in comparison, but chromite ores are generally more compact (hard lumpy) and less friable which is favourable for the smelting operation. They are also generally richer in chromium and have higher Cr:Fe ratios. The most important source of chromite from podiform deposits is located in Kazakhstan; other important deposits of this type are found in Russia and Turkey. Podiform ores were initially highly sought after, especially those from the deposits in Zimbabwe, as the best source of metallurgical grade chromite for high-carbon ferrochrome (ICDA 2011a).

There is a third type of chromite deposit, but it is currently of minimal commercial significance. These are the eluvial deposits that have been formed by weathering of chromite-bearing rock and release of the chromite spinels with subsequent gravity concentration by flowing water (ICDA 2011a). Chromium may also be concentrated in high-iron lateritic deposits containing nickel, and there have been attempts to smelt these to produce chromium-nickel pig iron for subsequent use in the stainless steel industry (ICDA 2011a).

Global resources and reserves[34]*:* At the end of 2018 the world's chromium resources are estimated to be higher than 12 billion tonnes of shipping-grade chromite (containing 45% of

[34] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of chromium in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do

Cr_2O_3), equivalent to about 3.7 billion tonnes of chromium content. Based on the current level of demand, the word resources are more than adequate to meet future demand. Global chromium resources are currently heavily geographically concentrated (95%) in southern Africa (i.e. South Africa and Zimbabwe) and Kazakhstan (USGS 2019a).

The identified world reserves are estimated to approximately 584 million tonnes of shipping-grade chromite (45% of Cr_2O_3), equivalent to about 180 million tonnes of chromium content. Kazakhstan, South Africa and India are hosts of the largest known chromium reserves.

Table 20: Global reserves of chromium in 2018. (USGS 2019a) (FODD 2017)

Country	**Estimated chromium reserves** (kt of shipping-grade chromite of 45% Cr_2O_3)	**Percentage of the total (%)**
Kazakhstan	230,000	39
South Africa	200,000	34
India	100,000	17
Finland[35]	27,000	5
Turkey	26,000	5
USA	620	<1
Other countries	Not available	
World total (rounded)	584,000	100

EU resources and reserves[36]*:* The currently known JORC-compliant resources of chromium are located in Finland (Kemi mine) and amount to 19.4 million tonnes of chromium content. Historical resource estimates of chromium resources for Greece are also available in the

not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

[35] Data reported by the US Geological Survey were complemented with reserve data for Finland (ore volume normalised to 45 % Cr_2O_3 content) as reported by the Fennoscandian Mineral Deposit database (FODD).

[36] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for chromium. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for chromium, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for chromium at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019). Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However a very solid estimation can be done by experts.

Minerals4EU website. The JORC-compliant reserves in Finland (not included in resources) are about 8.3 million tonnes in Cr content.

Table 21: Chromium resources data in the EU

Country [37]	Classification	Quantity (million tonnes of ore)	Grade (% Cr)	Reporting code	Reporting date	Source
Finland	Total resource	97.8	19.8	JORC	12/2017	(FODD 2017)
	Historic resource estimate	127	14.9	None		
Greece	Historic resource estimate	2	35-40 (% Cr_2O_3)	USGS	11/2014	(Minerals4EU)
		5	18-20 (% Cr_2O_3)			
		4	35-40 (% Cr_2O_3)			

Table 22: Chromium reserves data in the EU

Country	Classification	Quantity (million tonnes of ore)	Grade (% Cr)	Reporting code	Reporting date	Source
Finland	Total reserve (not included in resources)	41.8	19.8	JORC	12/2017	(FODD 2017)

5.4.2.2 Exploration and new mine development projects in the EU

An active project for chromite (Akanvaara project), currently at an advanced exploration stage, is situated in Finland (Strategic Resources Inc 2019)(GTK 2019b).

5.4.2.3 Chromite mining

Chromium ore is generally mined as a primary product, except for South Africa, where increasing volumes of chromite concentrates are recovered from tailings from PGM operations (Roskill 2014). About 14% of the world production of chromite, corresponding to a quarter of South African production, is a by-product of PGM mining in the UG2 horizon in the Bushveld Igneous Complex (BRGM 2017).

[37] Available data for chromium resources in Sweden reported by the Minerals4EU project and also listed by FODD, are not included in the table due to the very low grade (<0.7 % of Cr content)

Open-pit and underground mining methods are employed for chromite mining. Underground mining of stratiform deposits is most often required but can be particularly difficult due to the thin seam thickness (less than 1.5m), weathering close to the surface and faulting. Open-pit mining is generally applied to the podiform ores at first, progressing to underground mining as deeper levels of the deposit are reached. Weathering through serpentinisation and faulting are often encountered (ICDA 2011b).

Mechanical preparation and beneficiation of crude chromite is a relatively simple process. Run-of-mine chromite is crushed to reduce the maximum particle size to less than 150 mm and then screened into four categories according to size: lumpy (25-100) mm, small lumpy (6-25 mm), chips (1-6 mm) and fines (<1mm). Lumpy and small lumpy grades are marketed directly for ferrochrome production after initial processing by hand sorting. Chips and fines are further upgraded to chromite concentrates with a higher Cr_2O_3 content through simple concentration techniques to remove gangue materials, e.g. gravity separation, heavy media separation, magnetic separation, froth flotation (ICDA 2011) (Roskill 2014).

Chromium ores are traditionally classified into three types: high-chromium ores (46-55 % Cr_2O_3, Cr:Fe>2) used mainly in metallurgical applications; high-iron ores (40-46 % Cr_2O_3, Cr:Fe=1.5-2.1) used mainly in the chemical industry; and high-aluminium ores (32-38 % Cr_2O_3, 22-34 % Al_2O_3, Cr:Fe=2.0-2.5) used principally in refractories. Technological advances have enabled interchangeability among types concerning the end uses. The chromium ore is extracted, beneficiated and marketed in four distinct grades (Roskill 2014):

- Metallurgical-grade for the production of high-carbon ferrochrome (chromite with a typical composition of 48% Cr_2O_3 and a Cr:Fe ratio of 3:1), and charge chrome (chromite with 40-46 % Cr_2O_3 and Cr:Fe ratio of 1.5-2.0) used in argon oxygen decarburisation (AOD) steel production. Technological developments in ferrochrome smelting have made possible the use of lower-grade ore fines for charge-chrome production, e.g. agglomeration pre-treatment consisting of pelletising and sintering;
- Refractory-grade (typical 47 % Cr_2O_3) with a combined Cr_2O_3+Al_2O_3 content of >60%, Fe<15% and silica content of around 0.7%;
- Foundry-grade (typical Cr_2O_3 >46%) which generally needs to be beneficiated to remove talc, silica and clay impurities.
- Chemical-grade (typical Cr_2O_3 44-46%, SiO_2<3.5% Cr:Fe ratio 1.5-2.1)

In 2015, the highest share (96%) of the global chromite production was destined for ferrochrome production in the metallurgical industry. The chemical grade represented 2.1% of the chromite extracted, the foundry grade 1.7%, and the refractory grade 0.2% (BRGM 2017).

5.4.2.4 World and EU mine production

The world mine production of chromium reached 12,870 kt (in Cr_2O_3 content) [38] as an average over 2012-2016, which is equivalent to 8,804 kt in Cr content (WMD, 2019). According to the International Chromium Development Association statistics, the average world production of chromium ores and concentrates in the same period amounted to 29,075 kt expressed in gross weight (ICDA 2019). South Africa is the world's largest chromium ore producer, contributing about 47% of the total world supply. Other important suppliers of chromium ores and concentrates are Kazakhstan (15%), India (13%) and Turkey (10%). Chemical-grade chromite

[38] Production data for Finland are sourced from (GTK 2019a)

is produced in India, Kazakhstan and South Africa; refractory-grade in Oman and South Africa; and foundry-grade in South Africa and Oman (Roskill 2014).

The EU mine production of chromium is concentrated in Finland, as the small production in Greece terminated in 2012, and is averaged at about 481 kt (Cr_2O_3 content) or 329 kt (Cr content) per year over the period 2012-2016 (GTK 2019a) (WMD, 2019).

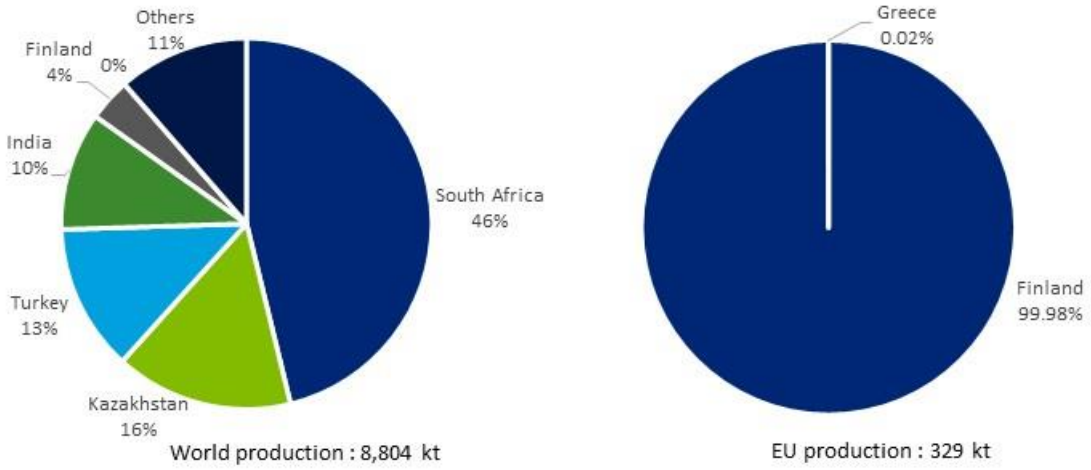


Figure 50: Global and EU mine production of chromite (in Cr content). Average 2012-2016. (WMD, 2019) (GTK, 2019a)

5.4.3 Processing of chromite ore

5.4.3.1 Ferrochrome production

Ferrochrome is produced from metallurgical-grade chromite by smelting a mixture of the ore (in the form of lumpy ore, fines or concentrates), a carbonaceous reductant (e.g. coke) and auxiliary flux materials in an electric arc furnace. AC arc, DC arc (or plasma) furnace technology is used for the high-temperature reduction (smelting). The smelting process is electrical-energy intensive requiring up to 4,000 kWh per tonne of material weight with the efficiency varying with ore grade, operating conditions, and production process (ICDA 2011).

Ferrochrome is an alloy of chromium and iron containing 45% to 75% chromium by weight with much lesser amounts of carbon and silicon (ICDA 2011); the amounts depend upon the grade or type of alloy. Its use depends primarily on carbon content. Ferrochrome can be generally classified as follows (Saxby 2017):

- *Charge chrome* (used exclusively for stainless steel);
- *High-carbon ferrochrome* (HC FeCr) with 4%–12% C (40% used for stainless steel, the rest for carbon and alloy steels);
- *Medium-carbon ferrochrome* (MC FeCr) with 0.5%–4% C and Low-carbon ferrochrome (LC FeCr) with 0.01%–0.5% C, used for carbon and alloy steels.

According to background data from (ICDA 2019), 91% of the global ferrochromium alloys production in 2018 comprised high-carbon and charge chrome, 6% medium & low-carbon ferrochrome, and 3% ferro-silicon-chrome.

The reducibility of diverse ores is quite different. Generally speaking, podiform ores are of higher quality, resulting in a high-Cr alloy, while stratiform ores have a lower chromite content and a low Cr to Fe ratio. For this reason, podiform ores will most often give a chromium

recovery above 90%, while for fine stratiform ores the recovery is below 70 % in conventional production routes, reaching higher recovery rates in the case of charging the furnace with sintered pellets. With the DC plasma process, recovery is reportedly above 90 %. This compensates for the higher consumption of electrical energy needed to increase the process temperature to achieve a faster reduction.

Depending on the different production routes and the desired carbon content of the ferrochrome, carbon or silicon is used as a reducing agent. For the production of HC FeCr, carbon is added to the process as a reducing agent, predominantly metallurgical coke (with a low phosphorus and sulphur content). For the production of LC FeCr, ferro-silicon-chromium and ferrosilicon are used in a silicothermic reduction as reducing agents and raw material.

5.4.3.2 World and EU ferrochrome production

The world production of ferrochrome reached 6,158 kt of chromium content, with China and South Africa the leading producers accounting for 37% and 28% respectively of the global supply, followed by Kazakhstan (14%) and India (8%) (see Figure 51). South Africa, China and Kazakhstan are the primary producers of high-carbon ferrochrome and charge chrome, while China and Russia account for the majority of global medium and low-carbon ferrochrome supply used in special steels (Roskill 2014).

Only Finland, Sweden and Germany produce ferrochromium in the EU, with an annual average production of about 493 kt of ferrochrome or 273 kt of contained chromium in the 2012-2016 period.

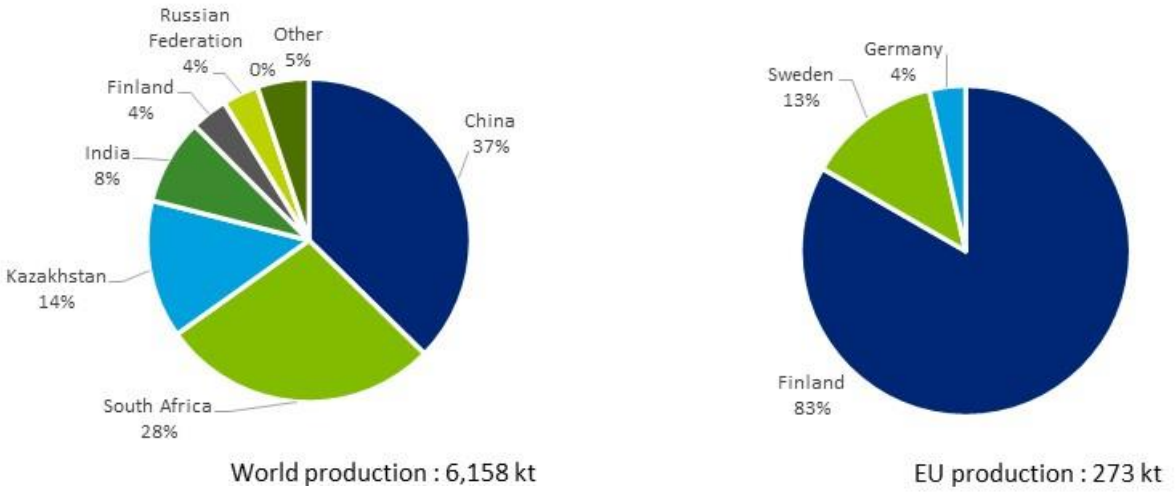


Figure 51: Global[39] and EU production of ferrochrome (in Cr content). Average 2012-2016. (BGS 2019)(USGS 2018b)(ICDA 2019)

[39] (USGS, 2018b) is the source of Chinese production of ferrochrome for 2012-2015, and (ICDA, 2019) the source of Chinese production for 2016.

5.4.3.3 Processing of non-metallurgical chromite grades

Refractory-grade chromite is used chemically unmodified. It requires a very low silica content (typically 0.7% SiO_2), and the amount of combined Cr_2O_3 and Al_2O_3 not exceeding 57%. The chromite is generally produced as a fine-grained concentrate from which most of the silica, which occurs in the gangue, has been removed. Refractory chromite in its granular form makes up the chromite foundry sand.

Chemical-grade chromite ore is processed, together with soda ash (sodium carbonate) by a rotary kiln roasting process to produce sodium chromate. The sodium chromate is then converted into a variety of chromium chemicals such as sodium dichromate, chromic acid and chromium oxide, which are subsequently manufactured into other chromium compounds (such as chromium (III) oxide).

Chromium metal is produced primarily through the aluminothermic process by the reduction of chromium (III) oxide and by the electrodeposition process using a wide variety of electrolytes. Chromium metal standard grades range from 99% to 99.4%.

5.4.3.4 World and EU production of chromium chemicals and chrome metal

No statistical data are available in the public domain for the production of chromium chemicals and chrome metal. China holds the largest production capacity for the production of chromium chemicals, and Russia for chromium metal (USGS 2019b).

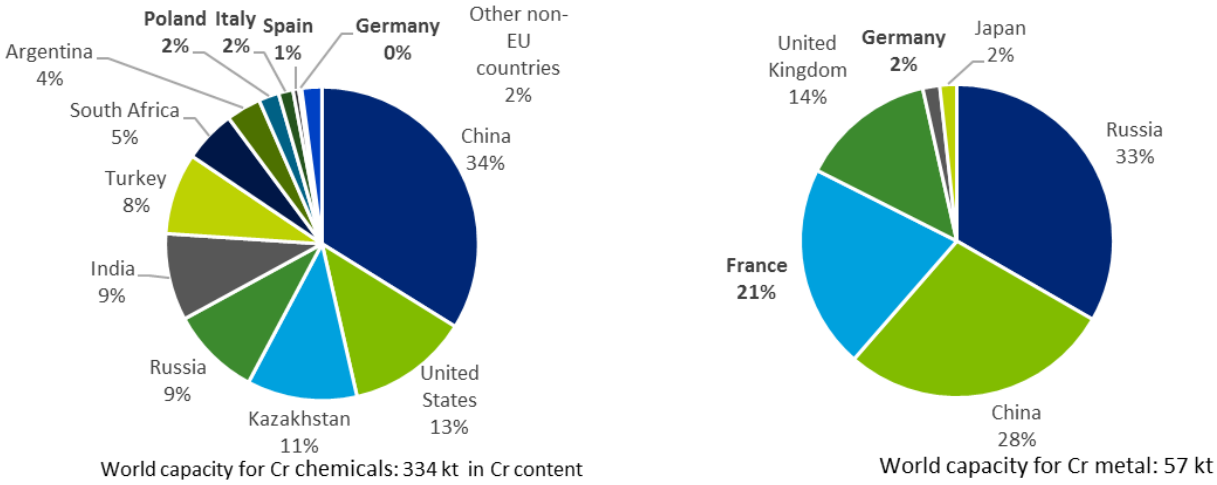


Figure 52: Global production capacity for chromium chemicals (left) and chromium metal (right) in 2017 (USGS 2019b)

5.4.4 Supply from secondary materials/recycling

5.4.4.1 Post-consumer recycling (old scrap)

Stainless steel, which accounts for almost three-quarters of chromium's consumption in the EU, is commonly recycled in separated flows as its properties will be lost if mixed with common

steel scrap. The post-consumer functional recycling of stainless steel reaches rates between 70% and 95%, depending on the product (BIO Intelligence Service 2015). In general, the scrap content in the production of stainless steel is estimated at 60%, of which 25% consists of old scrap and 35% of new scrap (BRGM 2017).

On the other hand, the detection and sorting of alloy steel products are more complicated; thus, the majority of these products ends up in carbon steel (i.e. non-functional recycling) (BIO Intelligence Service 2015). Non-ferrous alloys containing chromium (e.g. superalloys) are also recyclable in the same application if the scrap is sorted for the production of the same alloy. The other uses, such as leather tanning and pigments are dissipative (BRGM 2017).

According to (UNEP 2011), the global average end-of-life functional recycling rate (EOL-RR) for chromium was estimated to be above 50%, the fraction of secondary (scrap) metal in the total input to metal production to range between 10% and 25% (recycled content), and the share of old scrap in the total scrap flow (old scrap ratio) to be above 50%.

According to data provided by the MSA study of chromium, in 2013 the end-of-life recycling input rate (EOL-RIR) in the EU was 21%, the overall functional recycling rate (EOL-RR) was 48%, and the non-functional recycling rate was 24% (BIO Intelligence Service 2015).

Table 23: Material flows relevant to the EOL-RIR of chromium[40] in 2013. (BIO Intelligence Service 2015)

MSA Flow	Value (kt)
B.1.1 Production of primary material as main product in EU sent to processing in EU	278,621
B.1.2 Production of primary material as by product in EU sent to processing in EU	0
C.1.3 Imports to EU of primary material	801,796
C.1.4 Imports to EU of secondary material	90,060
D.1.3 Imports to EU of processed material	278,256
E.1.6 Products at end of life in EU collected for treatment	711,194
F.1.1 Exports from EU of manufactured products at end-of-life	8,588
F.1.2 Imports to EU of manufactured products at end-of-life	89,644
G.1.1 Production of secondary material from post consumer functional recycling in EU sent to processing in EU	383,138
G.1.2 Production of secondary material from post consumer functional recycling in EU sent to manufacture in EU	0

In 2013, the total EU production of crude stainless steel and alloy steel represented around 1,700 kt of chromium content, with an important input of 780 kt of chromium content as scrap. Specifically, the input from old scrap from recycled end-of-life products was around 380 kt, imports of secondary material represented 90 kt, and 310 kt came from new scrap (BIO Intelligence Service 2015).

The availability of stainless steel scrap is the limiting factor to higher use of scrap (BIO Intelligence Service 2015). According to Eurostat data for the trade code HS 720421 "Waste and scrap of stainless steel (excl. Radioactive, and waste and scrap of batteries and electric accumulators)", the EU is a net importer of recyclable stainless steel scrap with imports

[40] EOL-RIR=(G.1.1+G.1.2)/(B.1.1+B.1.2+C.1.3+D.1.3+C.1.4+G.1.1+G.1.2)

averaging to 480 kt and exports to 405 kt as an average in the 2012-2016 period (Eurostat 2019b). However, the domestic scrap availability is much lower than domestic demand.

5.4.4.2 Industrial recycling (new scrap)

In 2013, the input from new scrap from manufacturing and processing to the total chromium demand for stainless steel and alloy steels was estimated at 310 kt. About 170 kt of chromium in scrap were generated from the processing of steel in primary forms ("home" scrap), and directly remelted into new steel; 130 kt were generated as "new" scrap from the manufacturing of finished products (BIO Intelligence Service 2015).

5.5 Other considerations

5.5.1 Environmental issues

The production of ferroalloys is highly energy-intensive as the ores are reduced in electric arc furnaces; therefore, process emissions are intrinsic and unavoidable. With the technologies currently available, the European industry already operates very close to maximum thermodynamic efficiency, and the margin for future efficiency improvements and emissions reduction is relatively small and hard to achieve (Euroalliages 2019) (Wyns, Khandekar, and Robson 2018). A recent study commissioned by the EU Energy-Intensive sectors provides an overview of technology solutions, with current TRL levels from 2 to 5, to reduce the carbon footprint of the ferroalloys industry, i.e. switch to natural gas as energy source and reducing agent, flue gas fermentation to produce biomass and fuels, off-gas processing for highly efficient energy recovery, use of bio-carbon, and industrial symbiosis. The prevention of down-cycling and the exploitation of e-waste is another identified strategy to enhance circularity and reduce emissions in the ferroalloy sector (Wyns, Khandekar, and Robson 2018).

5.5.2 Contribution to low-carbon and green technologies

Ferrochromium is an essential material for the production of stainless steel and alloy steels, therefore, chromium enables the low-carbon solutions associated with applications of chromium-containing steels, e.g. speciality steels for lighter cars in the transport sector (Wyns, Khandekar, and Robson 2018). Energy technologies in which chromium's use is identified include wind turbines, carbon capture and storage installations for low carbon–based power generation, advanced ultra-supercritical gas-fired turbines (in nickel based components) for electricity generation operating at higher temperature steam for advanced efficiency, in boilers and pipework of advanced ultra-supercritical coal-fired power stations (World Bank 2017).

5.5.3 Health and safety issues

Chromium ions may be present in different oxidation states. The two most common oxidation states for chromium ions are 3 and 6. Trace elements of trivalent chromium are required in the human body to metabolise lipids and sugar; hence, chromium is used in many dietary supplements. However, while chromium metal and Cr (III) ion are not considered toxic, hexavalent chromium compounds are carcinogenic, toxic for reproduction and/or mutagenic, properties critical for the human health and the environment. Many chromium compounds are recognised as a substance of very high concern (SVHC) under the REACH regulation.

Cr (VI) compounds have a harmonised classification:

- Carc. 1B
- Skin Sens. 1
- Aquatic Acute 1
- Aquatic Chronic 1

Chromium (VI) compounds are included in the Restriction List of the REACH Regulation (Annex XVII), and they are subject to restrictions on the manufacture, placing on the market and use (ECHA 2019b). As an example, cement and mixtures containing cement may not be placed on the market or used, if they contain, when hydrated, more than 2 ppm of soluble chromium VI of the total dry weight of the cement. Moreover, leather articles and articles containing leather coming into contact with the skin shall not be placed on the market where they contain chromium VI in concentrations equal to or higher than 3 mg/kg of the total dry weight of the leather or the leather part.

In addition, several chromium (VI) compounds are included in the Authorization List of the REACH Regulation (Annex XIV) which means that they cannot be marketed or used after a specified date (the so-called "sunset date"), unless an approval is granted for their specific use, or the use is exempted from authorisation (ECHA 2019a). The sunset date for chromium trioxide, chromic and dichromic acid, sodium, potassium and ammonium dichromates, potassium and sodium chromates took effect on the 21 of September 2017 (European Commission 2013). Downstream users can continue using chromium (VI) compounds after the sunset of the substance even if the Commission has not decided to grant or not to grant an authorisation. This continuation is possible if a company up their supply chain has applied for authorisation for its use before the latest application date, which was 21 March 2016 (ECHA 2017).

Directive 2000/53/EC on end-of-life vehicles restricts the use of hexavalent chromium on new vehicles, while Directive 2011/65/EU on the restriction of the use of certain hazardous substances in electrical and electronic equipment restricts the placing on the market of new electrical and electronic equipment containing >0.1% hexavalent chromium.

In the defence sector, the European Defence Agency reported in October 2018 that hexavalent chromium compounds are still used after the sunset date for the surface treatment of many products, but in some circumstances, the hexavalent chromium and its compounds have been already replaced by trivalent chromium-based processes. However, the performance in terms of corrosion resistance is not equivalent, so further improvements are needed (EDA 2018).

At EU level, binding occupational exposure limit values[41] (OELs) are set for chromium (II, III and IV) to prevent occupational diseases or other adverse effects in workers exposed to chromium in the workplace.[42]

5.5.4 Socio-economic issues

South Africa, the leading supplier of chromium both at global and EU level, has a medium level of governance. South Africa is placed in the 50-75th percentile range for all the governance indicators, i.e. the rule of law, control of corruption, voice and accountability, government effectiveness, regulatory quality, except for "political stability and absence of violence"

[41] "OEL means the limit of the time-weighted average of the concentration of a chemical agent in the air within the breathing zone of a worker in relation to a specified reference period" (Skowroń 2017)

[42] Cr II & Cr III IOELV 2006/15/EC & Cr VI BOEL 2017/2398/EC

indicator, in which it ranks in the 25-50th percentile range. The other main global suppliers, Kazakhstan, Turkey and India, have a lower level of governance, especially for the indicator "political stability and absence of violence", in the case of Turkey and India, and for the indicators "voice and accountability" and "control of corruption" in the case of Kazakhstan. (World Bank 2018)

5.6 Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. The supply risk has been analysed at both stages of the value chain: mining (chromite) and processing (ferrochrome). Chromium was identified as critical in the 2014 assessment, whereas it was considered non-critical in the 2011 and 2017 exercises. The calculations of the Supply Risk (SR) for 2010 and 2014 lists have been performed for the mining stage, whereas in the 2017 assessment the results were based on the analysis of the processing stage only. The result of the current and previous assessments are shown in Table 24.

Table 24: Economic importance and supply risk results for chromium in the assessments of 2011, 2014, 2017, 2020 (European Commission 2011)(European Commission 2014)(European Commission 2017)

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Chromium	9.9	0.8	8.9	1.0	6.8	0.9	7.3	0.9

The revised criticality methodology affects both the economic importance and supply risk calculations of chromium, which explains the differences in EI and SR results across the 2011/2014 and the 2017/2020 assessments. For example, the decrease of economic importance of chromium between 2014 and 2017 is an interpretation biased by the change in methodology. More precisely, since 2017, the value-added for the calculation of economic importance is related to 2-digit NACE sectors rather than a 'megasector', which was used in the 2011 and 2014 assessments.

The Supply Risk (SR) was calculated using both the HHI for global supply and EU supply as prescribed in the revised methodology. According to the results, the processing stage has a marginally higher supply risk (SR=0.86) than the mining stage (SR=0.85), and it is practically equal to the 2017 result (SR=0.90). The stage with the highest score has been considered as representing the overall supply risk for chromium, i.e. processing stage, with SR=0.86 (rounded to 0.9).

For the economic importance indicator (EI), the same allocation of end uses and corresponding 2-digit NACE sectors was applied in the 2017 and the current assessment. The increase in EI in comparison to the 2017 assessment is because of the results scaling step[43], as the value-added of the largest manufacturing sector in the current assessment is lower as it corresponds to 27 Member States (i.e. excluding UK), whereas in the 2017 assessment it was related to EU28.

In the 2020 assessment, the EI for chromium (EI=7.3) meets the minimum EI criticality threshold, however its SR result (SR=0.9) does not. Even though in the 2017 and 2020

[43] The results are scaled by dividing the calculated EI score by the value of the largest manufacturing sector NACE Rev. 2 at the 2-digit level and multiplied by 10, in order to reach the value in the scale between 0-10.

exercises chromium is not considered as a critical raw material, it should be underlined that it is close to the supply risk threshold.

5.7 Data sources

The source of production data for the extraction stage was 'World Mining Data' developed by the Austrian Ministry for Sustainability and Tourism and the International Organising Committee for the World Mining Congress, with the exception of mine production from Finland for which data provided by the Geological Survey of Finland were used. The British Geological Survey's 'World Mineral Statistics' was the source of ferrochrome production data, complemented with data for the Chinese production published by the US Geological Survey and the International Chromium Development Association's statistical bulletin provided by Euroalliages. Trade data used in the assessment were sourced from Eurostat's Comext database, whereas the dataset developed by the EU MSA study of chromium was the source for the EOL-RIR.

The amount of chromium which exits and enters the EU economy via crude stainless steel, chromium metal and chromium chemicals, and scrap trade has not been taken into account in the assessment. The overall consumption of chromium and its compounds is difficult to evaluate because of the multitude of steel and alloys in which it enters with varying proportions.

5.7.1 Data sources used in the factsheet

Afarak EWW (2019) Speciality Alloys. Available at: http://www.elektrowerk.de/page/index-en.html (Accessed: 23 August 2019).

Alventa SA (2019) Chromium compounds, Products. Available at: http://www.alwernia.com.pl/chromium-compounds (Accessed: 27 August 2019).

BGR (2019) Publications and downloads. Commodity prices. Volatility monitoring. Available at: https://www.bgr.bund.de/EN/Themen/Min_rohstoffe/Produkte/produkte_node_en.html?tab=Commodity+prices (Accessed: 3 September 2019).

BGS (2019) World mineral statistics data, British Geological Survey. Available at: https://www.bgs.ac.uk/mineralsuk/statistics/wms.cfc?method=searchWMS.

BIO Intelligence Service (2015) Study on Data for a Raw Material System Analysis: Roadmap and Test of the Fully Operational MSA for Raw Materials. Available at: https://ec.europa.eu/jrc/en/scientific-tool/msa.

Black, M. et al. (2013) JRC Reference Report. Best Available Techniques (BAT) Reference Document for the Tanning of Hides and Skins. JRC 83005. European Commission. Joint Research Centre. doi: 10.2788/13548.

BRGM (2017) 'Le chrome (Cr) – éléments de criticité'. Bureau de Recherches Géologiques et Minières, pp. 1–9. Available at: http://www.mineralinfo.fr/page/fiches-criticite.

Buchholz P., Wellmer F.W., Bastian D., Liedtke M. (2019) Leaning against the wind: Low price benchmarks for acting anticyclically in the metal markets. Mineral Economics. https://doi.org/10.1007/s13563-019-00199-y

CORDIS (2019) HardAlt: New generation of protective coatings alternative to hard chrome. Available at: https://cordis.europa.eu/project/rcn/111053/factsheet/en (Accessed: 30 September 2019).

Cromital (2020) Leather Tanning Chemicals and Metal Treatment Solutions. Available at: http://www.cromital.eu/en/products (Accessed: 28 February 2020).

CRM experts (2019) 'CRM validation workshop. 10-12 September 2019 (Brussels)'.

DCX Chrome (2019) Chrome metal. Available at: http://dcx-chrome.com/ (Accessed: 22 August 2019).

ECHA (2017) Sunset date for Chromium VI compounds approaches - what should downstream users do? Available at: https://echa.europa.eu/-/sunset-date-for-chromium-vi-compounds-approaches-what-should-downstream-users-do- (Accessed: 25 September 2019).

ECHA (2019a) Authorisation List, European Chemicals Agency. Information on Chemicals. Available at: https://echa.europa.eu/authorisation-list (Accessed: 22 August 2019).

ECHA (2019b) Substances restricted under REACH, European Chemicals Agency. Information on Chemicals. Available at: https://echa.europa.eu/substances-restricted-under-reach?p_p_id=disslists_WAR_disslistsportlet&p_p_lifecycle=1&p_p_state=normal&p_p_mode=view&p_p_col_id=column-1&p_p_col_pos=1&p_p_col_count=2&_disslists_WAR_disslistsportlet_javax.portlet.action=searchDiss (Accessed: 22 August 2019).

EDA (2018) Position Paper On the impact of the entanglement of REACH Regulation , Critical Raw Materials and Circular Economy on European Defence.

Euroalliages (2019) Low carbon economy, Euroalliage webpage. Energy and Climate. Available at: http://www.euroalliages.com/web/low carbon economy/1011306087/list1187970084/f1.html (Accessed: 27 August 2019).

EUROFER (2019) About Stainless Steel. Available at: http://www.eurofer.org/Eurofer Stainless/About Stainless Steel.fhtml (Accessed: 29 September 2019).

European Commission (2011) Critical raw materials. Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en (Accessed: 8 July 2019).

European Commission (2013) Commission Regulation (EU) No 438/2013 of 17 April 2013 amending Annex XIV to Regulation (EC) No 1907/2006 of the European Parliament and of the Council on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), Official Journal of the European Union.

European Commission (2014) Report on critical raw materials for the EU - Critical raw materials profiles. Available at: https://ec.europa.eu/docsroom/documents/11911/attachments/1/translations/en/renditions/pdf.

European Commission (2017) Study on the review of the list of critical raw materials. Non-Critical Raw Materials Factsheets. European Commission. doi: 10.2873/876644.

European Commission (2019) Negotiations and agreements. Available at: http://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/ (Accessed: 7 July 2019).

Eurostat (2019a) Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). Available at: https://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2 (Accessed: 7 July 2019).

Eurostat (2019b) Easy Comext database. Available at: http://epp.eurostat.ec.europa.eu/newxtweb/.

Fastmarkets MB (2018) '2018 ICDA Conference: Oversupply to haunt chrome industry in the short term'. Available at: https://www.metalbulletin.com/Article/3843907/2018-ICDA-CONF-Oversupply-to-haunt-chrome-industry-in-the-short-term.html.

FODD (2017) Fennoscandian Mineral Deposits, Fennoscandian Ore Deposit database. V.2017. Available at: http://en.gtk.fi/informationservices/databases/fodd/index.html (Accessed: 9 August 2019).

GfE (2020) Gesellschaft für Elektrometallurgie mbH. Products and solutions. Available at: https://www.gfe.com/en/start (Accessed: 28 February 2020).

Graedel, T. et al. (2015a) 'On the materials basis of modern society', Proceedings of the National Academy of Sciences, 112(20). doi: 10.1073/pnas.1312752110.

GTK (2019a) 'Comments from GTK provided to DG GROW following the CRM Ad Hoc Working Group meeting and SCRREEN Experts Workshop.'

GTK (2019b) 'Mineral Deposit Report. Akanvaara LC', pp. 1–7.

ICDA (2011) 'Geology and Mineralogy', Discover Chromium. International Chromium Development Association.

ICDA (2011) 'Mining'. International Chromium Development Association. Available at: www.icdacr.com.

ICDA (2011) 'Ore Processing'. International Chromium Development Association. Available at: www.icdacr.com.

ICDA (2019) 'Statistical Bulletin 2019 (based on 2018 data)'. International Chromium Development Association.

ISSF (2019a) Introduction to Stainless Steel, International Stainless Steel Forum website. Available at: http://www.worldstainless.org/what_is_stainless_steel/introduction_to_stainless_steel (Accessed: 29 September 2019).

ISSF (2019b) Stainless Steel in Figures 2019, Statistics. Available at: http://www.worldstainless.org/statistics.

Johnson, J., Schewel, L. and Graedel, T. E. (2006) 'The contemporary anthropogenic chromium cycle', Environmental Science and Technology, 40(22), pp. 7060–7069. doi: 10.1021/es060061i.

KPMG (2018) 'KPMG commodity insights bulletin – chromite'. Available at: https://home.kpmg/xx/en/home/insights/2018/11/commodity-insights-bulletin-chromite.html.

Lanxess (2020) Krefeld-Uerdingen. Inorganic pigments and high-tech plastics. Available at: https://lanxess.com/en/Company/Locations/Krefeld-Uerdingen (Accessed: 28 February 2020).

Minerals4EU (2019) European Minerals Yearbook. Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html.

OECD (2019) Export Restrictions on Industrial Raw Materials. Available at: https://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials (Accessed: 5 July 2019).

Outokumpu (2015) 'This is Outokumpu Tornio Site'. Available at: http://ec.europa.eu/DocsRoom/documents/13762/attachments/7/translations/en/renditions/pdf.

Roskill (2014) Chromium: Global Industry Markets and outlook. Twelfth Edition. Available at: https://roskill.com/market-reports/.

Roskill (2018) 'Chromium : Roskill discusses changing supply structures at the ICDA in Baotou , Inner Mongolia', pp. 1–5. Available at: https://roskill.com/news/chromium-roskill-discusses-changing-supply-structures-at-the-icda-in-baotou-inner-mongolia/.

Rudnick, R. L. and Gao, S. (2014) Composition of the Continental Crust, Treatise on Geochemistry: Second Edition. Elsevier Ltd. doi: 10.1016/B978-0-08-095975-7.00301-6.

Saxby, A. (2017) 'Industrial minerals review 2016. Chromite', Mining Engineering, 26(July), p. 43. Available at: https://www.csaglobal.com/2016-industrial-minerals-review-now/.

SCRREEN workshop (2019) 'Validation workshop on Critical Raw Materials, 10-12 September 2019, Thon Hotel Brussels City Centre'. Brussels

Strategic Resources Inc (2019) Akanvaara Project , Finland. NI 43-101 Technical Report. Available at: https://strategic-res.com/site/assets/files/3618/akanvaara_43-101_10-06-2019.pdf.

UN Comtrade (2019) International Trade Statistics Database. Available at: https://comtrade.un.org/ (Accessed: 8 July 2019).

UNEP (2011) Recycling Rates of Metals – A Status Report, A Report of the Working Group on the Global Metal Flows to the International Resource Panel., Group. doi: ISBN 978-92-807-3161-3.

USGS (2017) 'Historical Statistics for Mineral and Material Commodities in the United States-Boron'. U.S. Geological Survey. Available at: https://www.usgs.gov/centers/nmic/historical-statistics-mineral-and-material-commodities-united-states#boron.

USGS (2018a) 2015 Minerals Yearbook. Chromium, USGS Mineral Resources Program. doi: 10.1016/j.ijporl.2012.07.018.

USGS (2018b) 'USGS Minerals Yearbook 2015. Ferroalloys'. US Geological Survey. Available at: https://www.usgs.gov/centers/nmic/chromium-statistics-and-information.

USGS (2019a) Mineral Commodity Summaries 2019. U.S Geological Survey. doi: 10.1007/978-3-540-47108-0-4.

USGS (2019b) '2017 Minerals Yearbook. Chromium. Advance data release'. Available at: https://www.usgs.gov/centers/nmic/chromium-statistics-and-information.Vargön Alloys AB (2019) Vargön Alloys AB website. Available at: http://www.vargonalloys.se/index_eng.html (Accessed: 23 August 2019).

World Bank (2017) The Growing Role of Minerals and Metals for a Low Carbon Future, The Growing Role of Minerals and Metals for a Low Carbon Future. doi: 10.1596/28312.

World Bank (2018) Aggregate Governance Indicators 1996-2017, Worldwide Governance Indicators. Available at: http://info.worldbank.org/governance/WGI/#home (Accessed: 7 July 2019).

Wyns, T., Khandekar, G. and Robson, I. (2018) Industrial Value Chain: a Bridge Towards a Carbon Neutral Europe. Available at: http://www.euroalliages.com/web/low carbon economy/1011306087/list1187970084/f1.html.

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

5.7.2 Data sources used in the criticality assessment

BGS (2019) *World mineral statistics data*, *British Geological Survey*. Available at: https://www.bgs.ac.uk/mineralsuk/statistics/wms.cfc?method=searchWMS.

USGS (2018b) 'USGS Minerals Yearbook 2015. Ferroalloys'. US Geological Survey. Available at: https://www.usgs.gov/centers/nmic/chromium-statistics-and-information.

ICDA (2019) 'Statistical Bulletin 2019 (based on 2018 data)'. International Chromium Development Association.

GTK (2019a) 'Comments from GTK provided to DG GROW following the CRM Ad Hoc Working Group meeting and SCRREEN Experts Workshop.'

Eurostat (2019b) *Easy Comext database*. Available at: http://epp.eurostat.ec.europa.eu/newxtweb/.

BIO Intelligence Service (2015) 'Study on Data for a Raw Material System Analysis: Roadmap and Test of the Fully Operational MSA for Raw Materials'. Available at: https://ec.europa.eu/jrc/en/scientific-tool/msa.

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

5.8 Acknowledgments

This factsheet was prepared by the JRC. The authors would like to thank the Ad Hoc Working Group on Critical Raw Materials, in particular the Geological Survey of Finland (GTK), Euroalliages and Euromines, as well as experts participating in SCRREEN workshops for their contribution and feedback.

6. COPPER

6.1 Overview

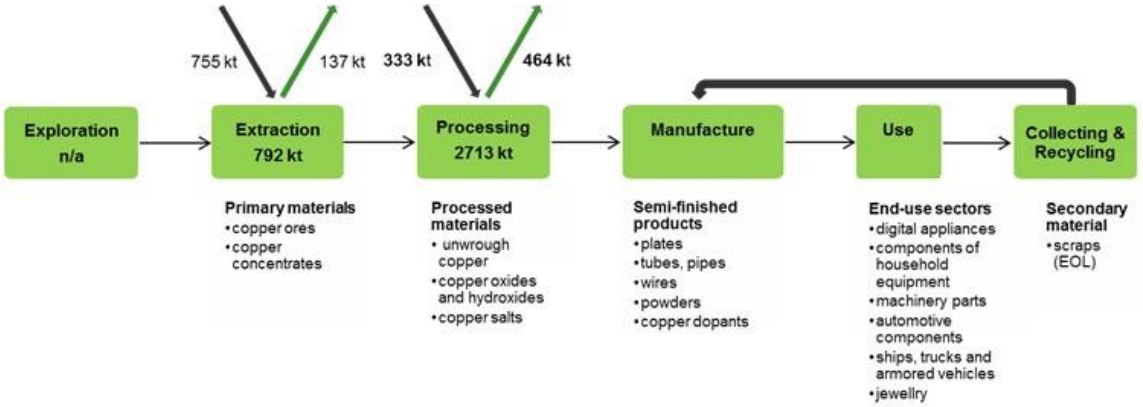
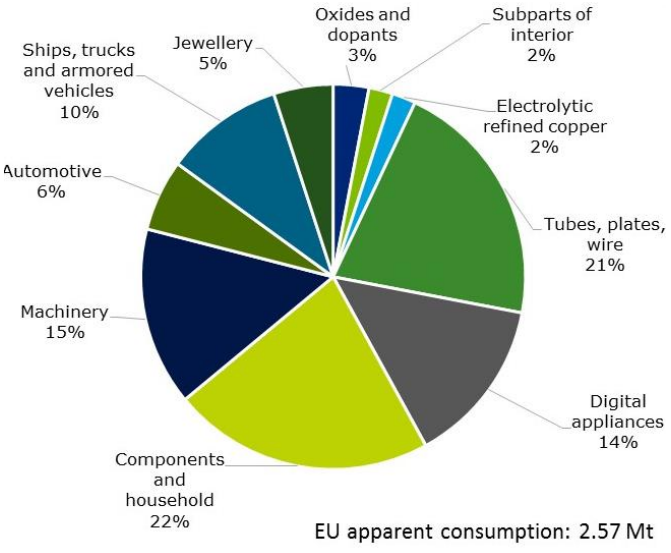
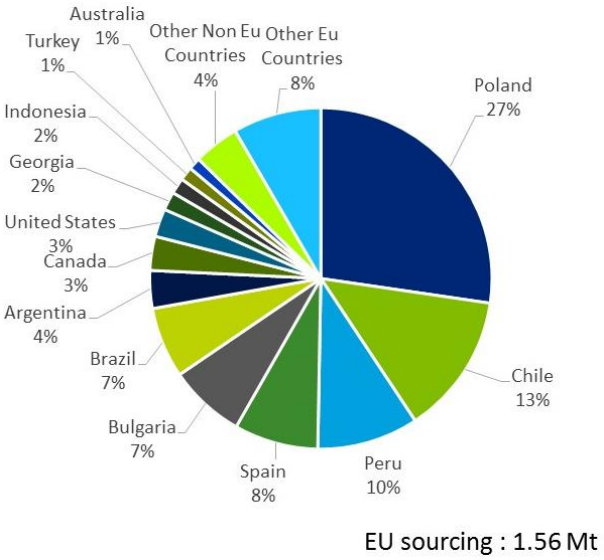


Figure 53: Simplified value chain for copper in the EU, average 2012-2016[44]

Copper (chemical symbol Cu; from Latin "cuprum") is a ductile, reddish metal, used since the early days of human history. It is an important trace element for many living organisms, including humans (Lossin, 2001). There are over 150 identified copper minerals, but only around ten of them are of economic importance. About half of world's copper production is mined from chalcopyrite ($CuFeS_2$) (BGS, 2007). Copper does not react with water, but slowly reacts with atmospheric oxygen. This oxidation forms a thin protective layer of brown-black copper oxide that prevents the bulk of the copper from being oxidised. In the absence of air copper is also resistant to many acids such as hydrochloric acid, sulphuric acid or acetic acid (Römpp, 2006).





[44] JRC elaboration on multiple sources (see next sections).

Figure 54: End uses (Gloeser et al., 2013a; ICA, 2012; SCRREEN, 2019)and EU sourcing of copper (ore stage), average 2012–2016

In most applications it is used for its very high thermal and electrical conductivity in combination with ductility and corrosion resistance. Today copper is the most frequently used heavy non-ferrous metal. It is used as pure metal but often also in form of its two common alloys: brass and bronze.

For the purpose of this assessment copper at both mine stage and processing stage are analysed. At mine stage, copper is assessed in the form of "ores and concentrates". At this stage copper is traded as concentrate. Depending on the source ores, their mineral assemblages, and the concentration technology, also the copper concentrates show a wide range of copper content, from about 10 to40% (Langner, 2011; Da Silva, 2019; Salomon-de-Friedberg and Robinson, 2015). For the calculation of the criticality assessment, an estimated average of 20% copper was assumed contained in the trade flows (CN 2603 00 00). At processing stage, refined copper is estimated as pure, with trade flows „refined copper" showing at least 99,85% by weight (CN 7403 11 00).[45]

The world mine production of copper in 2017 was 20 Mtonnes, while the world marked of refined copper was about 24 Mtonnes (ICSG, 2019a). Three commodity exchanges provide the facilities to trade copper: The London Metal Exchange (LME), the Commodity Exchange Division of the New York Mercantile Exchange (COMEX/NYMEX) and the Shanghai Futures Exchange (SHFE). The average price of grade A copper on the London Metal Exchange between 2011 and 2015 was 7,292.49 USD per tonne. The volatility of the price was relatively low in that period (DERA, 2016).

The average EU apparent consumption of copper in the period between 2012 and 2016 was about 2.57 Mtonnes per year. Major end uses were components and households (22%), tubes, plates and wire (21%), machinery (15%), digital appliances (14%), ships, trucks and armored vehicles (10%), and automotive (6%).
The biggest share of the refined copper supply was sourced from within the EU, namely the following member states (Figure 54): Germany (22%), Poland (18%), Spain (13%) and Belgium (13%). They made up two thirds of the average total sourcing for the period 2012-2016. By far the largest non-EU supplier was Russia (7%), followed by Kazakhstan, United Kingdom, Serbia and South Africa (each 1%). The world's main producers of refined copper, China, Chile and Japan, seem to direct their refined copper to other destination outside the EU or use the commodity themselves.

Due to its unique properties, copper is crucial for many applications. Copper is the best electrical conductor after silver and is used in the production of energy-efficient power circuits. As it is also corrosion resistant, ductile and malleable, it is mainly applied in all types of wiring; from electric energy supply from the power plant to the wall socket, through motor windings for electrical motors, to connectors in computers.

Copper is used in many forms in buildings including wiring, pipes and fittings, electrical outlets, switches and locks. It is corrosion resistant, antibacterial and impermeable and thus has been used in the production of water pipes for at least 4500 years (ECI, 2016a). Copper roofing is another common application where it is used for its functionality and architectural characteristics (ECI, 2016a).

[45] EU trade is analysed using product group codes. It is possible that materials are part of product groups also containing other materials and/or being subject to re-export, the "Rotterdam-effect". This effect means that materials can originate from a country that is merely trading instead of producing the particular material.

Copper and its alloys, mainly brass and bronze, are important raw materials for many kinds of mechanical parts such as sleeve bearings and other forged parts (CDA, 2016). In the automotive and transport sector, copper is an essential metal; there is an average 25 kg copper in every car. Aside from its use in electrical parts, copper is used in heat exchangers and radiators due to its high thermal conductivity. The development of modern hybrid cars – in which an electrical motor supports the combustion engine - leads to an even higher copper consumption in cars (ECI, 2016a).

For the main applications possible substitutes are as follows (Glöser *et al.*, 2013b; BGS, 2007):

- in electrical applications, aluminium can replace copper wiring, though it is prone to conduction loss through corrosion
- in telecommunications, cables made from optical fibres can substitute for copper wire
- for pipes and plumbing fixtures, plastics can replace copper
- for heat exchangers, titanium, stainless steel, aluminium or plastics can substitute for copper, depending on the requirements of the application (temperature, aggressive fluids, etc.).

Copper is essential for low-carbon technologies in the broad areas of transport (energy infrastructure, hybrid & electric vehicles and associated charging infrastructure); wind power (cabling and temperature control within wind turbines); solar power (heat exchangers of solar thermal systems, photovoltaic panels), tidal generation (ECI, 2012; Euromines, 2019a)

2014 USGS global assessment indicated that global identified copper resources contained about 2,100 Mtonnes of copper (porphyry deposits accounted for 1,800 Mtonnes of those resources), and undiscovered resources contained an additional estimated 3,500 Mtonnes (USGS, 2019). Europe has significant copper deposits such as resources of about 34 Mtonnes of copper in Poland (USGS, 2013). The world known reserves of copper amount 830 Mtonnes (USGS, 2019), mainly located in America (Chile, USA, Peru and Mexico).

Resources and reserves data are available for several countries in Europe at the European Minerals Yearbook (see Table 28, Table 29) (Minerals4EU, 2019). EU resources are located in Poland, Spain, Ireland, Sweden and Finland

Global production of copper between 2012 and 2016 amounted to 22.0 Mtonnes per year in average. The global production of refined copper is rising since the beginning of data recording, reaching an all-time high of 23.5 Mtonnes in 2017 (ICSG, 2019a).

Most of the copper is used in its metallic form or in copper alloys. Thus, nearly all copper products can be recycled over and over again without loss in product properties (DKI, 2016). Only very minor copper usages are dissipative, like copper in fungicides.

Most of the recycled copper originates from scrap different than end-of-life scrap (i.e. new or old primary scrap). Depending on its impurity content, the scrap must be conditioned and is then used for smelting and casting new products (Lossin, 2001).

The end-of-life recycling input rate for copper in the EU is estimated to be 17% for the criticality assessment.

There are no export quota or prohibition in place between the EU and its suppliers (OECD, 2016). Export taxes have been raised by two EU suppliers of copper concentrates: Indonesia (20-60%, eliminated in 2016) and Argentina (10%, eliminated in 2016). Also two EU suppliers

applied export tax on refined copper: 10%[46] in China and 10% in Russia (eliminated in 2014) (OECD, 2018).

6.2 Market analysis, trade and prices

6.2.1 Global market analysis and outlook

The copper price formation takes place predominantly in three commodity exchanges: The London Metal Exchange (LME), the Commodity Exchange Division of the New York Mercantile Exchange (COMEX/NYMEX) and the Shanghai Futures Exchange (SHFE). On the LME, copper is traded in 25 tonne lots and quoted in US dollars per tonne; on COMEX, copper is traded in lots of 25,000 pounds and quoted in US cents per pound; and on the SHFE, copper is traded in lots of 5 tonnes and quoted in Renminbi per tonne. More recently, mini contracts of smaller lots sizes have been introduced at the exchanges.(ICSG, 2019a) The exchanges facilitate to hedge, store and to a limited degree also trade copper.

According to Marscheider-Weidemann et al. (2016) copper demand will grow in the coming decades. As electric vehicles imply increased copper demand, the shift from cars with combustion engines to electric vehicles will amplify that demand from the transport sector (SGU 2019). The usage of electrical motors in both industrial applications and electrical vehicles thus will lead to additional demand for copper.

Given the global volume of identified and undiscovered resources (USGS, 2019), there is good evidence that global reserves of copper can continue to meet expected demand increases. For a qualitative forecast of supply and demand of copper see Table 25.

Table 25: Qualitative forecast of supply and demand of copper

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Copper		x	+	+	+	+	+	+

6.2.2 EU trade

For the purpose of this assessment copper at both mine stage and processing stage are analysed. At mine stage, copper is assessed in the form of "ores and concentrates", with an estimated average of 20% copper contained in the trade flows (CN2603 0000)[47]. As copper is commonly not traded as ore, but in the form of concentrates (and mattes), the average percentage and the following figures refer to concentrates.

The average EU imports of copper ores and concentrates for the period 2012-2016 amounted to 766 ktonnes. The EU imported from 24 supplier countries, many of them with very minor tonnages (practically all in form of concentrates). According to Eurostat ComExt data, the main countries, from which the EU imported, were Chile (27%), followed by Peru (19%) and Brazil

[46] For 99.9999%>copper content>99.9935%, a reduced export tax of 5% was applied.

[47] EU trade is analysed using product group codes. It is possible that materials are part of product groups also containing other materials and/or being subject to re-export, the "Rotterdam-effect". This effect means that materials can originate from a country that is merely trading instead of producing the particular material.

(14%), related to the average for the period 2012-2016. Other notable originating countries were Argentina and Canada (each 7%), United States (5%). The shares of the importers are shown in Figure 55.

Within the EU, major international importers of ores and concentrates are Germany, Bulgaria, and Finland (ICSG, 2019a).

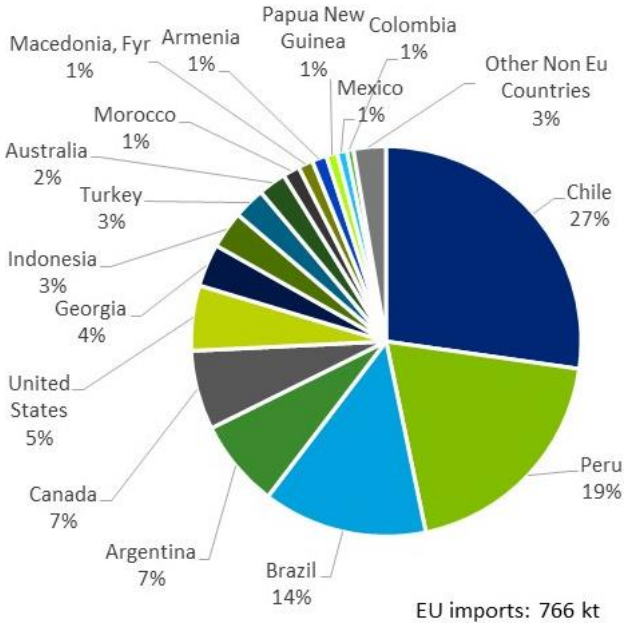


Figure 55: EU imports of copper ores and concentrates, average 2012-2016 (Eurostat, 2019a)

For the period 2012-2016, the EU is a clear net importer of copper ores and concentrates (Figure 56).

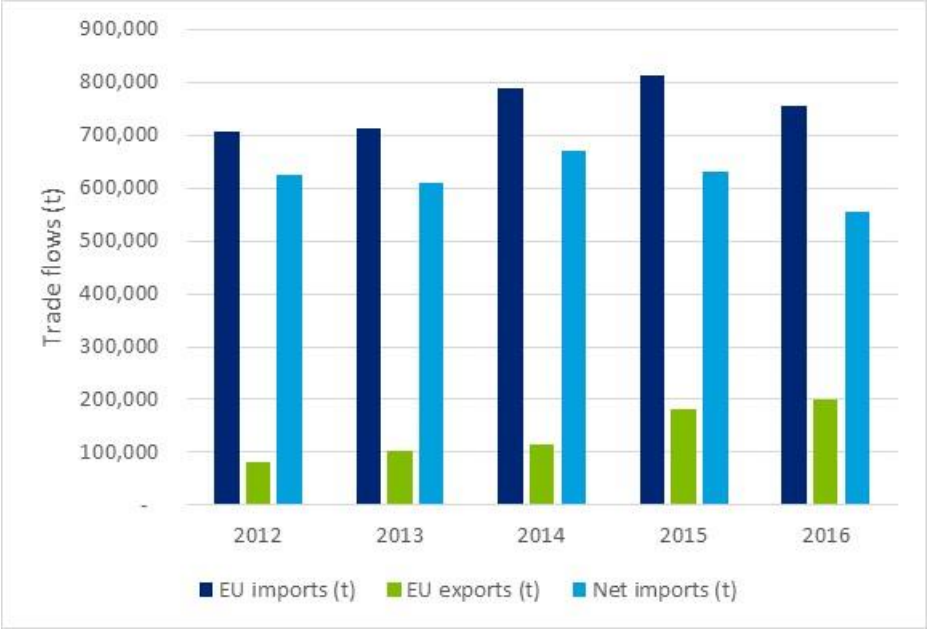


Figure 56: EU trade flows for copper ores and concentrates 2012-2016 (Eurostat Comext, 2019a)

The EU imported for the period 2012-2016 in average 334 ktonnes per year of refined copper. Russia is by far the most important supplier of refined copper to the EU, taking almost 67%, or 224 ktonnes per year, of the import share to the EU (Figure 57). Kazakhstan and United Kingdom follow with 10% and 6%, respectively, while the imports from the UK are re-exports (Euromines, 2019b). The world's main producers of refined copper, China, Chile and Japan, seem to direct their refined copper production to other destination outside the EU or use the commodity themselves.

Germany, Italy and the Netherlands are among the major international importers of refined copper, while the Netherlands is also among the major exporters of refined copper (ICSG, 2019).

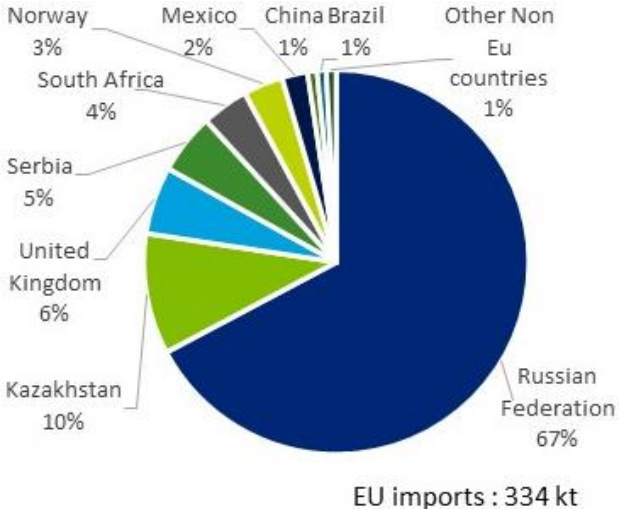


Figure 57: EU imports of refined copper, average 2012-2016 (Eurostat, 2019a)

In the period 2012-2016, the EU foreign trade pattern of refined copper changed basically. While the exports almost halved (-44%), the imports almost doubled (+88%). This way the EU changed from a net exporter (about 350 ktonnes per year in 2012 and 2013) to a net importer (140 ktonnes per year in 2016).

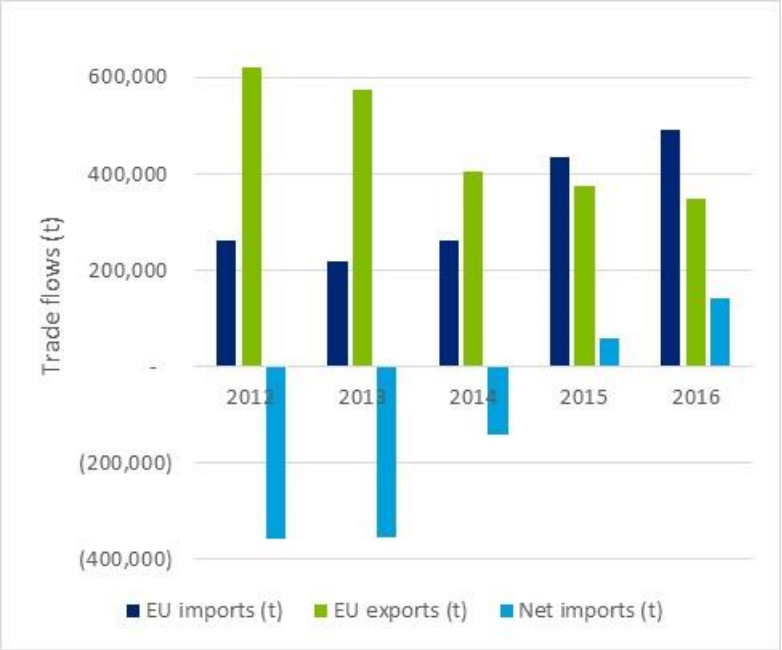


Figure 58: EU-27 trade flows for refined copper 2012-2016 (Eurostat, 2019a)

There are no export quota or prohibition in place atthe suppliers of the EU (OECD, 2018). Export taxes have been raised by two EU suppliers of copper concentrates: Indonesia (20-60%, eliminated in 2016) and Argentina (10%, eliminated in 2016). Also two EU suppliers applied export tax on refined copper: China (10% [48]) and Russia (10%, eliminated in 2014) (OECD, 2018).

6.2.3 Prices and price volatility

Important trading platforms are the London Metal Exchange (LME), the New York Commodities Exchange (COMEX), the Shanghai Futures Exchange (SHFE). Commonly, copper prices are determined by supply and demand. Copper is the industry metal that is considered being traded most intensely. Further factors influencing the price are exchange rates, speculations, and information on production downtimes (DERA, 2013).

Figure 59 shows how the global supply and demand influenced copper prices during the last century (DERA, 2013). There have been several price peaks: the first one due to the First World War and the second due to the Vietnam War. However, in the early 1970s, demand from the military was still so high that prices went up dramatically, until the first oil crisis induced a price decrease. Between 2003 and 2011 (Euromines, 2019b), an economic boom in Asia, low production figures and low copper stocks led to an excess of demand over supply, implying a significant price increase. Since then the global recession has reduced demand and hence prices (Figure 60).

[48] For 99.9999%>copper content>99.9935%, a reduced export tax of 5% was applied.

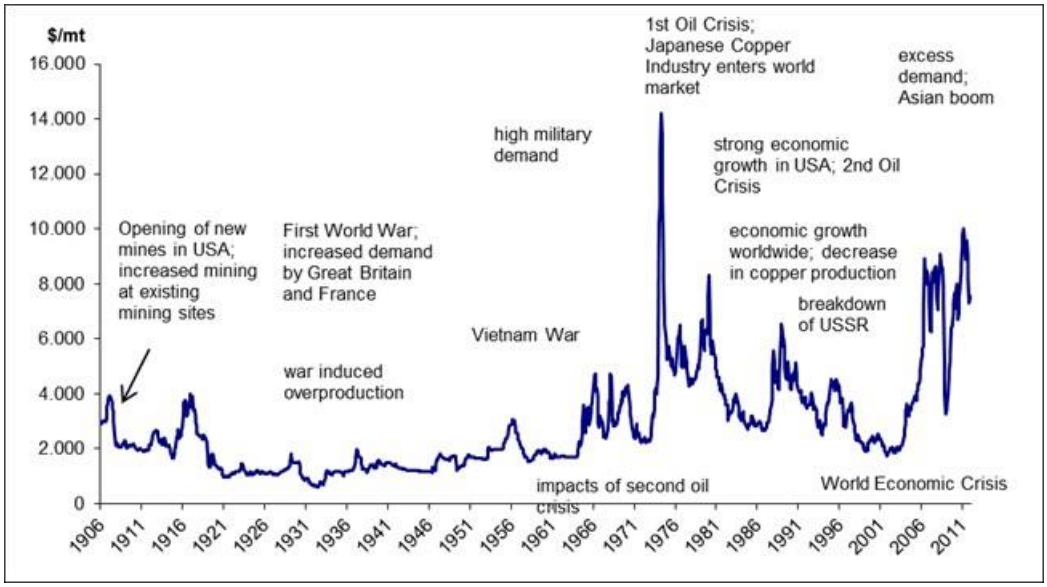


Figure 59: Global developments in price of copper (constant prices), average 1906-2013 (DERA, 2013, translated to English by Fraunhofer ISI)

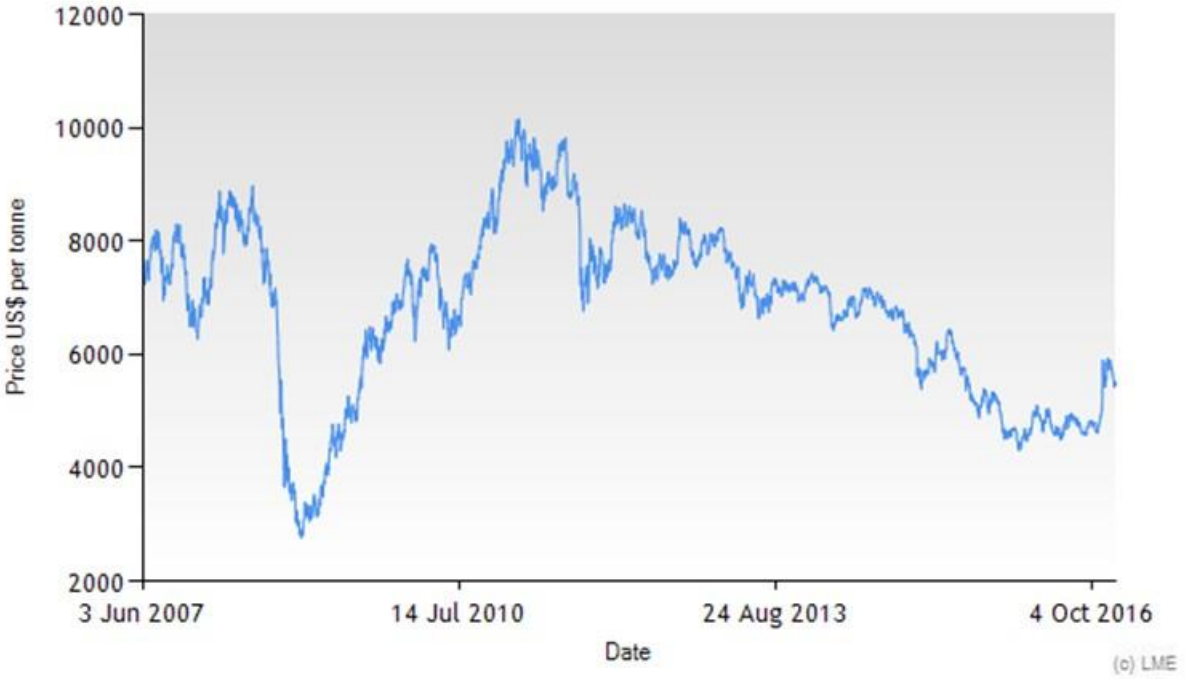


Figure 60: Monthly average cash price for copper in USD per tonne (LME, 2017)

The average price of grade A copper[49] on the London Metal Exchange between 2014 and 2018 was 5,982.04 USD per tonne. The volatility of the price was relatively low in that period (15%)(DERA, 2019a). The price decreased slightly in the period October 2017 to October 2019, reaching 5.742,00 USD per tonne in October 2019 (Figure 61) (DERA, 2019b).

[49] LME, grade A, cash, in LME warehouse

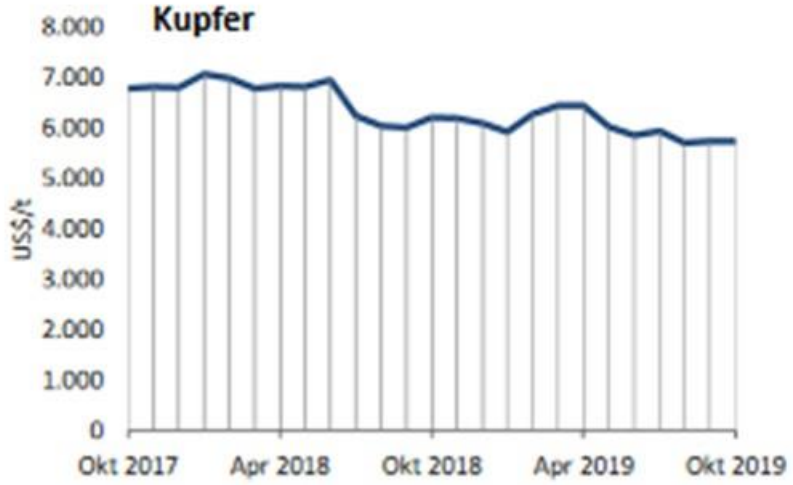


Figure 61: Monthly average cash price for copper in USD per tonne (DERA, 2019b)

The long-term prices of copper are shown in Figure 62. The price curve shows real prices.



Figure 62: Copper prices in USD per tonne. Vertical dashed line indicate breaks in price specification.(Buchholz *et al.,* 2019)

6.3 EU demand

Generally, the annual global demand in copper has been increasing consecutively since the 1950s. In 2018, the global apparent consumption of copper has reached a maximum of 24.5 Mtonnes pear year.(ICSG, 2019a)

6.3.1 EU demand and consumption

The apparent EU consumption of refined copper was about 2.6 Mtonnes per year on average between 2012 and 2016, which was also used for the criticality assessment. The International Copper Study Group suggests a larger use of refined copper, 4.1 Mtonnes in 2016 (ICSG, 2019b).

6.3.2 Uses and end-uses of Copper in the EU

Copper is crucial for several applications due to its unique properties. It is the best electrical conductor after silver and is used in the production of energy-efficient power circuits. As it is

also corrosion resistant, ductile and malleable, its main application is in all types of wiring; from electric energy supply from the power plant to the wall socket, through motor windings for electrical motors, to connectors in computers.

Copper is used in many forms in buildings including as wiring, pipes and fittings, electrical outlets, switches and locks. It is corrosion resistant, antibacterial and impermeable and thus has been used in the production of water pipes for at least 4,500 years (ECI, 2016a). Copper roofing is another common application where it is used for its functionality and architectural characteristics (ECI, 2016a).

Copper and its alloys, mainly brass and bronze, are important raw materials for many kinds of mechanical parts such as sleeve bearings and other forged parts (CDA, 2016). In the automotive and transport sector, copper is an essential metal; on average there are 25 kg copper in every car. Aside from its use in electrical parts, copper is used in heat exchangers and radiators due to its high thermal conductivity. The development of modern hybrid cars – in which an electrical motor supports the combustion engine – leads to an even higher copper consumption in cars (ECI, 2016a).

The end uses of copper are shown in Figure 63.

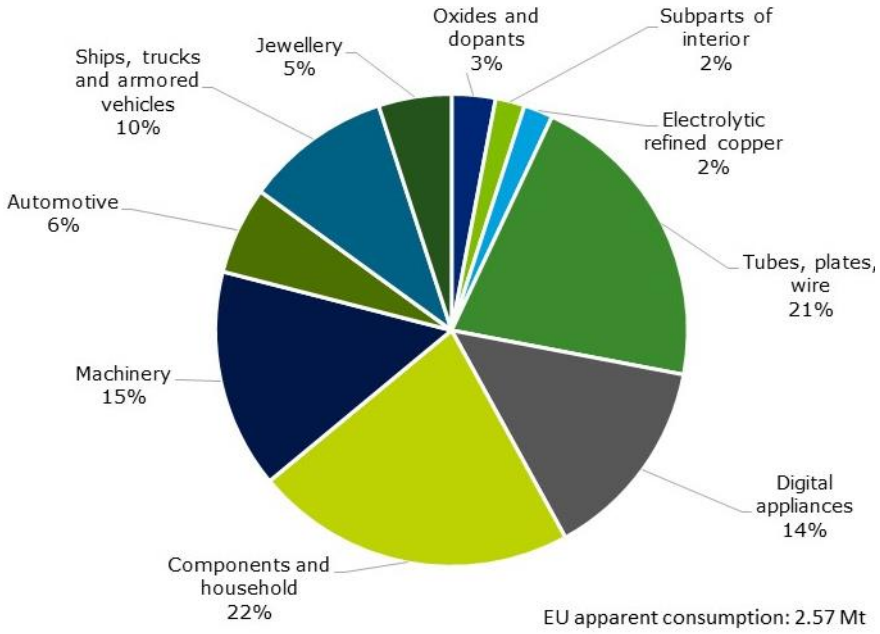


Figure 63: EU end uses of copper. Average figures for 2012-2016 (Gloeser *et al.* 2013a; ICA, 2012; SCRREEN, 2019)

For comparison purposes, Figure 64 shows the global end use sectors in 2018.

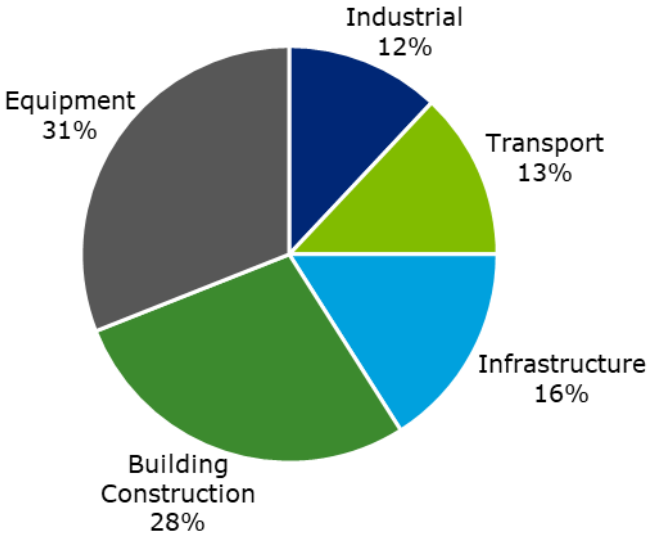


Figure 64: Global end use sectors of copper in 2018 (ICSG, 2019a).

Relevant industry sectors are described using the NACE sector codes (Eurostat, 2016c). The calculation of economic importance is based on the use of the NACE 2-digit codes and the value added at factor cost for the identified sectors (Table 26).

Table 26: Copper applications, 2-digit NACE sectors, associated 4-digit NACE sectors, and value added per sector (Eurostat, 2019c)

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (millions €)
Oxides and dopants	C20 - Manufacture of chemicals and chemical products	C20.13 - Manufacture of other inorganic basic chemicals	105,514
Electrolytic refined copper	C24 - Manufacture of basic metals	C24.20 -Manufacture of tubes, pipes, hollow profiles and related fittings, of steel	55,426
Tubes, plates, wire	C25 - Manufacture of fabricated metal products, except machinery and equipment	C25.91 - Forging, pressing, stamping and roll-forming of metal; powder metallurgy	148,351
Digital appliances	C26 - Manufacture of computer, electronic and optical products	C26.11 - Manufacture of electronic components	65,703
Components and household	C27 - Manufacture of electrical equipment	C27.32 -Manufacture of other electronic and electric wires and cables	80,745
Machinery	C28 - Manufacture of machinery	C28.15 -Manufacture of bearings, gears, gearing	182,589

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (millions €)
	and equipment n.e.c.	and driving elements	
Automotive parts	C29 - Manufacture of motor vehicles, trailers and semi-trailers	C29.20 - Manufacture of bodies (coachwork) for motor vehicle	160,603
Ships, trucks and armoured vehicles	C30 - Manufacture of other transport equipment	C30.20 -Manufacture of railway locomotives and rolling stock	105,514
Subparts of interior	C31 - Manufacture of furniture	C31.01 -Manufacture of office and shop furniture	26,171
Jewellery	C32 - Other manufacturing	C32.11 - Manufacture of jewellery and related articles	39,160

6.3.3 Substitution

The unique properties of copper make it difficult to substitute in various applications, especially due to its thermal and electrical conductivity. For main applications possible substitutes are as follows (Glöser *et al.*, 2013b; BGS, 2007; USGS, 2019):

- in electrical applications, aluminium can replace copper in electrical equipment like wiring or power cables though it is prone to conduction loss through corrosion;
- in telecommunication applications, cables made from optical fibres can substitute for copper wire;
- for pipes and plumbing fixtures, plastics can replace copper, for example in and water pipes, plumbing fixtures, and drain pipes;
- for heat exchangers, titanium, stainless steel, aluminium or plastics can substitute for copper, depending on the requirements of the application (temperature, aggressive fluids, etc.). For example, aluminum can substitutes copper in automobile radiators, or cooling and refrigeration tubes.

For each application, the sum of the shares of the substituting materials are assumed to make up 50%. This is rather a high estimate, since there are relatively few technical impediments (Tercero Espinoza *et al.*, 2013) to substitute copper as described above. The substitution decision is commonly based on an economic and technical performance of the substitute.

6.4 Supply

The copper flows through the EU economy are shown in Figure 65.

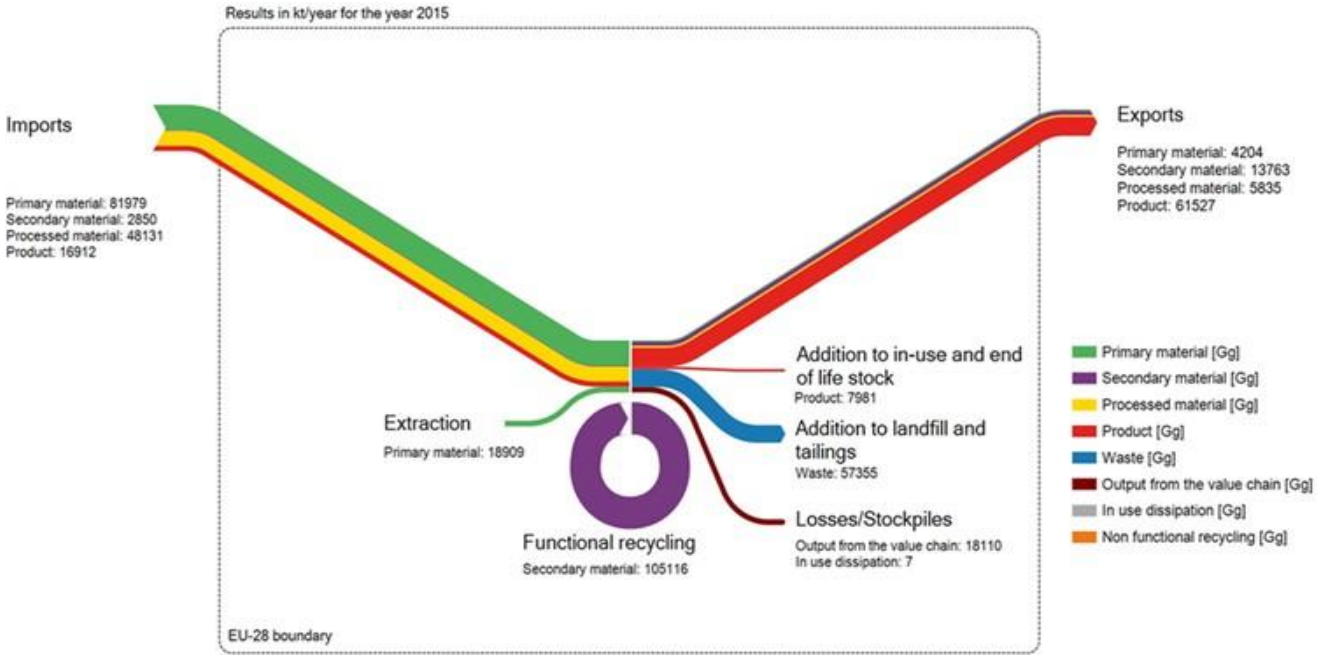


Figure 65: Simplified MSA of copper flows in the EU in 2014 (Passarini *et al.*, 2018)

6.4.1 EU supply chain

Mining activity in the EU mainly takes place in Poland, Spain, Bulgaria, Sweden, Portugal, and Finland. In addition, small amounts are mined in Romania, Cyprus and Slovakia. The total mining production was 792 ktonnes per year on average annually between 2012 and 2016. Further minor amounts of copper mining in Europe are reported in Serbia and Albania.(WMD, 2019)

In 2016, the EU's refined copper production was 2.71 Mtonnes, representing 12% of worldwide production (BGS, 2019). The main copper refinining member states are Germany, Poland, Spain, and Belgium. The final products from smelting and refining (copper cathodes) are made through electrolytic processes. These are either sold directly into the market, or melted and cast into shapes, typically referred to as billets and cakes, for easier processing by downstream users (ECI, 2016b).

Further downstream in the EU, many companies operate in the semi-fabricated products sector. About 80 companies, employing some 35,000 people throughout the EU-28, produce copper and copper alloy rods, bars, wires, sections, tubes, sheet and strip. Around 30 companies have integrated foundries, for the in-house production of cakes, billets and other shapes while the others purchase their requirements on the merchant market (ECI, 2016b).

At the ores and concentrate stage, the import reliance of the EU is 44%. Figure 66 presents the EU sourcing (domestic production plus imports) for copper concentrates. At the metal stage, there is no import reliance as EU exports exceed the imports.

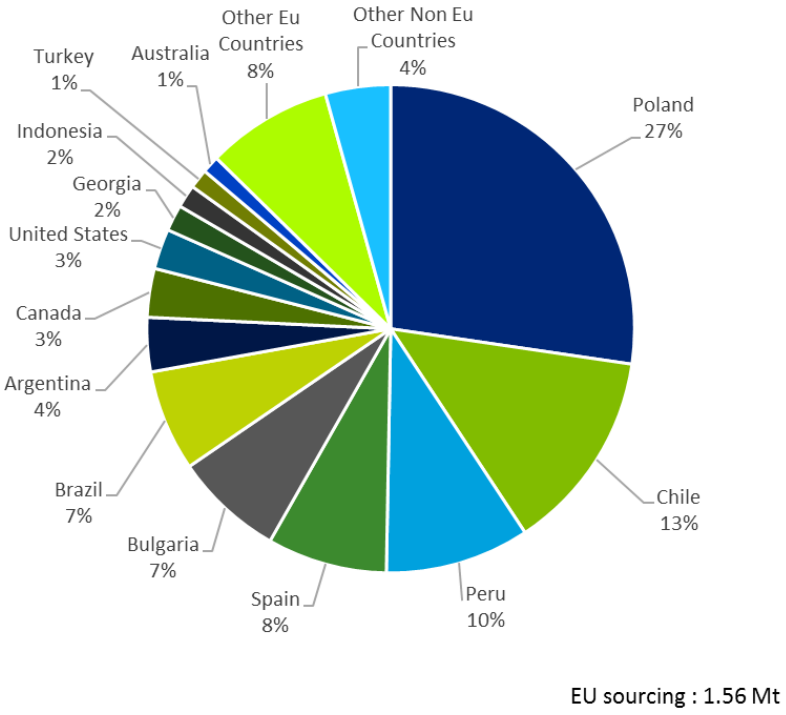


Figure 66: EU sourcing (domestic production plus imports) of copper ores and concentrates, average 2012-2016 (WMD, 2019; Eurostat, 2019a).

Several countries have restrictions concerning trade with copper ores and concentrated (OECD, 2016). According to the OECD´s inventory on export restrictions, Indonesia and Mongolia show export taxes bigger than 25%. Further countries with export taxes on ores and concentrates are Zambia (15%), China (10%), Democratic Republic of Congo (DRC) (10%), and Argentina (10%). Several of these countries also require a licensing agreement. Indonesia has shifted its export tax in 2012 several times (even prohibited exports temporarily), only to remove restrictions afterwards. Indonesia has issued an export ban for a couple of months in 2014, with partial lifts of the bans after that time. Of the countries listed, only Argentina and Indonesia have been EU suppliers in the period 2012-2016.

Less countries have restrictions in place concerning trade with refined copper: China, Russia and DRC apply export taxes below 25% on refined copper, of which only China and Russia exported to the EU in the period 2012-2016. There is also a wide range of other countries imposing trade restrictions on products with a high percentage of copper content.

6.4.2 Supply from primary materials

6.4.2.1 Geology, resources and reserves of copper

Geological occurrence: The presence of copper in the earth's crust ranks it as a moderately present element, with 28 parts per million upper crustal abundance (Rudnick & Gao, 2014). Copper combines with numerous elements and more than 150 copper minerals have been identified (BGS, 2007). The most important minerals for copper extraction are chalcopyrite ($CuFeS_2$) and chalcocite (Cu_2S). Further relevant copper minerals are chrysocolla ($Cu_4H_4[(OH)_8|Si_4O_{10}] \cdot n\ H_2O$) and malachite ($Cu_2[(OH)_2|CO_3]$)(MEC, 2019). Copper is one of the few metals that occurs sometimes in nature in a directly usable metallic form ("native metal").

Copper deposits are found worldwide in a variety of geological environments (BGS, 2007). Hydrothermal deposits are most significant on a global scale, although magmatic and supergene deposits are locally important. Porphyry copper deposits are currently the world's main source of copper (50-60% of world production), with copper grades generally from 0.2% to > 1% (BGS, 2007). They occur in Canada, Chile, Indonesia, Philippines and Papua New Guinea but also in Sweden, Greece and Bulgaria. Sediment-hosted deposits, mainly located in the Central African Copperbelt, but also Poland and Germany, are the world's second most important source of copper (about 20% of world production), grading about 2% copper. Volcanogenic massive sulphide (VMS) deposits are also important sources of copper, with grades at 1% copper (BGS, 2007). A major VMS deposit currently mined is Cobre Las Cruces, Andalusia, Spain.

The Minerals4EU (2019) reports that some exploration projects in Europe for copper are done in Greenland, UK, Spain, Portugal, Sweden, Switzerland, Macedonia, Kosovo, Albania, Ukraine, Poland, Czech Republic, Slovakia, Hungary and Romania. Moreover, Greece and Bulgaria are major porphyry copper targets, with two significant exploration projects going on.

Global resources and reserves [50] : 2014 USGS global assessment of copper deposits indicated that identified resources contain about 2,100 Mtonnes of copper (porphyry deposits accounted for about 1,800 Mtonnes of those resources), and undiscovered resources contained an estimated 3,500 Mtonnes (USGS, 2019a).

The world known reserves of copper amount to 830 Mtonnes (USGS, 2019), mainly located in America (Chile, Peru, Mexico and USA), see Table 27. Further extensive reserves are also reported for Australia, Russia and Indonesia.

Table 27: Global reserves of copper in year 2019 (USGS, 2019).

Country	Copper reserves (Mt)	Percentage of total (%)
Chile	170	21
Australia	88	11
Peru	83	10
Russia	61	7
Indonesia	51	6
Mexico	50	6
United States	48	6
China	26	3
Dem. Republic Congo	20,000,000	2
Zambia	19	2
Other countries	210	25
World total (rounded)	830	100

[50] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of copper in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template.[50], which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

EU resources and reserves[51] *:* Europe has significant copper deposits in Poland with resources of about 34 Mtonnes of copper (USGS, 2013). Resource data for some countries in Europe are available in the Minerals4EU (2019) website (see Table 28) but cannot be summed as they are partial and they do not use the same reporting code.

Table 28: Resource data for the EU compiled in the European Minerals Yearbook (Minerals4EU, 2019).

Country	Reporting code	Quantity	Unit	Grade	Code Resource Type
Albania	Nat. rep. code	66,703	Mt	1-4%	Cat A
Czech Republic	Nat. rep. code	49	kt	0.45%	Potentially economic
Finland	NI43-101 JORC	342 521	Mt Mt	0.23% 0.13%	Measured Measured
Greece	USGS	2.8	Mt	-	Measured
Hungary	Russian Classification	129.7	Million m^3	1.71 t/m^3	A+B
Ireland	None	14.13	Mt	0.85%	Historic Resource Estimates
Macedonia	Ex - Yugoslavian	35.3	Mt	0.42%	A
Norway	NI43-101 JORC	4.63 10.65	Mt Mt	0.12% 1.03%	Indicated Indicated
Poland	Nat. rep. code	32.8	Mt	1.93%	A+B+C1
Portugal	NI43-101	33.95	Mt	1.68%	Measured
Romania	UNFC	448	Mt	-	333
Serbia	NI43-101	65.3	Mt	2.6%	Inferred
Slovakia	None	43.92	Mt	0.72%	Not specified
Spain	Various	17.97	Mt	0.99%	Measured
Sweden	NI43-101 JORC FRB-standard	5.02 0.493 528.9	Mt Mt Mt	2.2% 0.7% 0.21%	Measured Measured Measured
Turkey	NI43-101 JORC	4.46 36.26	Mt Mt	2.67% 1.95%	Measured Measured
UK	NI43-101 JORC	0.023 2.114	Mt Mt	0.02% 0.58%	Measured Indicated
Ukraine	Russian Classification	31.1	kt	-	P1

[51] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for copper. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for copper, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for copper the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019).Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However a very solid estimation can be done by experts.

Reserve data for some countries in Europe are available at the Minerals4EU website (see Table 29) but cannot be summed as they are partial and do not use the same reporting code.

Table 29: Reserve data for the EU compiled in the European Minerals Yearbook (Minerals4EU, 2019)

Country	Reporting code	Quantity	Unit	Grade	Code Reserve Type
Finland	NI43-101 JORC	1.5 189	Mt Mt	0.27% 0.8%	Proved Proven
Macedonia	Ex - Yugoslavian	35.31	Mt	0.42%	A
Poland	Nat. rep. code	23.67	Mt	-	Total
Portugal	NI43-101	16.52	Mt	1.82%	Proven
Romania	UNFC	98	Mt	-	121
Spain	various	10.13	Mt	2.58%	Proven
Sweden	NI43-101 FRB-standard	3.8 516.2	Mt Mt	2.2% 0.24%	Proven Proven
Turkey	NI 43-101	4.49	Mt	3.02%	Proven

6.4.2.2World and EU mine production

The annual global production of copper ore between 2012 and 2016 was 18.7 Mtonnes per year on average. Figure 67 shows that Chile is the leader in world copper mining, with about 5.7 Mtonnes per year in the period 2012-2016, accounting for almost one third of world mine production. Together with China (9%), Peru (9%), and the USA (7%), the four largest mining countries share more than half of the world mine production. In recent decades there has been a strong growth in production in South America, mainly in Chile (from 16% in 1985 to 30% of world production today) (BGS, 2007; WMD, 2019). Asian production is also growing (e.g. China's production increased from less than 4% in 1994 to 9% today) (USGS, 2019a; WMD, 2019). Many of the world's largest copper mines are located in the American Cordillera: *Escondida* and *Collahuasi* in Chile are the two mines with the largest production capacity in 2019, followed by *Buenavista del Cobre* in Mexico, *Morenci* in the United States, and by *Cerro Verde II* and *Antamina* in Peru (ICSG, 2019a).

European mine production is dominated by the production in Poland which accounts for over half of copper mining in Europe (WMD, 2019).

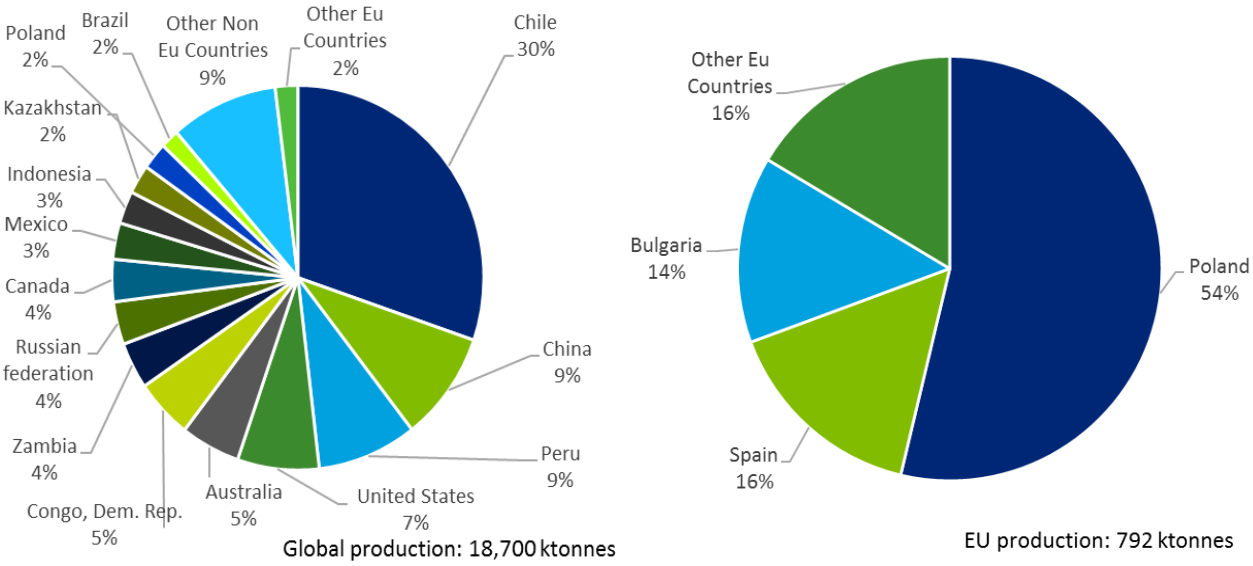


Figure 67: Global and EU mine production of copper, average 2012-2016 (WMD, 2019)

6.4.3 Supply from secondary materials/recycling

Most of the copper is used in its metallic form or in copper alloys. Thus, nearly all copper products can be recycled over and over again without loss in product properties (DKI, 2016). Secondary copper constitutes a significant input to the processing. Globally, 8,400 ktonnes of copper were recycled in 2017 (ICSG, 2019a). As European mined copper is not sufficient to meet demand, the EU is highly dependent on refining and on smelting imported concentrates as well as on recycling production scrap and end-of-life products (BGS, 2007). In the EU, the processing included 1,959 ktonnes of secondary copper in 2014, the majority of which originating from domestic EU manufacturing (47%) and end-of-life collection and recycling (37%) (Passarini *et al.*, 2018).

6.4.3.1 Post-consumer recycling (old scrap)

End-of-life recycling input rate (EoL-RIR) for copper is estimated at 17% for the criticality assessment, based on the results of the Material System Analysis on copper (Table 30) (Ciacci *et al.*, 2018). This value is used for the criticality assessment.

The global ten year-average (2008-2017) of the EoL-RIR is 17% and supports the order of magnitude also for the EU (ICSG, 2019a).

Table 30: Material flows relevant to the EoL-RIR of copper

MSA Flow	Value (t)
B.1.1 Production of primary material as main product in EU sent to processing in EU	356’215
B.1.2 Production of primary material as by product in EU sent to processing in EU	0
C.1.3 Imports to EU of primary material	2’621’444
C.1.4 Imports to EU of secondary material	305’484
D.1.3 Imports to EU of processed material	300’492
E.1.6 Products at end of life in EU collected for treatment	2’625’328
F.1.1 Exports from EU of manufactured products at end-of-life	595
F.1.2 Imports to EU of manufactured products at end-of-life	0
G.1.1 Production of secondary material from post consumer functional recycling in EU sent to processing in EU	729’568
G.1.2 Production of secondary material from post consumer functional recycling in EU sent to manufacture in EU	0

Values from primary material input, recycled end-of-life material, scrap used in fabrication (new and old scrap) and scrap used in production (new and old scrap), found in (UNEP, 2011), imply a much higher EoL-RIR (55%).

6.4.3.2Industrial recycling (new scrap)

Most of the recycled copper originates from scrap different than end-of-life scrap (i.e. new scrap). Depending on its impurity content, the scrap must be conditioned and is then used for smelting and casting new products (Lossin, 2001).

6.4.4 Processing of Copper

There are three main techniques for mining copper: open pit mining, underground mining and leaching operations (heap leaching, and to a minor extent also in-situ leaching)(Euromines, 2019b). Open pit mining is the most common form and appropriate for low grade ores that are close to the surface (< 100 m). For example the open pit copper mines at Bingham Canyon in Utah, USA, and Chuquicamata in Antofagasta, Chile, belont to the largest man-made excavations in the world. Underground mining is suitable for higher grade ores and carried out for example in the Lubin mine, Poland. With in-situ leaching a weak sulphuric acid leach solution is pumped through lower grade ore bodies to dissolve copper. This technique is used for example in the Mufulira mine (Mopani Copper Mines) in the Zambian Copperbelt.

Mined ores generally contain 0.5 to 3% copper. The first phase in processing the ore is concentration which increases the copper content to 25 to 35%. This is carried out at the mine site, involving crushing and grinding, followed by physical processing and separation stages. The conversion into pure copper is done using two techniques: pyrometallurgical processes (including smelting and electrolytic refining) and hydrometallurgical processes (including leaching, solvent extraction and electro-winning).

Figure 68 shows the production figures and the country shares of the global production and the EU production, respectively, of refined copper. The global production of refined copper is rising steadily since 2003, reaching an all-time high of 23.5 Mtonnes in 2017 (ICSG, 2019a).

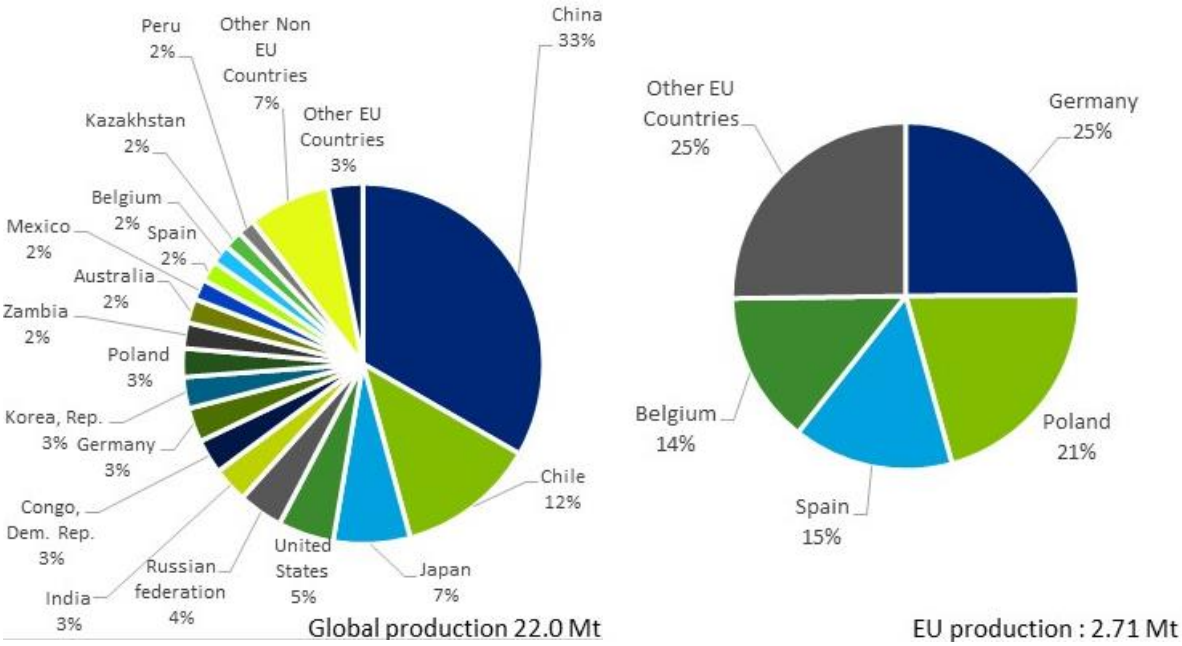


Figure 68: Estimation of global (left) and EU (right) production capacity of refined copper, average 2012-2016 (BGS, 2019; Eurostat, 2019a).

6.5 Other considerations

6.5.1 Environmental and health and safety issues

The REACH regulation has an impact on the use of copper in chemicals placed on the market. Despite improvements in accurate registration, authorisation and restriction of substances, industrial stakeholders' flag a need to assess risks from the manufacturing and use of hazardous substances and mixtures in a more evidence-based and less precautionary way (Eurometaux, 2016).

According to ICA (2019)[52], the recycling and reuse intensity of water at production sites has almost doubled from 2011 (192 m^3/tonne copper) to 2017 (382 m^3/tonne copper). In the same period, the carbon dioxide emissions intensity increased by 14% (3.7-4.2 tonnes CO_2/tonne copper), and so did the energy intensity (+18%). Several Copper Alliance members committed to use only renewable energy on site and to reduce fuel/energy use.(ICA, 2019)

Investments in equipment and training, but also application of the standard Occupational Health and Safety Assessment Series (OHSAS) 18001 resulted in significant industry-wide decrease of accidents. The injury rate is reported to have dropped from > 6.2 injuries per million hours worked (2011-2013) to < 4.8 injuries per million hours worked (2014-2017) (ICA 2019).

EU occupational safety and health (OSH) requirements exist to protect workers' health and safety. Employers need to identify which hazardous substances they use at the workplace,

[52] The International Copper Alliance (ICA) represents the primary copper producers, smelters, refiners and fabricators along the world's copper supply chain (https://copperalliance.org/ica-membership/ica-members/).

carry out a risk assessment and introduce appropriate, proportionate and effective risk management measures to eliminate or control exposure, to consult with the workers who should receive training and, as appropriate, health surveillance[53].

6.5.2 Socio-economic issues

The copper processing industry is a significant employer. On a global scale, the International Copper Alliance surveyed for its members employment of over 323,000 employees (ICA, 2019). In the EU many companies operate in the semi-fabricated products sector. About 80 companies, employing some 35,000 people throughout the EU-28, produce copper and copper alloy rods, bars, wires, sections, tubes, sheet and strip (ECI, 2016b).

Strikes of workers occasionally occur especially in Latin America, where some of the largest copper mines are located. The reasons are not only related to the mining business, but sometimes rooted deep in societal inequality (Jamasmie, 2019). For example, the Escondida mine, was hit in 2018 by the longest private sector mining strike in Chile (44-days). In addition, mines in Chile can also be affected by strikes in ports like in October 2019 when a strike in Escondida mine was superposed by strikes at various sea ports handling copper concentrates (including Iquique, Tocopilla, Antofagasta and Ventanas) (Bloomberg, 2019).

Within Europe, the price spikes after 2000 have infamously created theft of copper objects from the public space. Thieves stole copper parts and then sold the valuable scrap metal to recyclers. The lack of these copper objects then caused disruptions of infrastructure, in particular overhead contact lines of electricity driven trains, trams and trolleybuses, but also power cables. Similarly, copper claddings were stolen from public and non-public buildings.

6.6 Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. Supply risk has been analysed at both mine stage and processing stage. The higher supply risk is for the mine stage (copper ores and concentrates).

The results of this and earlier assessments are shown in Table 31.

Table 31: Economic importance and supply risk results for copper in the assessments of 2011, 2014, 2017, 2020 (European Commission, 2011; European Commission, 2014; European Commission, 2017)

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Copper	5.71	0.21	5.76	0.22	4.7	0.2	5.3	0.32

The results of copper are similar to the previous criticality assessments. The decrease in economic importance from 2014 to 2017 is linked to the methodological revision, allocating to NACE-2 digit sectors instead to the mega sectors. This change in methodology generally reduced the economic importance of materials used in metal products, in particular true for copper. The increase of the economic importance from 2017 to 2020 is caused primarily by

[53] https://ec.europa.eu/social/main.jsp?catId=148

economic developments. The increase in the supply risk from 2017 to 2020 is caused by a revision of the end-of-life recycling input rate.

6.7 Data sources

The data shows in general a very strong coverage. Data is available on EU level, for time series and updated at regular intervals. The data required is publicly available.

The product group describing the international trade of copper ores and concentrates is coded CN 2603 00 00, the one for refined copper is coded CN 7403 11 00.

6.7.1 Data sources used in the factsheet

BGS (2007). Commodity profile copper. [online] Available at: http://www.bgs.ac.uk/downloads/directDownload.cfm?id=1410&noexcl=true&t=Copper%20

BGS (2019). World mineral statistics data. [online] Available at: https://www.bgs.ac.uk/mineralsuk/statistics/wms.cfc?method=searchWMS, accessed 13.05.2019.

Bloomberg (2019). Chile Faces Mine Stoppages as Workers Join Protests. By Laura Millan Lombrana, 21.10. 2019. [online] Available at: https://www.bloomberg.com/news/articles/2019-10-21/copper-king-chile-faces-mine-stoppages-as-workers-join-protests, accessed at 17.11.2019.

Buchholz P., Wellmer F.W., Bastian D., Liedtke M. (2019) Leaning against the wind: Low price benchmarks for acting anticyclically in the metal markets. Mineral Economics. https://doi.org/10.1007/s13563-019-00199-y

CDA (2016). Copper Development Association inc. Applications – Machined products. [online] Available at: https://www.copper.org/applications/rodbar/

Da Silva, O. (2019). Types of Copper Deposits in the World. Investing News Network: Copper. 23.05.2019. Available at: https://investingnews.com/daily/resource-investing/base-metals-investing/copper-investing/types-copper-deposits-world/, accessed at 22.01.2020.

DERA (2013). DERA Rohstoffinformationen, Rohstoffrisikobewertung – Kupfer. Available at: http://www.deutsche-rohstoffagentur.de/DE/Gemeinsames/Produkte/Downloads/DERA_Rohstoffinformationen/rohstoffinformationen-16.pdf?__blob=publicationFile&v=7

DERA (2016). Pricelist of raw materials/ [online] Available at: http://www.bgr.bund.de/DE/Themen/Min_rohstoffe/Produkte/Preisliste/cpl_16_11.pdf?__blob=publicationFile

DERA (2019). Volatilitätsmonitor. Oktober 2019. [online] Available at: https://www.deutsche-rohstoffagentur.de/DERA/DE/Rohstoffinformationen/Rohstoffpreise/Volatilitaetsmonitor/volatilitaetsmonitor_node.html, accessed 17.11.2019.

DKI (2016) Deutsches Kupferinstitut/copperalliance Anwendungen für Kupfer und Kupferegierungen. [online] Available at: https://www.kupferinstitut.de/de/werkstoffe/anwendung.html

ECI (2012). The environmental profile of copper products. A 'cradle-to-gate' life-cycle assessment for copper tube, sheet and wire produced in Europe. www.copper-life-cycle.org

ECI (2016a). European Copper Institute. Curious about copper. [online] Available at: http://copperalliance.eu/docs/default-source/resources/curious-about-cu.pdf?sfvrsn=2

ECI (2016b). European Copper Institute. The EU copper industry structure. [online] Available at: http://copperalliance.eu/industry/structure

Eurometaux (2019). Information on copper recycling. Personal communication, 27.06.2019.

Euromines (2019a). The raw materials contribution to the implementation of the EU Sustainable Finance Action Plan. Euromines position paper on the draft Regulation establishing the framework to facilitate sustainable investment (www.euromines.org)

Euromines (2019b). Information on copper imports. Personal communication, 25.10.2019.

European Commission (2011). Critical raw materials for the EU. [online] Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission (2014). Report on critical raw materials for the EU – Non Critical raw materials profiles.

European Commission (2016). DG Trade. Agreements [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/

Eurostat (2019a). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2019b). Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2019c). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

Glöser, S., Marcel Soulier, M., Tercero Espinoza, L., (2013b). Dynamic Analysis of Global Copper Flows. Global Stocks, Postconsumer Material Flows, Recycling Indicators, and Uncertainty Evaluation. Environmental Science & Technology. 47(12). Available at: https://www.researchgate.net/publication/237001310_Dynamic_Analysis_of_Global_Copper_Flows_Global_Stocks_Postconsumer_Material_Flows_Recycling_Indicators_and_Uncertainty_Evaluation

International Copper Alliance (2019). Sustainable Copper. Available at: https://sustainablecopper.org/ica-indicators/, accessed 28.1.2020

International Copper Study Group (2016). Statistical yearbook. [online] Available at: http://www.icsg.org/index.php/publications

International Copper Study Group (2019a). The World Copper Factbook 2019. [online] Available at: https://www.icsg.org/index.php/111-icsg-releases-latest-copper-market-forecast-2019-2020, accessed 16.11.2019

International Copper Study Group (2019b). Statistics at the ICSG website: Copper mine, smelter, refinery production, and refined copper usage by geographical area (table 2). Available at: http://www.icsg.org/index.php/component/jdownloads/finish/165/872, accessed 16.11.2019.

Jamasmie, C. (2019). Workers at Chile's Escondida copper mine, world's largest, to down tools. Mining.com. [online] Available at: https://www.mining.com/workers-at-chiles-escondida-copper-mine-worlds-largest-to-down-tools/ (21.10.2019), accessed at 17.11.2019.

Langner, B.E. (2011). Understanding Copper: Technologies, Markets, Business. Eigenverlag, Lüneburg, 375.

London Metal Exchange (2017). Copper pricing. https://www.lme.com/metals/non-ferrous/copper/#tab2

Lossin, A. (2001). Copper. Ullmann's Encyclopedia of Industrial Chemistry. Available at: http://onlinelibrary.wiley.com/doi/10.1002/14356007.a07_471/abstract

Marscheider-Weidemann, F., Langkau, S., Hummen, T., Erdmann, L.,Tercero Espinoza, L., Angerer, G., Marwede, M. & Benecke, S. (2016): Rohstoffe für Zukunftstechnologien 2016. DERA Rohstoffinformationen 28: 353 S., Berlin. Available at: http://www.isi.fraunhofer.de/isi-de/n/projekte/Rohstoffe_Zukunftstechnologie_II_325422.php

MEC (2019). Periodic Table of the Elements. Mining & Minerals Information. Website of the Minerals Education Coalition. [online] Available at: https://mineralseducationcoalition.org/elements/copper/

Minerals (2016). The mineral copper. [online] Available at: http://www.minerals.net/mineral/copper.aspx

Minerals4EU (2019). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

Römpp (2006). Kupfer. [online] https://roempp.thieme.de/roempp4.0/do/data/RD-11-02420

Rudnick, R.L., Gao., S. (2014). Composition of the Continental Crust. In: Treatise on Geochemistry, 2nd edn. Editor: Roberta L. Rudnick. Executive Editors: Heinrich D. Holland and Karl K. Turekian. pp. 659. ISBN 0-08-043751-6. Elsevier, p.1-64.

Salomon-de-Friedberg, H. and Robinson, T. (2015). Tackling Impurities in Copper Concentrates. Available at: https://pdfs.semanticscholar.org/f8b7/59917e0235a383f91cad73cdeb84a0609360.pdf, accessed 22.01.2020.

SCRREEN (2019). Validation workshop on Critical Raw Materials, 10-12 September 2019, Thon Hotel Brussels City Centre.

SGU (2019). Information on copper demand by electric vehilces. Swedish Geological Service. Personal communication, 11.09.2019.

USGS (2011). Edelstein, D. L.. USGS mineral yearbook copper. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/copper/myb1-2009-coppe.pdf

USGS (2013) 2013 Minerals Yearbook - Poland. Available at: https://minerals.usgs.gov/minerals/pubs/country/2013/myb3-2013-pl.pdf

USGS (2016). Brininstool, M. Copper USGS Minerals Yearbook 2014. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/copper/myb1-2014-coppe.pdf

USGS (2019). Mineral Commodity Summaries 2019. Available at: https://www.usgs.gov/centers/nmic/mineral-commodity-summaries

USITC (2012). United States International Trade Commission. Briefing on trade. China's dominance as a global consumer and producer of copper. Available at: https://www.usitc.gov/publications/332/2012-08_ChinaCopper(HammerLin).pdf

WMD (2019) World Mining Data 2019, Reichl, C.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx

6.7.2 Data sources used in the criticality assessment

BGS (2019). World mineral statistics data. [online]. Keyworth, Nottingham British Geological Survey, Available at: https://www.bgs.ac.uk/mineralsuk/statistics/wms.cfc?method=searchWMS, accessed 13.05.2019

Da Silva, O. (2019). Types of Copper Deposits in the World. Investing News Network: Copper. 23.05.2019. Available at: https://investingnews.com/daily/resource-investing/base-metals-investing/copper-investing/types-copper-deposits-world/, accessed at 22.01.2020

European Commission (2014). Report on critical raw materials for the EU. Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

Eurostat (2016a). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

Eurostat (2016b). International trade in goods database (COMEXT) Available at: http://ec.europa.eu/eurostat/data/database

Glöser, S., Soulier, M., Tercero Espinoza, L., Faulstich, M. (2013a). Using dynamic stock and flow models for global and regional material and substance flow analysis in the field of industrial ecology: The example of a global copper flow model. The 31st International Conference of the System Dynamics Society. Available at: https://scholar.google.de/citations?view_op=view_citation&hl=en&user=AgOVPJ0AAAAJ&citation_for_view=AgOVPJ0AAAAJ:u5HHmVD_uO8C

ICA (2012). Copper Applications Technology Roadmap. Available at: https://copperalliance.org/trends-and-innovations/technology/ (Accessed 28.01.2020)

Langner, B.E. (2011). Understanding Copper: Technologies, Markets, Business. Eigenverlag, Lüneburg, 375

OECD (2016). Export restrictions on Industrial Raw Materials database [online]. http://qdd.oecd.org/table.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

Passarini, F., Ciacci, L., Nuss, P., Manfredi, S. (2018). Material flow analysis of aluminium, copper, and iron in the EU-28

Salomon-de-Friedberg, H. and Robinson, T. (2015). Tackling Impurities in Copper Concentrates. Available at: https://pdfs.semanticscholar.org/f8b7/59917e0235a383f91cad73cdeb84a0609360.pdf, accessed 22.01.2020.

SCRREEN (2019). Validation workshop on Critical Raw Materials, 10-12 September 2019, Thon Hotel Brussels City Centre.

Tercero Espinoza, L., Hummen, T., Brunot, A., Hovestad, A., Pena Garay, I., Velte, D., Smuk, L., Todorovic, J., van der Eijk, C., Joce, C. (2015). Critical Raw Materials Substitution Profiles. September 2013 Revised May 2015. CRM_InnoNet. Available at: http://www.criticalrawmaterials.eu/wp-content/uploads/D3.3-Raw-Materials-Profiles-final-submitted-document.pdf

UNEP (2011). Recycling rates of metals. Available at: http://www.unep.org/resourcepanel/portals/24102/pdfs/metals_recycling_rates_110412-1.pdf

WMD (2019) World Mining Data 2019, Reichl, C.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels. Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx

6.8 Acknowledgments

This Factsheet was prepared by JRC. The authors thank the Ad Hoc Working Group on Critical Raw Materials, in particular Johannes Drielsma (Euromines), Kamila Slupek and Laura Fazio Bellacchio (Eurometaux), Katia Lacasse (European Copper Institute), Antje Wittenberg (BGR), Ulrike Dorner (BGR), and the experts participating in the copper session of the SCRREEN workshop for their contribution and feedback, notably Nikolaos Arvanitidis (SGU), Mukund Bhagwat (European Copper Institute) and Henryk Karaś.

7. DIATOMITE

7.1 Overview

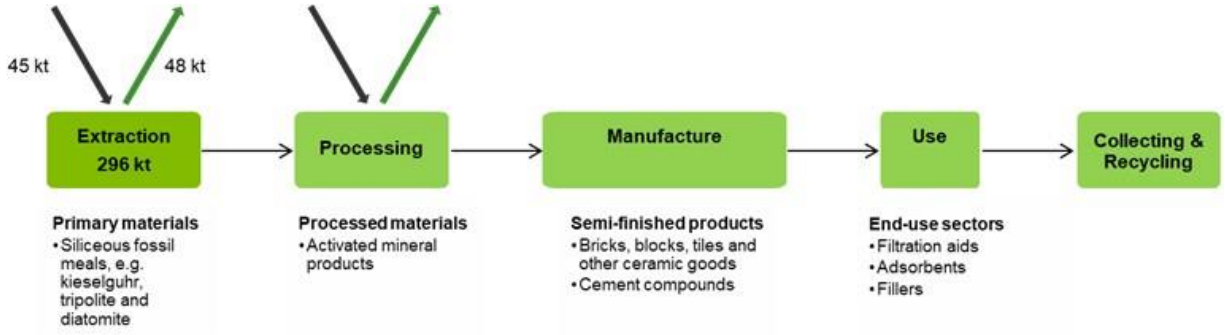


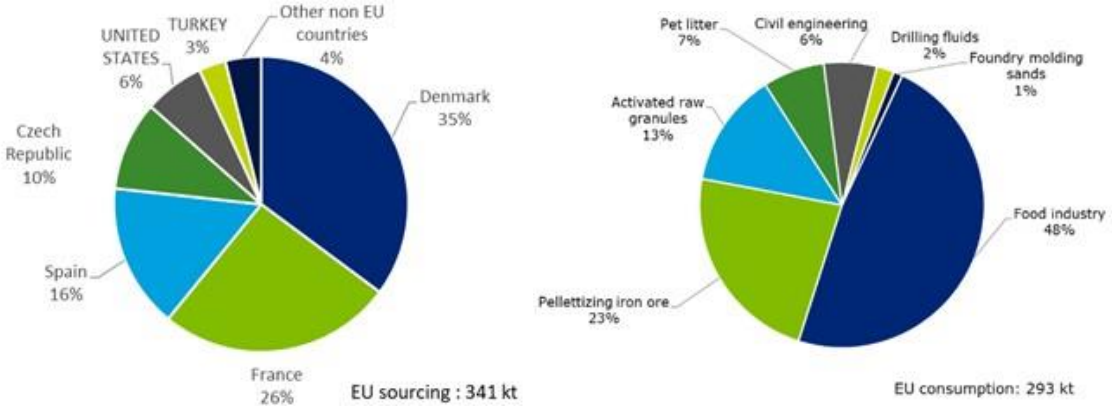
Figure 69: Simplified value chain for diatomite for the EU[54], averaged over 2012-2016

Diatomite is a powdery, siliceous, sedimentary rock. It is of very low density, extremely porous and chemically inert (Crangle, 2016). The exact characteristics of these properties are determined by the diatom forms in the diatomite. There are 15,000-20,000 different forms of diatoms known, due to the fact that they are created from thousands of different fossilized species. Synonyms of diatomite are tripolite and kieselguhr. Further, distinctions in quality and possible applications derive from the impurities in the raw material such as clay minerals, iron content, or fine-grained carbonates. With its outstanding filtration properties, and low thermal and acoustic conductivity, it is a very versatile raw material.

For the purpose of this assessment diatomite is analysed at the extraction stage, using the CN8 code 25120000 (which also contains other minerals) (Eurostat Comext, 2019).

The world annual production of diatomite is about 2.2 Mt, with 35% of production in Unites States and 19% in China (WMD, 2019). The European production of diatomite is 296 kt.

The EU apparent consumption of diatomite is 293 kt, sourced through domestic production, mainly from Denmark, France, Spain, and Czechia and imported from United States and Turkey. The EU is a net exporter of diatomite (Import reliance -0,8%).



[54] JRC elaboration on multiple sources (see next sections)

Figure 70: End uses (IMA-Europe, 2018) and EU sourcing of diatomite (2012-16).

Diatomite is used in a wide range of applications, e.g. filter aids in food industry, absorbents and fillers/carriers in food & beverage manufacturing and chemical industry. In the EU, diatomite is used for filter aids, absorbents for industrial spills, as functional filler in a variety of products from paints to dry chemicals, carrier for active ingredients and diluents.

Global reserves and resources of diatomite are estimated to be large and are adequate for the foreseeable future (USGS, 2019). In Europe, reserves of diatomite are present in Spain, Denmark, Czechia and Slovakia, according to Minerals4EU (2019).

Diatomite is not commonly recovered from waste, therefore there is limited contribution from secondary sources (EoL-RIR 4%).

No trade restrictions are reported on product groups containing diatomite (OECD, 2019).

7.2 Market analysis, trade and prices

7.2.1 Global market analysis and outlook

In the coming decade(s), both the demand and supply of diatomite are not expected to see drastic changes (BGR, 2016). However, due to the various uses of this materials in industrial applications (e.g. in crop protection and water treatment chemicals) its demand is expected to increase globally. Major players in the diatomite market include Grefco Minerals, Inc., EP Minerals, Imerys, Celite Corp., Showa Chemical Industry Co. Ltd., Damolin, Moltan Co., CECA and Eagle-Picher Industries Inc. (GrandView Research 2019).

Table 32: Qualitative forecast of supply and demand of diatomite

Materials	Criticality in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Diatomite		x	0/+	0/+	0/+	0/+	0/+	0/+

7.2.2 EU trade

Since 2015, the EU has become a net exporter of diatomite. Import was about 45.4 kt/y in the period 2012-2016, while export is about 47.8 kt/y according to Comext (Eurostat, 2019a).

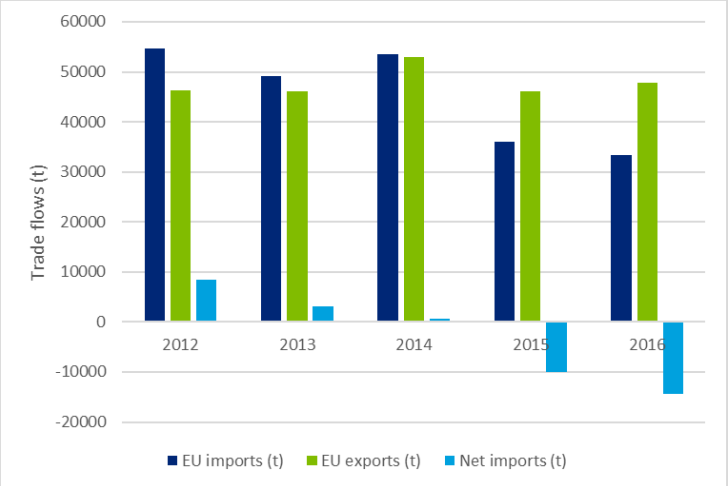


Figure 71: EU trade flows of diatomite (Eurostat, 2019)

The main suppliers to the EU are the United States (50%), Turkey (22%), Mexico (16%) and Russian Federation (5%.

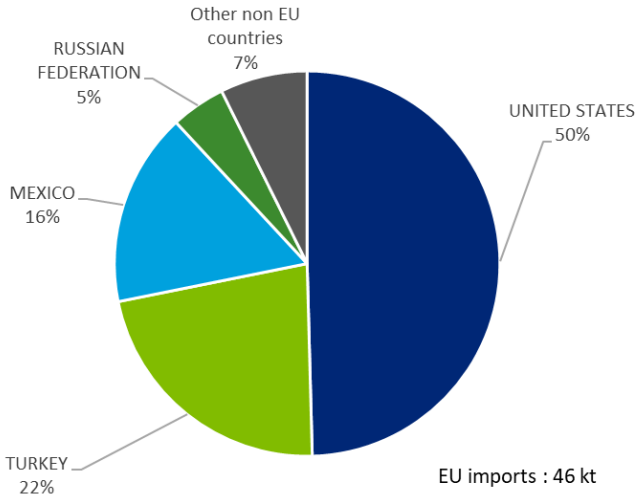


Figure 72: EU imports of diatomite, average 2012-16 (Eurostat, 2019)

The EU sourced about 87% of diatomite from intra-EU trade, mainly form Denmark (35%), France (26%), Spain (13%) and Czechia (10%). (10%).

7.2.3 Prices and price volatility

The unit value of diatomite varied widely in 2018, from approximately USD 10 per tonne when used as a lightweight aggregate in Portland cement concrete to more than USD 1,000 per tonne for limited specialty markets, including art supplies, cosmetics, and DNA extraction (USGS, 2019). The average price of diatomite filter aids between 2011 and 2015 was USD 619.50 per tonne (DERA, 2016). Diatomite's price volatility is relatively low.

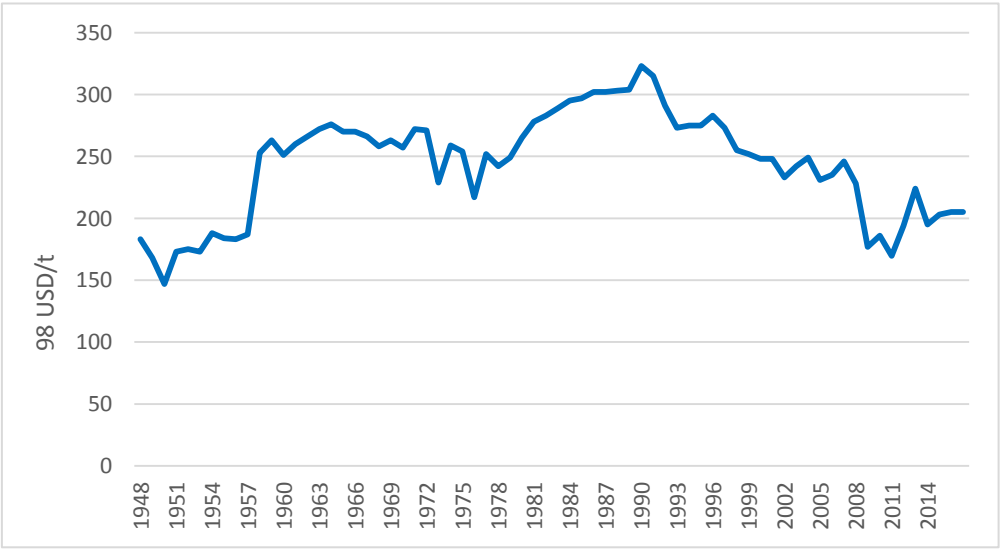


Figure 73: Developments in price of diatomite in the US. (USGS, 2016)

7.3 EU demand

7.3.1 EU demand and consumption

The EU consumption of diatomite averaged around 293 kt annually between 2012 and 2016. The import of diatomite is mostly determined by the specific properties a certain diatomite mineral needs to have, which can make it economical for the material to be shipped from outside the EU.

7.3.2 Uses and end-uses of diatomite in the EU

The unique properties of diatomite include being lightweight, having a high porosity, high absorbence, high purity, multi-shapeness and inertness (IMA, 2018).

Diatomite has a wide range of applications. The most important are:

- Filter aids (food industry): The combination of high porosity, low density and inertness makes diatomite an excellent filtration medium. Diatomite hasthe ability to remove microscopically small suspended solids from liquids to process clear filtrates at high flow rates. It is commonly used in the filtration of beverages (beer, wine or juice), wastewater or paints.
- Absorbents (various industries): With high capacity for liquids, diatomite variantsare used in gas purification processes as well as in the production of pet litter. Calcined diatomite powder is also used in the production of explosives or seed coating. (Inglethorpe, 1993) Diatomite is further used in the clean-up of spills in different industries (IDPA, 2016).
- Fillers/carriers (food & beverage manufacturing and chemical industry): Diatomite is used as filler in rubber or plastic. High quality dust white grade is also used as delustering agent or to adjust the viscosity of paints .
- Minute amounts of diatomite are used as powder in polishes, toothpastes, and silver polishes. It is also used as packing material for hazardous liquids. (various industries).

In terms of economic sectors, diatomite is allocated to the food industry (filtration aid) (48%), chemical industry and other applications (NACE 23) (49%). Base metal and machinery manufacturing receive smaller shares.

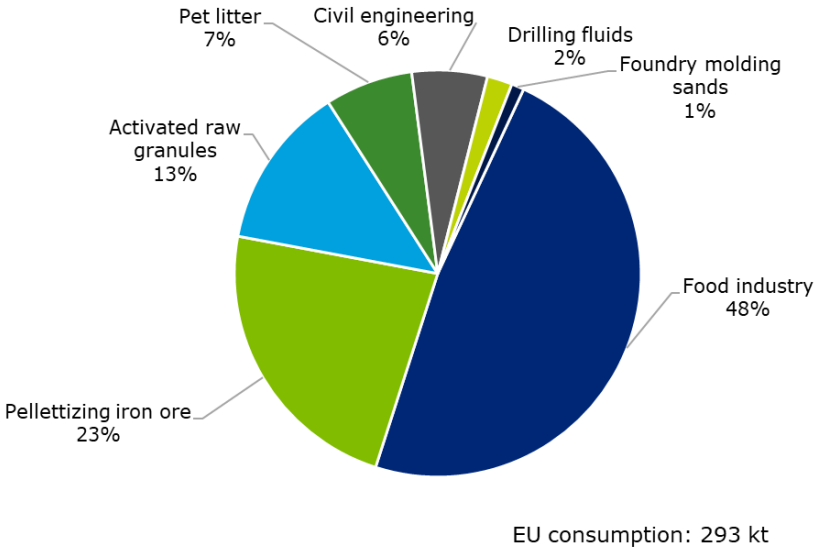


Figure 74: EU end uses of diatomite. Average figures for 2012-2016. (IMA Europe, 2018)

Relevant industry sectors are described using the NACE sector codes (Eurostat, 2019c).

Table 33: Diatomite applications, 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2019c)

Applications	2-digit NACE sector	Value added of sector (millions €)
Food industry	C11 - Manufacture of beverages	32,505
Pellettizing iron ore	C23 - Manufacture of other non-metallic mineral products	57,255
Activated raw granules	C23 - Manufacture of other non-metallic mineral products	57,255
Pet litter	C23 - Manufacture of other non-metallic mineral products	57,255
Civil engineering	C23 - Manufacture of other non-metallic mineral products	57,255
Drilling fluids	B09 - Mining support service activities	3,400
Foundry molding sands	C24 - Manufacture of basic metals	55,426

7.3.3 Substitution

Although diatomite has unique properties it can be substituted in nearly all applications. A possible substitute for filtration is expanded perlite. Synthetic filters (ceramic, polymeric or carbon membrane) compete with diatomite as filter aid. In the beverage industry, cellulose or potato starch can replace diatomaceous earth and there are other methods to filter beer such as mechanical centrifuging (USGS, 2016). Possible substitutes for filler applications are kaolin clay, Ground Calcium Carbonate (GCC), ground mica, perlite or talc. The high costs associated with these alternatives and sometimes the lowered performance and cultural preference toward the use of diatomite in the brewing and wine industries indicate a strong likelihood for the continued widespread use of diatomite in filtration (USGS, 2016).

7.4 Supply

7.4.1 EU supply chain

The annual average European production of diatomite over 2012-2016 is around 296 kt (WMD, 2019). Between 2012 and 2016, the EU production mainly took place in Denmark, France, Spain, Czechia and Poland (WMD, 2019).

Europe is a net exporter of diatomite, import reliance for this materials is therefore negative. Imports of diatomite to Europe from extra-EU countries are mainly from United States, Turkey, Mexico, Russian Federation, China, Armenia and UK.

Diatomite is barely recovered as such during waste management and therefore the contribution from secondary sources is rather limited. During experts consultations (SCRREEN workshops, 2019) it emerged that some forms of functional recycling from uses in civil engineering and foundry could be considered, which correspond to an overall EoL-RIR of 3.5%.

7.4.2 Supply from primary materials

7.4.2.1 Geology, resources and reserves

Geological occurrence: Diatomite deposits are formed from accumulated amorphous silica cell walls of dead diatoms in oceans or fresh water. Diatomite deposits are located worldwide. The largest deposits in the world however are found in the USA, followed by China and Turkey (USGS, 2016). Diatomite deposits are frequently associated with volcanic activity. Diatom-rich marine sediments also accumulate in ocean basins in regions associated with the upwelling of nutrients such as the zone of ocean current divergence in the sub-Antarctic (Inglethorpe, 1993).

Global resources and reserves[55]:

Table 34: Global reserves of diatomite in year 2018 (USGS,

Country	Diatomite Reserves (tonnes)
United States	250,000,000
Argentina	N/A
China	110,000,000
Turkey	44,000,000
Czech Republic	N/A
Denmark	N/A
France	N/A
Japan	N/A
Mexico	N/A
Peru	N/A

[55] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of diatomite in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template (www.crirsco.com), which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

Russian federation	N/A
Spain	N/A
United States	N/A
World total (rounded)	*Large*

EU resources and reserves: Because every diatomite deposit has a different composition (different diatom species and different chemical fingerprints) which determines its potential market applications and potential economic value, broad summaries of reserves, production and shipments do not paint the full picture. For example, the diatomite deposits from Denmark produce high quality absorbents but cannot be used for filter aids. Other diatomite deposits in the US or China produce excellent filters but are not suitable for granular absorbents. It is generally true, however, that for every application world resources of crude diatomite are sufficient for the foreseeable future. Reserve data for some countries in Europe are available at Minerals4EU (2019) but cannot be summed as they are partial and they do not use the same reporting code.

Table 35: Reserve data for the EU[56] compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2019)

Country	Reporting code	Quantity	Unit	Code Reserve Type
Spain	None	5,010	kt	Proven
Denmark	None	16.1	Million m^3	estimated
Czech Republic	Nat. rep. code	1,808	kt	Economic explored
Slovakia	None	2,207	kt	Verified (Z1)

7.4.2.2World and EU mine production

World Yearly world production of diatomite can be summarised as follows (average 2012-2016): the United States (787 kt), China (420 kt), Argentina (216 kt), Denmark (120 kt) and Peru (120 kt) are the major producing countries. Production from the United States and China accounts for 46% of the overall supply, equal to approximately 1.2 Mt/y. There are many countries that produce diatomite for their own use, which is reflected in the large share of countries producing smaller quantities (WMD, 2019).

In Europe, Denmark in the largest producer (5% of global production) but France is also an important producer (4% of global production). Overall five countries are recorded as diatomite producers in Europe.

[56] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for diatomite. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for diatomite, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for diatomite the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019). Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However a very solid estimation can be done by experts.

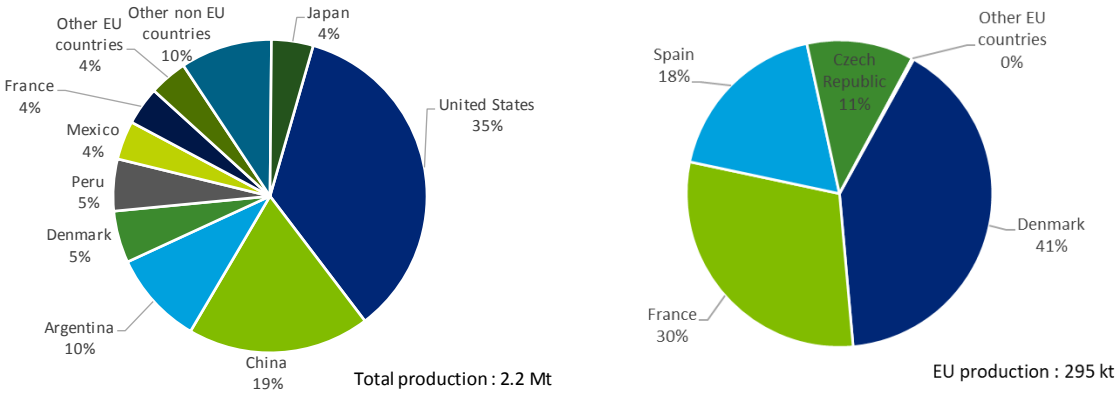


Figure 75: Global and EU mine production of diatomite. Average 2012-2016 (WMD, 2019)

7.4.3 Supply from secondary materials/recycling

End of life recycling input rate for diatomite is estimated at 3.5 %[5758].

Due to the complex morphology of the diatom skeletons it is very difficult to regenerate diatomite filter aids once they have been employed for filtration. Nevertheless, used filter aids are re-used for different purposes, mainly in agricultural industries, e.g. as fertiliser or animal feed. They can also be used in the construction industry (e.g. in the cement industry or the asphalt industry) (Johnson, 1997). Some recent (Chinese) patents have appeared for recycling of diatomite.

7.5 Other considerations

7.5.1 Environmental and health and safety issues

Diatomaceous earth (which includes diatomite), is composed primarily of amorphous silica and can also have a crystalline silica component which varies depending on ore source and processing method. During diatomite processing, exposure to process-generated respirable crystalline silica (RCS) can create negative health effects. In particular, prolonged inhalation of crystalline silica has been associated with damage of the respiratory system, silicosis and cancer (IDPA, 2017). In 2016, the EU Commission has issued a proposal[59] to include "work involving exposure to respirable crystalline silica dust generated by a work process" in Annex I of the Carcinogens and Mutagens Directive (2004/37/EC). It proposes the establishment of a binding European occupational exposure limit at 0.1 mg/m³ (respirable fraction, 8h TWA) in Annex III.³ (respirable fraction, 8h TWA) in Annex III.

7.5.2 Socio-economic issues

No specific issues were identified during data collection and stakeholders consultation.

[57] JRC estimated 50% recycling in case of civil engineering and foundry: (6%+1%)x50% = 3.5%
[58] The EOL-RIR rate might be too low, as the material is not used in a dissipative way (BGR, 2019).
[59] COM(2016)0248 Proposal for a Directive of the European Parliament and of the Council amending Directive 2004/37/EC on the protection of workers from the risks related to exposure to carcinogens or mutagens at work.

7.6 Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. Both supply risk and economic importance have slightly increased between 2017 and 2020.

The results of this and earlier assessments are shown in Table 36.

Table 36: Economic importance and supply risk results for diatomite in the assessments of 2011, 2014, 2017, 2020 (European Commission, 2011-2014-2017)

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Diatomite	3.73	0.34	3.02	0.24	3.8	0.3	2.18	0.46

7.7 Data sources.

The CN product group code that is used to list diatomites is 2512 00 00, and is labelled "Siliceous fossil meals, e.g. kieselguhr, tripolite and diatomite, and similar siliceous earths, whether or not calcined, of an apparent specific gravity of ≤ 1". The volumes of diatomite in the product group are considered equal to the volumes of the product group, since kieselguhr and tripolite are merely synonyms of diatomite.

The data has a very strong coverage. It is available on EU level, is available for time series and updated at regular intervals and is publicly available.

7.7.1 Data sources used in the factsheet

BGR (2019). A. Wittenberg, expert consultation.

BGS (2016). World Mineral Production 2010-2014 [online]. Keyworth, Nottingham British Geological Survey, Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.html

DERA (2016). Pricelist of raw materials/ [online] Available at: http://www.bgr.bund.de/DE/Themen/Min_rohstoffe/Produkte/Preisliste/cpl_16_11.pdf?__blob=publicationFile

European Commission (2011). Critical raw materials for the EU. [online] Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission (2014) Report on critical raw materials for the EU – Non Critical raw materials profiles.

European Commission (2019). DG Trade. Agreements [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/

Eurostat (2019a). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2019)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2019)c. Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

GrandView Research (2019) Diatomite Market Analysis, Market Size, Application Analysis, Regional Outlook, Competitive Strategies, And Segment Forecasts, 2015 To 2022

Inglethorpe, S. D. J., (1993). Industrial minerals laboratory manual. Diatomite BGS Technical Report WG/92/39. Available at: https://www.bgs.ac.uk/research/international/dfid-kar/WG92039_col.pdf

IDPA (2016). Diatomite-Products [online] Available at: http://www.diatomite.org/Diatomite-Products

IDPA (2017). A Guide to Safe Handling of Diatomaceous Earth Products European Version. Available at: https://www.ima-europe.eu/sites/ima-europe.eu/files/publications/IDPA%20Guide%20for%20Safe%20Handling%20European%20version%20-final%20%28low%20resolution%29.pdf

Johnson, M. (1997). Management of spent diatomaceous earth from the brewing industry. Available at: http://www.ceme.uwa.edu.au/__data/assets/pdf_file/0008/1637270/Johnson_1997.pdf

IMA (2016) Commitments [online] Available at: http://www.ima-europe.eu/commitments/biodiversity

Minerals4EU (2019). European Minerals Yearbook. [online] Available at: http://minerals4eu.brg

OECD (2019). Export restrictions on Industrial Raw Materials database [online]. http://qdd.oecd.org/table.aspx?Subject=ExportRestrictions_IndustrialRawMaterials c

SCRREEN workshops (2019). "Validation Workshop on Critical Raw Materials, 10-12 September 2019, Thon Hotel Brussels City Centre."

USGS (2016). Crangle, R. D. USGS 2016 Minerals Yearbook, diatomite.

USGS (2019). Crangle, R. D. USGS 2019 Minerals Commodity Survey, diatomite.

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

7.7.2 Data sources used in the criticality assessment

BGS (2016). World Mineral Production 2010-2014 [online]. Keyworth, Nottingham British Geological Survey, Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.html

European Commission (2014). Report on critical raw materials for the EU. Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

Eurostat (2016). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2
Eurostat Comext (2016). International trade in goods database (COMEXT) Available at: http://ec.europa.eu/eurostat/data/database

IMA (2011). What is diatomite? [online] Available at: http://www.ima-europe.eu/sites/ima-europe.eu/files/minerals/Diatomees_An-WEB-2011.pdf

OECD (2019). Export restrictions on Industrial Raw Materials database [online]. http://qdd.oecd.org/table.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

USGS (2016). Crangle, R. D. USGS 2016 Minerals Yearbook, diatomite. Available at: https://s3-us-west-2.amazonaws.com/prd-wret/assets/palladium/production/mineral-pubs/diatomite/myb1-2016-diato.pdf

USGS (2019). Crangle, R. D. USGS 2019 Minerals Commodity Survey, diatomite. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/diatomite/myb1-2015-diato.pdf https://prd-wret.s3-us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/atoms/files/mcs-2019-diato.pdf

7.8 Acknowledgments

This factsheet was prepared by the JRC. The authors would like to thank the Ad Hoc Working Group on Critical Raw Materials, in particular Ms. Aurela Shtiza and Ms. Francesca Girardi of IMA-Europe, as well as experts participating in SCRREEN workshops for their valuable contribution and feedback.

8. FELDSPAR

8.1 Overview

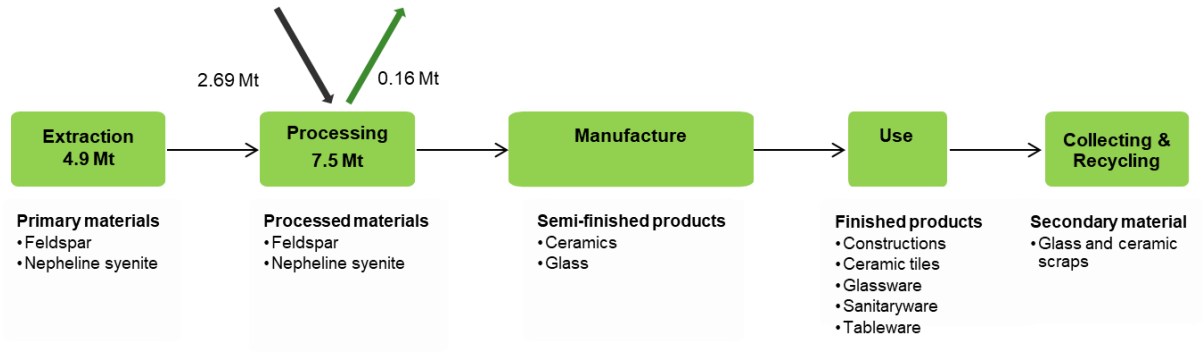
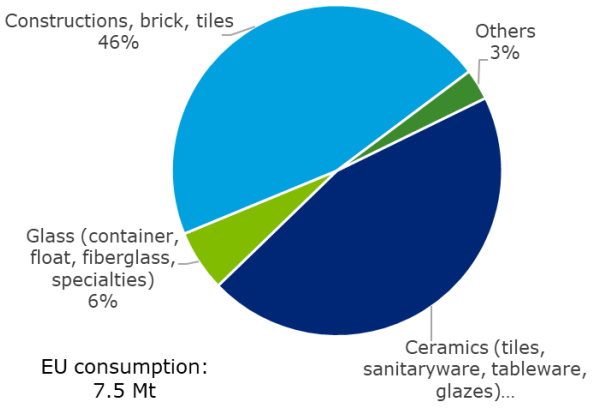
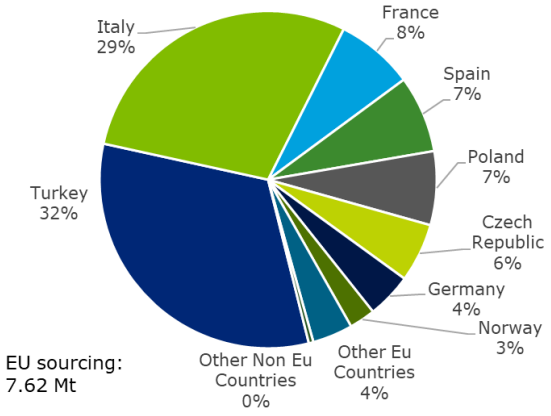


Figure 76: Simplified value chain for feldspar[60] (2012-16 average)

Feldspars (and feldspathoids) are a group of rock-forming minerals, which are alumino-silicates of sodium, potassium, calcium or combinations of these elements. They constitute as much as 60% of the Earth's crust and are recovered from a wide range of rocks, which are the actual raw materials used by industry. In fact, the amount of feldspars and feldspathoids in commercial products rarely exceeds 85% and is usually in the 30-80% range. Such feldspathic rocks encompass igneous (e.g., aplite-pegmatite, nepheline syenite), sedimentary (e.g., arkosic sand) and metasomatic types (e.g., albitite) along with their metamorphic equivalents (Potter, 2006; McLemore, 2006; Dondi, 2018). Feldspar was not on the list of CRMs in 2011, 2014, and 2017.

Since feldspars and feldspathoids are by far the most abundant minerals in the Earth's crust, the mere occurrence of feldspar in a given rock is not a valid criterion to turn it into a feldspar source. Feldspars are sought-after by industry because of specific chemical and physical properties. For instance: fusibility and supply of alumina and alkali to liquid phase in ceramics and glasses; optical properties and stability in contact with polymers and other organic compounds when used as filler (Potter, 2006; McLemore, 2006; Dondi, 2018).





[60] JRC elaboration on multiple sources (see next sections)

Figure 77: End uses (IMA-Europe, 2018) and EU sourcing (Dondi, 2018; Eurostat, 2019) of feldspar (average 2012-16).

Any feldspar-bearing rock used in applications, where the occurrence and role of feldspars are unperceived or not valued, is not considered as a feldspar raw material. Examples are in the construction sector: fine aggregates (for high-performance mortars) or pumice (for pozzolanic cements) can contain a fair amount of feldspars and/or feldspathoids, but they are not included among feldspar commodities. Also, feldspathic rocks exploited as alumina source in the production of aluminium metal are not considered here.

European resources contain sodium feldspar as well as potassium feldspar and mixed feldspars. Feldspar surrounds us in our daily life in the form of ceramic tiles, glasses, tableware and sanitaryware, glass for protection and glass wool for insulation (IMA-Europe, 2018).

There is no general definition of "feldspar" as industrial mineral and single countries adopt their own classification (Dondi, 2018). Thus, feldspathic raw materials on the market have a large variability as feldspar + feldspathoid content (30-90%) and take a plethora of commercial names (sodic feldspar, potassic feldspar, mixed feldspar, pegmatite, aplite, feldspathic sand, granite, nepheline syenite, etc). As a consequence, some sources of information include in the feldspar figures other raw materials, which may contain significant amounts of feldspars, but are addressed to end-uses not explicitly employing “feldspar”. Trade flows can be traced under the following CN8 codes (Eurostat, 2019): 25291000 (FELDSPAR) and 25293000 (LEUCITE, NEPHELINE AND NEPHELINE SYENITE). Quantities are given with no reference to the actual feldspar (and feldspathoid) content .

The world market of feldspar was on average 26.3 Mt in the period 2012-2016 (Dondi, 2018; WMD, 2019) and kept growing to 2018, when the global output was 28.4 Mt and worth 2,000 million €. The majority of feldspar is sold on the open market and only some users signed annual contracts of supply (Dondi, 2018). According to average export values (Eurostat, 2018), prices of feldspar were nearly constant in the period 2011-2018. These prices depend on the type and content of feldspar, ranging from EUR30 per tonne (quartz-feldspathic rocks) to EUR70 per tonne (sodic feldspar) up to EUR 200 per tonne (potassic feldspar). In contrast, nepheline syenite exhibited a certain price volatily, with a upward trend from 2013 to 2016 (EUR 105 to 135 per tonne) followed by a stabilization around EUR 120 per tonne.

The EU consumption of feldspar was around 7.5 Mt per year (average 2012-2016) but grew up to 10.9 Mt (2018). The European demand, 97% feldspathic rocks and 3% nepheline syenite, is fed through domestic production, mainly in Italy, France, Poland, Spain, Germany and Czechia, and importing mainly from Turkey (which accounts for 94% in quantity and 72% in value of EU import) and Norway (5% in quantity and 20% in value). Import reliance is 34% (average 2012-2016) but increased up to 53% (2018). The EU demand is in constant growth since 2010, when it was around 6 Mt; it means +93% in less than a decade (2018). Such increment is mirrored by the global growth of feldspar production, which occurred at a pace of 770 kt/y in the same period (Dondi, 2018). The use of feldspathic materials in the ceramic and glass industries is overwhelming in Europe and other technical end-uses account for a minimal share. This circumstance is driving a gradual shift of the EU demand towards products with high fusibility (mainly sodic feldspar) as a consequence of the technological innovation in the ceramic tile sector (Dondi, 2018).

Feldspar turned to be crucial for the EU ceramic industry, which is moving its production towards highly vitrified bodies (porcelain stoneware and vitreous china) and ever-larger sizes that require batches containing a high percentage of fluxes and a low amount of chromophores. These raw materials are essentially represented by sodic feldspar and

nepheline syenite. Other feldspar types are successfully utilized in ceramic batches only together with fluxes of high fusibility. In fact, it is the availability of low melting fluxes (like sodium feldspar) that enables a large-scale utilisation of quartz-rich, mixed Na-K feldspathic materials (like those constituting the most part of EU production). Thus, these latter sources, despite their local abundance in the EU, cannot satisfactorily substitute sodic feldspar or nepheline syenite (Dondi, 2018). Feldspar can be replaced in ceramic batches, but only in small amounts, due to either technological constraints (dolomite, lime, recycled glass, slags) or the much higher cost and limited availability of substitutes (wollastonite, Lithium silicates, low-iron talc) (Dondi, 2018; IMA-Europe, 2018).

Overall, reserves are thought to be "large", simply because of the feldspar abundance in the Earth's crust, even though their quantification is missing in most cases (Potter, 2006; McLemore, 2006; Dondi, 2018). As a matter of fact, data are accessible just for a few countries, but they are approximate and not directly comparable to each other, due to different approaches followed in the various countries to define the reserves. These estimations span from optimistic (with sufficient reserves for centuries at the present rate of consumption, e.g. Brazil, Egypt, Iran) to conservative (with an amount of feldspar certainly available for two or three decades with current mining production, e.g. India, Poland, Turkey). Considering that the market will progressively move towards feldspar types with high fusibility and a low amount of iron oxide, it is necessary to get data (resources and reserves) specific for every source, with special emphasis on sodic feldspar and nepheline syenite (Dondi, 2018).

The world annual production of feldspathic materials is about 28 Mt (2018) with 29% of production in Turkey and 14% in China (Dondi, 2018; WMD, 2019). Feldspar is recovered from different geological sources: albitites (37%), pegmatites and aplites (24%), granitoids (16%), feldspathic arenites (11%), nepheline syenites (6.5%), rhyolites and porphyries (2.5%), metamorphics and epithermal alterations (1.5% each). The EU production of feldspar is around 5 Mt (Dondi, 2018; WMD, 2019) . The major producers are Italy (2.3 Mt), France, Poland and Spain (600kt each), the Czechia (460kt) and Germany (310kt). The feldspar output of Portugal, Bulgaria, Finland, Austria and Sweden is individually between 30 kt and 100 kt, with minor production also in Romania and Slovakia. The EU production comes from the following geological sources: feldspathic arenites (46%), granitoids (26%), pegmatites and aplites (11%), albitites (9%), rhyolites and porphyries (4%), nepheline syenites and epithermal alterations (2% each).

No trade restrictions exist for feldspar. Some moderate concern is about the toxicity of respirable crystalline silica (quartz, cristobalite) by workers in the mining and manufacturing industries. Various aspects are regulated by the EU Directive 2017/2398 and by CLP Regulation 1278/2008 and Regulation (EC) 1272/2008.

8.2 Market analysis, trade and prices

8.2.1 Global market analysis and outlook

The global production of feldspar highlights a continuous growth over time, but with some strong fluctuations, essentially linked to the economic recession in the period 2008–2012. The average growth rate was globally of +770 kt per year over the last decade. The EU production of feldspar was rather stable in the same period, fluctuating around 5 Mt (±5%) per year. The increasing global demand was not followed by a uniform growth in the production from the various sources of feldspar, which determined deep changes in both the market structure and supply patterns, affecting in particular the EU (Dondi, 2018). The global trend of feldspar production is well correlated with the increasing demand from the ceramic industry. This is

justified by the worldwide diffusion of the production of porcelain stoneware tiles (whose batches contain the largest amount of fluxes) prior basically restricted to Italy. In the last decade, such a growth has been fundamentally fed through an expansion in the capacity of sodium feldspar producers from albitite (and to a minor extent of pegmatite suppliers) since the other sources show just a limited production increment or even a diminution since 2006. In particular, the production from albitite and pegmatite deposits grew 53% and 43%, respectively, in the last decade (Dondi, 2018).

The Global Feldspar market is expected to reach 992.95 million USD by 2026 growing at 7.8% during the forecast period. The global demand is expected to keep growing, since the ceramic production is linked to demographic drivers, especially in southern Asia. The effect of conversion to porcelain stoneware, at expenses of other ceramic batches that use less feldspar, is expected to stabilise in the incoming years (Table 37). Availability of sodic feldspar is one of the main factors behind this product innovation. In the EU, such conversion is already accomplished in Italy and Portugal (>90% of ceramic tile output is porcelain stoneware) but still partial in Spain and Poland (50% porcelain stoneware).

The key vendors are Imerys Minerals, Eczacibasi Esan, Gimpex, EL Waha Mining & Fertilizers, EP Minerals, Inc., Micronized Group, Minerali Industriali, Sibelco Nordic, Pacer Corporation, Asia Mineral Processing, I-Minerals, Sun Minerals, The Quartz Corp. and Polycor Inc.

Table 37: Qualitative forecast of supply and demand of feldspar

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Feldspar		x	++	++	+	+	+/-	?

8.2.2 EU trade

Thanks to a high number of feldspar deposits in 15 countries, Europe is able to cover approximately half of the internal demand of feldspar. In particular, EU is substantially self-sufficient for potassic feldspar, mixed alkali feldspar and quartz-feldspathic materials, but depends on importation for about 90% of sodic feldspar and nepheline syenite (Dondi, 2018). The import reliancein the period 2012-2016 was 34%, but grew to 53% in 2018, as import has gradually doubled from 2010 to 2018. There is a strong trade deficit (-167 million € in 2018) that grew +122% since 2010 (Eurostat, 2019).

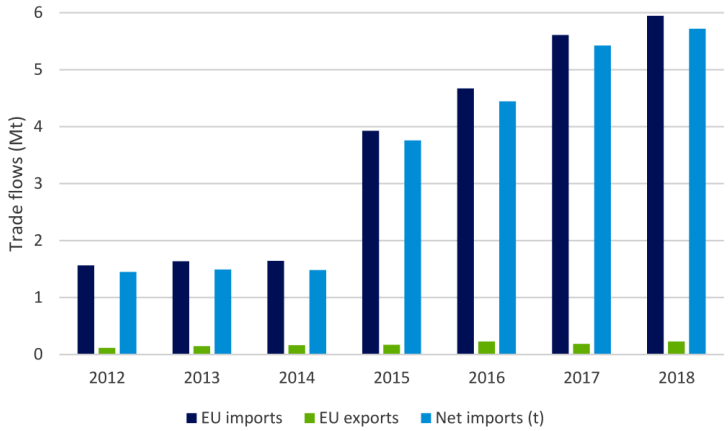


Figure 78: EU trade flows for feldspar[61], (Eurostat, 2019).

Figure 78 shows the development of the international trade in feldspar by the EU. The supplying countries outside the EU are shown in Figure 79. By far the largest amount of feldspar imported into the EU was from Turkey (and Norway for nepheline syenite).

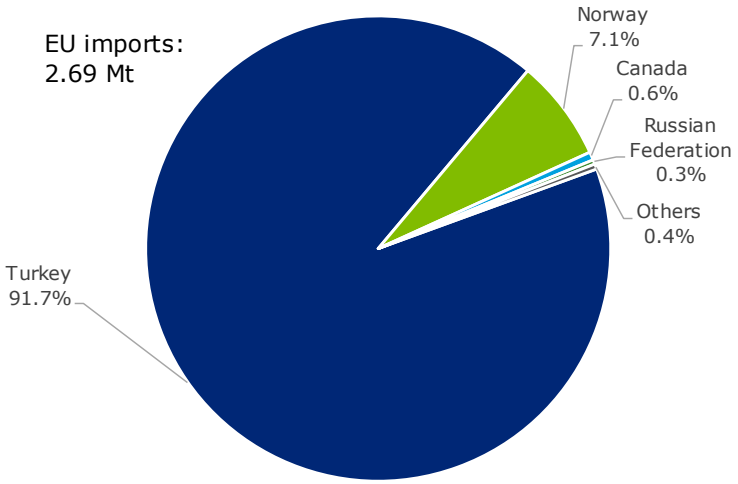


Figure 79: EU imports of feldspar, 2012-2016 (Eurostat, 2019).

EU trade is analysed using product group codes (CN8): 25291000 (FELDSPAR) and 25293000 (LEUCITE, NEPHELINE AND NEPHELINE SYENITE). It is possible that materials are part of product groups also containing other materials and/or subject to re-export (Rotterdam-effect).

Currently there are EU free trade agreements in place with all the major suppliers: Turkey (Customs Union), Norway (European Economic Area), Canada, Macedonia and Morocco (bilateral/regional agreement) but Russia (European Commission, 2019). There are no exports quotas or prohibition in place between the EU and its suppliers (OECD, 2019).

8.2.3 Prices and price volatility

According to average export values (Eurostat, 2019), prices of feldspar were nearly constant in the period 2011-2018. These prices depend on the type and content of feldspar, ranging from EUR 30 per tonne (quartz-feldspathic rocks) to EUR 70 per tonne (sodic feldspar) up to EUR 200 per tonne (potassic feldspar). In contrast, nepheline syenite exhibited a certain price volatily, with an upward trend from 2013 to 2016 (EUR 105 to 135 per tonne) followed by a stabilization around EUR 120 per tonne. Feldspar is not included in the price monitoring service (DERA, 2019).

[61] 2017 and 2018 data not used in criticality calculations

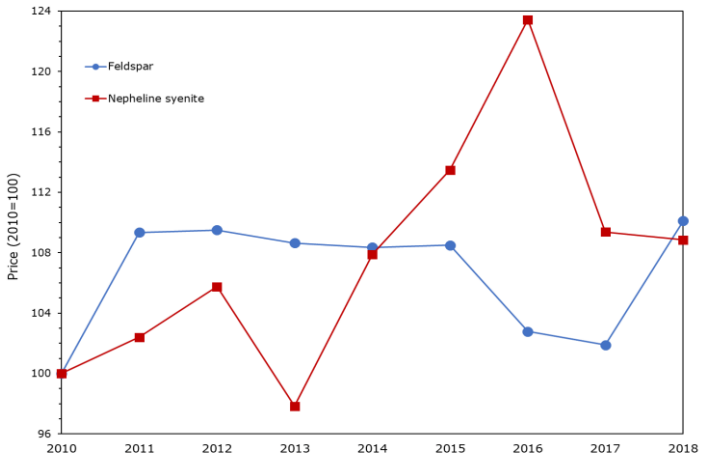


Figure 80. Prices of feldspar (2010=100), calculated from Eurostat Comext (2019)

8.3 EU demand

8.3.1 EU demand and consumption

The annual consumption of feldspar in the EU was on average 7.5 Mt (2012-2016) but the yearly value gradually grew beyond this period, culminating at 10.9 Mt in 2018 (Dondi, 2018; Eurostat, 2019). The demand varies upon the type of feldspar and feldspathoid minerals. However, there is no general definition of "feldspar" as industrial mineral and single countries adopt their own classification (Dondi, 2019).

8.3.2 Uses and end-uses of feldspar in the EU

The use[62] of feldspathic materials in the ceramic, and to a lesser estent in glass industries, is predominant in the EU. Other technical end-uses (functional fillers in the paint, plastic, rubber and adhesive industries) account for a minimal share (Dondi, 2018; IMA-Europe, 2018). Basically, the properties which make feldspars useful for downstream industries are their ability to melt and provide at high temperature a liquid phase rich in alkali and alumina (fundamental for ceramics and glasses) and their ability to act as opacifier and provide stable suspensions in contact with organic compounds (when applied as filler and extender). Feldspathic materials on the market have a large variability as feldspar content (30-90%) and in terms of commercial definition (feldspar, aplite, feldspathic sand, granite, nepheline syenite, etc). Nevertheless, some broad typologies can be distinguished: sodic, potassic and mixed feldspars, depending on their alkali ratio, and nepheline syenite.

The most important applications are (Potter, 2006; Mclemore, 2006; Dondi, 2018; IMA-Europe, 2018; SCRREEN workshops, 2019):
Ceramics: feldspars are fundamental ingredients of many batches for a wide range of ceramic products: wall and floor tiles, sanitaryware, tableware, and related glazes and glassy coatings. Their primary function is to melt during firing, so providing a liquid phase that is responsible for viscous flow sintering and partial vitrification. Fluxes are introduced in the various ceramic batches in different amount: from a few percent up to 60% and over. The quantity of flux

[62] It must be noticed that in this factsheet “feldspar” is intended – among the industrial minerals containing significant amounts of feldspars and/or feldspathoids – as a raw material used in processes where the feldspar properties are expressly valued.

depends on the characteristics of finished products: porous, semi-vitrified or vitrified bodies, and engobes or glassy coatings. The importance of feldspar in the ceramic industry has been enhanced by the progressive transition from porous to vitrified bodies (especially porcelain stoneware and vitreous china).
Glass: feldspar and nepheline syenite are important raw materials in glass manufacture, where they play basically the role of alumina (and alkali) source. Feldspar acts as a fluxing agent, reducing the glass batch melting temperature and thus helping to save energy and reduce production costs. The alumina content of feldspar improves hardness, durability and resistance to chemical corrosion of the final product. The importance of feldspar in the glass industry has been reduced by the large recourse to recycled cullet glass from sorting of municipal wastes, which covers at least two thirds of raw material supply.
Filler and extender: feldspar is used in applications such as paints, plastics and rubber. Further end-uses are in mild abrasives, urethane, welding electrodes steel production, and latex foam.

Applications where the occurrence of feldspar is unperceived or not valued are excluded. Thus, construction sand for mortar and concrete; road aggregates; nepheline syenite or anorthosite as a source of aluminium are repositioned to the relevant sections.

It must be highlighted that the EU consumption of 7.5 Mt estimated during the criticality assessment includes feldspatic sand, whereas IMA-Europe reports 3.2 Mt (IMA-Europe, 2018).

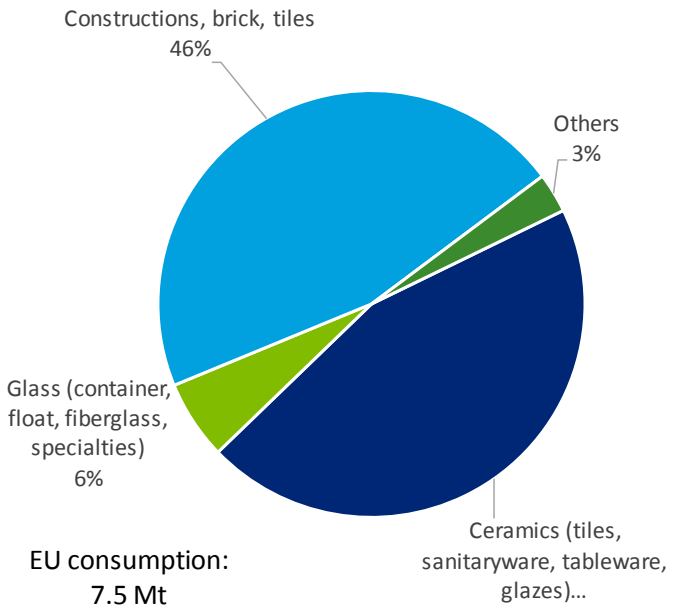


Figure 81: EU end uses of feldspar. Average figures for 2012-2016.

The calculation of economic importance is based on the use of the NACE 2-digit codes and the value added at factor cost for the identified sectors.

Table 38: Feldspar applications (IMA-Europe, 2018), 2-digit NACE sectors, associated 4-digit NACE sectors, and value added per sector (Eurostat, 2019).

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (millions €)

Ceramics (tiles, sanitaryware, tableware, glazes)	C23 - Manufacture of other non-metallic mineral products	23.31, 23.42, 23.41, 23.4	57,255
Glass (container, float, fiberglass, specialties)	C23 - Manufacture of other non-metallic mineral products	23.11, 23.13, 23.14, 23.19	57,255
Constructions, brick, tiles	C23 - Manufacture of other non-metallic mineral products		57,255

The allocation of the use to NACE sector "Manufacture of non-metallic mineral products" (23) is justified by the fact that 98% of the feldspar is addressed to the production of ceramics (87%) and glass (11%).

8.3.3 Substitution

As batch design is strictly constrained in the glass industry, well defined alternatives can be indicated, the more common is kaolin as alumina source. A similar consideration can be done about fillers and extenders, even if the range of substitutes is undoubtedly larger, encompassing calcium carbonate, talc, wollastonite, kaolin, mica, pyrophyllite, silica, diatomite, bentonite, among others (IMA-Europe, 2018; Kogel, 2006; SCRREEN workshops, 2019). In contrast, the ceramic technology is versatile and allows the use of a wide range of raw materials in replacement of feldspar. The different technological behavior of substitutes can be compensated by a combination of raw materials in variable amounts (Dondi, 2018). Thus, the picture is extremely varied and hard to be reconducted to a simple scheme of a given substitute in a determined subshare. There are several feldspar substitutes in the ceramic (and glass) industries. The following found some industrial use (Dondi, 2018; Dondi, 2019):
- low-melting materials, like sericite or natural glass in volcanic rocks, which constitute pottery stone, eurite or some rhyolites;
- sintering promoters, like talc, diopside, dolomite, chlorite-bearing rocks and basic igneous rocks;
- waste from quarry dumps, instead of freshly mined rocks, with environmental benefit and slope stabilization;
- fired scraps and processing sludges from the manufacture of vitrified ceramics, such as porcelain stoneware tiles and vitreous china sanitaryware;
- glassy materials from municipal waste sorting, including soda-lime container glass, glass from PC-TV screen, borosilicate vial glass, glasses from various types of lamps.
Furtherly, there are candidates that did not find extensive application yet:
- sludges from cutting and polishing of ornamental stones, particularly granite
- stabilized incinerator ashes from municipal solid wastes or biomass combustion in thermal power plants.

8.4 Supply

8.4.1 EU supply chain

Italy is the major producer of feldspar in Europe, even though Spain, France, Poland, the Czechia, Germany and Portugal are also important suppliers of feldspar within the EU (Dondi, 2018; WMD, 2019; Brown, 2016;,USGS, 2019). The EU is a net importer of feldspar, and has an increasing import reliance from 34% (average 2012-2016) to 53% (2018).

8.4.2 Supply from primary materials

8.4.2.1 Geological occurrence/exploration

Feldspars and feldspathoids are essential components of many igneous, sedimentary and metamorphic rocks, to such an extent that the classification of a number of rocks is based upon the feldspar and feldspathoid content (Potter, 2006; McLemore, 2006; Dondi, 2019). The feldspar group includes orthoclase ($KAlSi_3O_8$), albite ($NaAlSi_3O_8$) and anorthite ($CaAl_2Si_2O_8$). Compositions comprised between albite and anorthite are known as "plagioclase", while those comprised between albite and orthoclase are called "alkali feldspar" due to the presence of sodium and potassium. The alkali feldspars are of particular interest in terms of industrial use of feldspars. Among feldspathoids, only nepheline, $(Na,K)AlSi_2O_6$, meets a wide industrial interest.

Feldspathic raw materials are mined from a wide range of deposits in different geological contexts (Dondi, 2019). The main sources are granitic suites, including acid differentiates (pegmatite and aplite) and the corresponding extrusive and hypabyssal terms (rhyolite, porphyry). Leucogranite is the most important resource among granitoids. Alkaline complexes with silica-undersaturated rocks are the source of nepheline syenite and its extrusive equivalent (nepheline phonolite). Among the deposits of sedimentary origin, feldspathic arenites are widely exploited, principally arkoses. Metamorphic and metasomatic rocks are extensively utilized, especially albitites and phyllites.

8.4.2.2 Resources and reserves

The resources of feldspathic raw materials are thought to be huge, because of the feldspar abundance in the Earth's crust, even though not always conveniently accessible to the principal centers of consumption. According to the USGS (2019), identified and undiscovered resources of feldspar are more than adequate to meet anticipated global demand, although their quantification is missing in most cases. Quantitative data of different feldspar sources (e.g., feldspathic sand, granite, pegmatite, albitite) have not been compiled (USGS, 2019).

Reserves data are accessible just for a few countries, but they are approximate and not directly comparable to each other, due to different approaches followed in the various countries to define the reserves. Estimations span from optimistic (with sufficient reserves for centuries at the present rate of consumption, e.g. Brazil, Egypt, Iran) to conservative (with an amount of feldspar certainly available for two or three decades with current mining production, e.g. India, Poland, Turkey).

Table 39: Global reserves of feldspar in year 2017-2018

Country	Feldspar Reserves (kt)	
	(USGS, 2019)	(Dondi, 2018)
Brazil	150,000	320,000
China	NA	NA
Czech Republic	23,000	28,000
Egypt	1,000,000	1,000,000
India	320,000	45,000
Iran	630,000	630,000
Italy	NA	NA
Korea	240,000	NA
Malaysia	NA	NA

Poland	16,000	14,000
Spain	NA	40,000
Thailand	960	NA
Turkey	240,000	240,000
United States	NA	NA
World total	*Unknown, but large*	

NA: data not available

Reserve data for some countries in Europe are available from Minerals4EU (2019) but cannot be summed as they are partial and they do not use the same reporting code. Considering that the market will progressively move towards feldspar types with high fusibility and a low amount of iron oxide, it is necessary to get data (resources and reserves) specific for every source, with special emphasis on sodic feldspar and nepheline syenite.

Table 40: Reserve data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU , 2019)

Country	Reporting code	Quantity	Unit	Grade	Code Reserve Type
Spain	None	174.1	Mt	-	Proven
Ukraine	Russian Classification	0.36	Mt	-	(RUS)A
Poland	Nat. rep. code	5.2	Mt	-	Total
Romania	UNFC	2	Mt	-	111
Slovakia	None	3.1	Mt	-	Probable (Z2)
Czechia	Nat. rep. code	25.9	Mt	-	Economic explored

8.4.2.3World mine production

The global production of feldspar between 2012 and 2016 was annually 26.3 Mt on average (WMD, 2019; Brown, 2016; USGS, 2019). It was still growing and in 2018 reached 28.2 Mt (Dondi, 2018). Turkey, China and Italy are the leading producers for feldspathic raw materials worldwide. Turkish mining companies expanded the feldspar production by 18% since 2010, overpassing 8 Mt in 2018. In Italy a contraction of about one third of annual output was registered in the same period. Data for China are estimates that do not allow any detailed analysis. Further major suppliers, with a yearly output overpassing 1 Mt, are India, Thailand, Indonesia, and Iran, which had an increase of production between 30% and 70% in the last decade. The major producers of nepheline syenite are Canada (700kt, increasing 18% in the last decade) and Norway (320kt, decreasing 19% in the same period). Further important producers of nepheline syenite are Russia, Brazil, Turkey, and China.

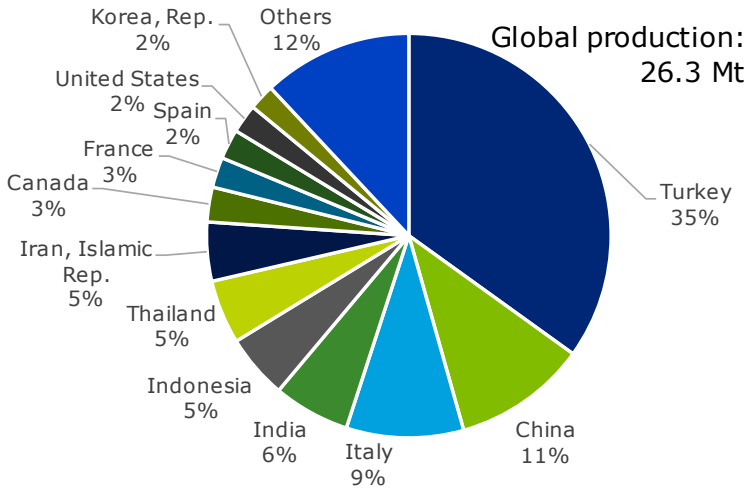


Figure 82: Global mine production of feldspar, average 2012-16 (Dondi, 2018; WMD, 2019; Brown, 2016).

The EU production accounts for about 19% of the total world production. Beyond Italy (~2.3Mt), major producers are: France, Poland and Spain (600kt each, the Czechia (460kt), Germany (310kt) and Portugal (100kt). Further suppliers, with minor annual output, are Bulgaria, Finland, Austria, Sweden, Romania, and Slovakia. Italian statistics include feldspar

and feldspathic sands. A small production of nepheline phonolite is ensured by France, Germany and the Czechia.

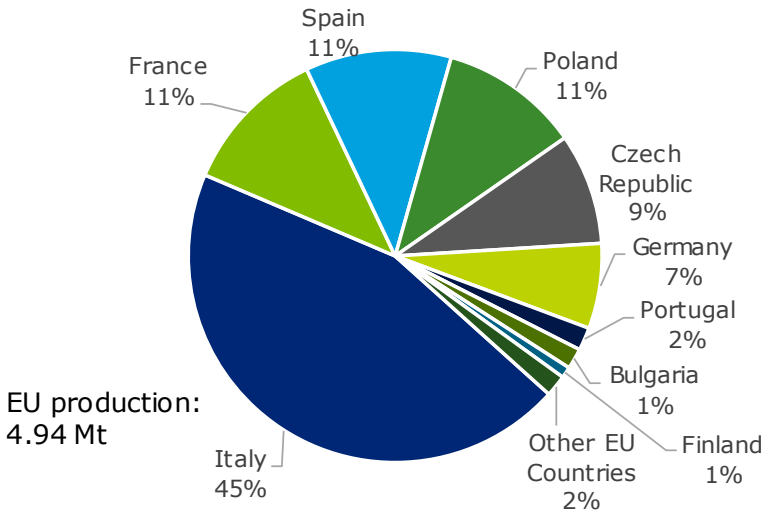


Figure 83: EU mine production of feldspar, average 2012-16 [WMD, 2019; Brown, 2016).

8.4.3 Supply from secondary materials/recycling

Feldspars (and feldspathoids) are mainly used as fluxes in ceramic and glass production (98.5%). In these applications, they are melted and no feldspars exist in the finished products (Dondi, 2018; IMA-Europe, 2018). Thus, recycling entails end-of-life glass and ceramics (containing the original feldspars transformed in a vitreous phase) that can act as flux.

Feldspars and feldspathoids used as fillers and extenders are englobed into paints, glues, plastic and rubber products, so no recycling is possible.

Glass can be recycled without any loss in purity and quality, but the average glass recycling rate in the EU is around 73% in the EU Member States (IMA-Europe, 2018). This because of loss during waste collection and sorting, and the occurrence of various contaminants (ceramics, metals, plastics, glues). In other terms, recycled glass (after primary and secondary beneficiation processing) is reducing feldspar consumption up to 70% in glass manufacturing.

Overall, when combining fledspar end-uses and recycling at end-of-life of products, the recycling rate (EoL-RIR) for feldspar is estimated to be around 7-8%.

8.4.4 Processing of feldspar

Processing of feldspathic raw materials encompasses washing, comminution, and beneficiation-concentration steps (Potter, 2006; McLemore, 2006). Various mineralurgical treatments are set up according to the desired characteristics of the final product. Comminution consists in primary and secondary crushing, often in circuit with high-field magnetic separation (and/or electrostatic separation) to remove micas, amphiboles and other undesired minerals (containing iron or titanium). Further wet or dry grinding (rod or ball mills) may be necessary to get the standard particle size (with a desliming step). Sometimes air classification is performed to get micronized powders in the dry route. High-quality feldspar products require further beneficiation or concentration, typically done by flotation and acid leaching. Flotation can be performed in multiple stages: cationic (to separate mica), anionic (to remove garnet,

ilmenite and other iron-bearing minerals) and cationic by amine with hydrofluoric acid (to enrich feldspars by separating quartz).

8.5 Other considerations

8.5.1 Environmental and health and safety issues

There are no major issues about health and safety associated to feldspar. Since feldspathic raw materials usually contain some quartz (*), there is some concern about Respirable Crystalline Silica (RCS) in the framework of the EU Directive 2017/2398 on "Protection of workers from exposure to carcinogens or mutagens at work", which implements a set of legal limits on exposure to certain substances in industrial workplaces. RCS is known to cause lung diseases in workers who are exposed high levels of it regularly for many years. This concern does not apply to nepheline syenite and other quartz-free raw materials. However, Directive 2017/2398 has no impact upon product classification and labelling, which is ruled by other separate legislation (the CLP Regulation 1278/2008). Directive 2017/2398 addresses respirable dust generated by work processes, not the substance itself. Feldspar placed on the market is subject to the classification obligation under Regulation (EC) 1272/2008, while crystalline silica dust generated by a work process is not placed on the market and therefore is not classified in accordance with that Regulation (IMA-Europe, 2019).

8.5.2 Socio-economic issues

No specific issues were identified during data collection and stakeholders consultation.

8.6 Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. The results of this and earlier assessments are shown in Table 41.

Table 41: Economic importance and supply risk results for Feldspar in the assessments of 2011, 2014, 2017, 2020 (European Commission, 2011; 17; 18)

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Feldspar	5.19	0.22	4.82	0.35	2.4	0.7	2.8	0.78

The supply risk increased continuously from ~0.2 (2011) to ~0.8 (2020) reflecting a trend that is still evolving through a strong increase of the EU import reliance, with a dependence of the EU industry substantially on one single mining district situated in Turkey. When using recent data (2017-2019) the supply risk would be very close to the threshold, thus suggesting that feldspar is a potentially critical raw material, despite its abundance on the Earth's crust.

8.7 Data sources

Data for the production of feldspar (WMD, 2019) have been integrated with those of nepheline syenite (Brown, 2016;,USGS, 2019) and corrected for the incorrect figure of Germany.

8.7.1 Data sources used in the factsheet

Brown, T.J., Idoine, N.E., Raycraft, E.R., Shaw R.A., Deady, E.A., Hobbs, S.F. & Bide T. (2016). World Mineral Production 2011-15, British Geological Survey, Keyworth, 96 p.

DERA (2019). Commodity prices: Commodity Price List, Volatility monitoring. German Mineral Resources Agency (DERA) and Federal Institute for Geosciences and Natural Resources (BGR).

Dondi, M. (2018). Feldspathic fluxes for ceramics: Sources, production trends and technological value. Resources, Conservation and Recycling, 133, 191-205.

Dondi, M., Guarini, G., Conte, S., Molinari, C., Soldati, R., Zanelli, C. (2019). Deposits, composition and technological behavior of fluxes for ceramic tiles. Periodico di Mineralogia, 88. doi: 10.2451/2019PM861.

European Commission (2011). Materials. Critical raw materials for the EU, Report of the Ad-hoc Working Group on defining critical raw materials.

European Commission (2014). Communication On the Review of the List of Critical Raw Materials for the EU and the Implementation of the Raw Materials Initiative, COM(2014)297final. Brussels.

European Commission (2017a). Communication on the List of Critical Raw Materials 2017, COM(2017) 490 Final. Brussels.

European Commission (2017b). Study on the review of the list of Critical Raw Materials – Non-critical raw materials factsheets. DG Internal Market, Industry, Entrepreneurship and SMEs (Deloitte Sust., BGS, BRGM, TNO), 476 p.

European Commission. (2019). "Negotiations and Agreements - Trade." http://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/ (July 7, 2019).

Eurostat (2019). "Easy Comext Database." http://epp.eurostat.ec.europa.eu/newxtweb/.

IMA-Europe (2018a). Recycling industrial minerals, 24 p., Brussels.

IMA-Europe (2018b). Using crystalline silica safely, White Paper, 22 p., Industrial Minerals Association, www.safesilica.eu

Kogel, J.E., Trivedi, N.C., Barker, J.M. & Krukowski, S.T. (eds.) (2006). Industrial Minerals and Rocks: Commodities, Markets and Uses, Littleton, Colorado, Society of Mining, Metallurgy and Exploration, 1565 p.

McLemore, V.T. (2006). Feldspar, in Industrial Minerals and Rocks: Commodities, Markets and Uses (Kogel, J.E., Trivedi, N.C., Barker, J.M. & Krukowski, S.T., eds.). Littleton, Colorado, Society of Mining, Metallurgy and Exploration, 653-670.

Minerals4EU (2019) European Minerals Knowledge Data Platform (EU-MKDP), www.minerals4eu.eu.

OECD. 2019. "Export Restrictions on Industrial Raw Materials." https://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials (July 5, 2019).

Potter, M.J. (2006). Feldspar, in Industrial Minerals and Rocks: Commodities, Markets and Uses (Kogel, J.E., Trivedi, N.C., Barker, J.M. & Krukowski, S.T., eds.). Littleton, Colorado, Society of Mining, Metallurgy and Exploration, 451-460.

SCRREEN workshop. 2019. "Validation Workshop on Critical Raw Materials, 10-12 September 2019, Thon Hotel Brussels City Centre."

USGS (2019). Feldspar and nepheline syenite, 58-59, in Mineral Commodity Summaries, Tanner, A.O, U. S. Geological Survey, 204 p.

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

8.7.2 Data sources used in the criticality assessment

BGS (2019a). European Mineral Statistics 2010-2014, British Geological Survey, 2016, Keyworth, Nottingham, 378 p.

BGS (2019b). World Mineral Production 2011-15, British Geological Survey, 2016, Keyworth, Nottingham, 96 p.

Dondi, M. (2018). Feldspathic fluxes for ceramics: Sources, production trends and technological value. Resources, Conservation and Recycling, 133, 191-205.

European Commission (2017a). Study on the review of the list of Critical Raw Materials – Report. DG Internal Market, Industry, Entrepreneurship and SMEs (Deloitte Sust., BGS, BRGM, TNO).

European Commission (2017b). Study on the review of the list of Critical Raw Materials – Non-critical raw materials factsheets. DG Internal Market, Industry, Entrepreneurship and SMEs (Deloitte Sust., BGS, BRGM, TNO), 476 p.

Eurostat (2019). "Easy Comext Database." http://epp.eurostat.ec.europa.eu/newxtweb/.

IMA-Europe (2018). Recycling industrial minerals, 24 p., Brussels.

Kogel, J.E., Trivedi, N.C., Barker, J.M. & Krukowski, S.T. (eds.) (2006). Industrial Minerals and Rocks: Commodities, Markets and Uses, Littleton, Colorado, Society of Mining, Metallurgy and Exploration, 1565 p.

USGS (2019). Feldspar and nepheline syenite, 58-59, in Mineral Commodity Summaries, Tanner, A.O, U. S. Geological Survey, 204 p.

WMD (2019). World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, Non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels.

8.8 Acknowledgments

This factsheet was prepared by the JRC in collaboration with Mr. Michele Dondi (CNR-ISTEC, Faenza, Italy). The authors would like to thank the Ad Hoc Working Group on Critical Raw Materials, in particular Ms. Aurela Shtiza and Ms. Francesca Girardi of IMA-Europe, as well as experts participating in SCRREEN workshops for their valuable contribution and feedback.

9. GOLD

9.1 Overview

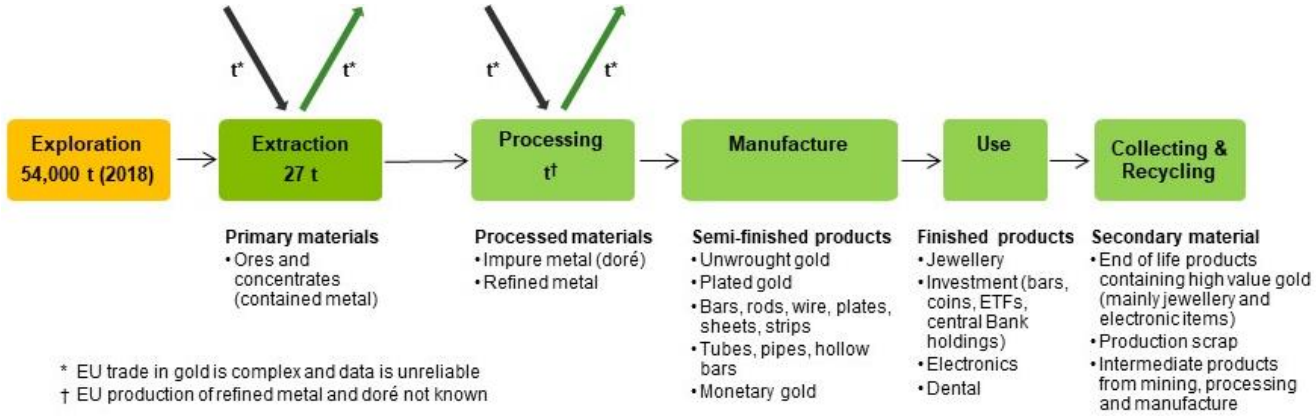
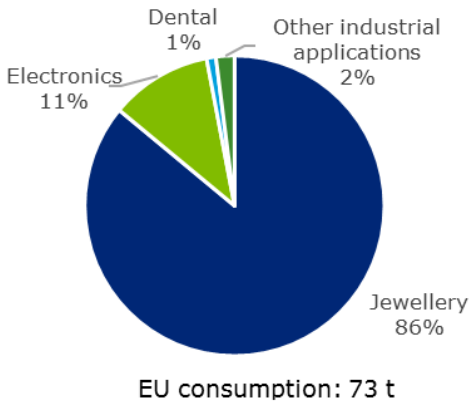
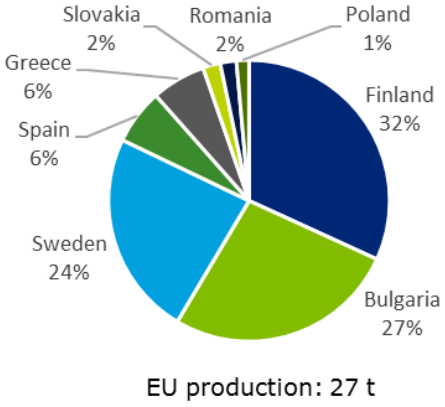


Figure 84: Simplified value chain for gold[63], average 2012-2016

Gold (chemical symbol Au; atomic number 79; atomic weight: 196.967; melting point: 1,064.18°C; boiling point: 2,856°C; density: 19.32 g/cm^3) is a dense, soft, malleable and ductile metal with a bright yellow colour and lustre. Gold, like silver and the platinum-group metals, is a noble and a precious metal. The term 'noble' refers to gold's ability to resist corrosion and oxidation in moist air. It has high thermal and electrical conductivity. It is rare in the Earth's crust with an estimated abundance of 0.004 ppm (Lide 2008). It is found in veins and alluvial deposits chiefly as the native metal, although it commonly occurs in a solid solution series with silver (as electrum) and alloyed with copper and palladium. Less commonly, it occurs in minerals as gold compounds, often with tellurium. Gold can be highly polished which, together with its colour and resistance to tarnishing, impart its 'precious' character, making it a treasured material for jewellery, which is its most important use. In addition, gold is used as a common monetary standard in coins and bars as a safe haven for storing wealth, for decoration, and as a plated coating on a wide variety of electrical and electronic equipment, as well as in dentistry and medicine (the radioisotope gold-198, with a half-life of 2.69 days, is used for radiotherapy in certain cancer treatments (Hainfeld et al. 2008)).



EU consumption: 73 t



EU production: 27 t

[63] JRC elaboration on multiple sources (see next sections)

Figure 85: Global end uses of gold and EU production (World Gold Council, 2019d; WMD, 2019)

Gold is mined in several EU member states but the corresponding production levels are relatively small on a global scale (0.8% in total; 27 t/y).

However, Europe has important gold refining and fabrication industries based on supply from both primary and secondary materials, derived from sources within and outside the EU. Gold is assessed at the extraction stage in the form of gold ores and concentrates. Gold and its alloys are traded in a wide variety of forms including unwrought gold, plated gold, powder, granules, bars, rods, wire, plates strips, sheets, foils, tubes and pipes. Most gold is traded as refined gold of 995 minimum fineness. In this factsheet, quantities are expressed in tonnes of gold metal content, and all figures are averaged over 2012–2016 data unless otherwise specified. It should be mentioned that EU trade in gold is rather complex and data is either unreliable or unavailable.

The price of gold is set on the LBMA (London Bullion Market) gold price auction with the price set in USD per fine troy ounce[64]. The LBMA publishes prices in US dollars, pounds sterling and euros. Following a sharp increase in 2012 to a historical high price of USD 1,669 per troy ounce, the price has gradually declined to an average annual price in 2018 of USD 1,268 per troy ounce (World Gold Council 2019c). In 2019 the price started increasing again to new historical highs; by September 2019, the price of gold was USD 1,538 per fine troy ounce. Though, below the 2011 peak of USD 1,877 per fine troy ounce, the price of gold is considered to be high and since the political instability around the world remains, a new significant increase of the price of gold might occur.

Given the diversity of forms in which gold is traded, the complexity of the market, the opaque nature of many transactions and possible uncertainties in trade statistics, it is not possible to derive a reliable single measure of gold consumption. However, regular publications by the World Gold Council provide some insight into gold demand by sector and its variation across the world. In 2018 the global demand for jewellery, which is by far the largest non-monetary use of gold, was approximately 2,241 tonnes or 51% (World Gold Council 2019b). China and India dominated the market with almost 1,341 tonnes (60% of the jewellery global demand together), while European demand for gold in jewellery was approximately 74.3 tonnes , or 3 % of the world total (World Gold Council 2019b).

Gold has a range of uses, both monetary and non-monetary. Monetary uses, comprising investment and holding of gold reserves by central banks, accounted in average for approximately 39 % of total gold demand between 2012 and 2016 (World Gold Council 2019b). In year 2018 this percentage increased to 41%. For the purposes of criticality assessment, it is however the non-monetary, industrial uses of the metal that are of interest. Hence, the remaining applications of gold are to be highlighted hereinafter.

As already mentioned above gold is mostly used in the production of jewellery, universally prized for its beauty and value. Technology demand for gold (electronics, other industrial and dentistry) is relatively small (7.6%), averaging approximately 350 tonnes per year from 2012 to 2016. In 2018 global technology demand amounted to 335 tonnes, of which about 80 % was used in electronics, 4.5% in dentistry and the rest in other industrial applications (World Gold Council 2019b).

Manufacturers are continually looking for ways to reduce the amount of gold required to make an object or substitute a less expensive metal. In jewellery, gold has no technical function and

[64] one troy ounce (oz t) equals exactly 31.1034768 grams

could theoretically from this point of view be replaced by other precious metals or by cheaper (gold) alloys. In electronic devices platinum, palladium and silver are possible substitutes for gold, but their uptake has been limited in the past, partly by their high prices. However, as gold prices have risen while those of the PGMs have been less buoyant in recent years this price differential has been eroded and increasing substitution has taken place.

There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of gold in different geographic areas of the EU or globally. USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. According to the U.S. Geological Survey, the world's reserves of gold are estimated at 54,000 tonnes (USGS 2019).

The global gold mine production was 3,197 t/y, as an average over 2012-2016. In 2018 mine production reached 3,502 t/y. As aforementioned, China is the world's largest producer (14%), followed by Australia (8%), Russia (8%) and the United States (7%). In the EU, Finland is the biggest producer averaging 8.6 tonnes per year (0.3% worldwide) over 2012-2016. Bulgaria and Sweden produce 7.2 tonnes per year and 6.4 tonnes per year, respectively, and the rest of Europe contributes with another 4.8 tonnes per year (WMD, 2019) . The post-consumer functional recycling of gold is well established, contributing to gold supply from secondary sources.

The gold related production processes are complex and they involve, similar to the processing of many other materials, the use of chemicals and other potential toxic compounds. However, when mining and processing are regulated adequately as in Europe, for example, no issues are expected. Yet, when it comes to artisanal and small-scale mining and processing of gold, the use of cyanide, mercury and other toxic substances may harm the surrounding ecosystems and pose threat to the inhabitants and artisans. Within the EU, gold mining and processing is already regulated by a strong legal framework to protect the environment as the main issue of concern.

9.2 Market analysis, trade and prices

9.2.1 Global market

The market value of the annual gold production is estimated at USD 7 trillion. Despite the size of its market, the way that gold is traded is often poorly understood (World Gold Council 2019d). The gold market is inherently global and gold is traded continuously throughout all time zones. Gold's disparate trading centres around the world are linked as market participants drive convergence of local gold prices through arbitrage activity. However, there are still important distinctions across different countries such as trade restrictions, taxes on gold and differing bar standards such that a single integrated gold trading market does not exist (World Gold Council 2019d). In addition to that, the diversity of forms in which gold and its alloys are traded makes its marketability an even more complicated issue.
Most gold is sold as refined gold bullion ranging in purity from 995-998 fineness, where fineness refers to the weight proportion of gold in an alloy or in impure gold, expressed in parts per thousand ("per mill"). By definition, 1000 fine is pure gold. Most gold bullion is traded on a 24 hour basis in over-the-counter (OTC) transactions. The governance of the market is maintained through the London Bullion Market Association's (LBMA) publication of the Good Delivery List. This is a list of accredited refiners whose standards of production and assaying meet LBMA specifications. Only bullion conforming to these standards is acceptable in

settlement against transactions conducted in the bullion market. Gold can also be traded in other forms including unwrought gold, plated gold, powder, granules, bars, rods, wire, plates strips, sheets, foils, tubes and pipes.

The global gold market is not dominated by any country. China is the leading producer of refined gold but its production is not that much higher compared to the producer countries following in descending order. In the recent years more than 50 countries around the world have been recorded to mine gold, while the top ten of them hold 63% of the global mine production (World Gold Council 2019d).

As regards the most important export restrictions in place in 2018, only China, Indonesia and Zimbabwe apply an export tax up to 25%.

9.2.2 Outlook for supply and demand

Excluding the monetary uses of gold, its consumption closely follows the trends in demand for jewellery (World Gold Council 2019d). Demand increases in countries like China and India, however, do not impose any supply risk. Global supply of gold is sufficient and its continuous trading all over the world ensures that there will be no supply chain disruption. Besides, the recycling rate of end-of-life products that contain high purity gold (electronic compounds and jewellery) is remarkably high (29%)[65]. Prices had no significant volatility during 2018, while in 2019 started increasing again, but not to an extent that would cause a stir in the global market.

Table 42: Qualitative forecast of supply and demand of gold

Material	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Gold		x	+	+	?	+	+	?

9.2.3 EU trade

Gold is traded in a wide variety of purities including: ores and concentrates; impure metal (doré); and refined metal or bullion. Gold and its alloys are traded also in a wide variety of forms including unwrought gold, plated gold, powder, granules,bars, rods, wire, plates, strips, sheets, foils, tubes and pipes. Most gold is traded as refined gold of 995 minimum fineness. However, in use it is normally alloyed with one or more other metals to provide specific properties of colour, abrasion resistance, hardness and strength. The alloy compositions and the forms in which they are available are determined by the intended use, whether in jewellery, dentistry, electronics or other applications. Most bullions are supplied in LBMA 400 ounce 'good delivery bars'.

Given the diversity of forms and purities in which gold is traded and in the sources from which it is derived, it is not possible to make up a reliable quantitative assessment of the EU gold trade. Accordingly the first stage in the value chain, ores and concentrates, for which complete and reliable global production data are available, was examined in the criticality assessment of gold. Trade data were extracted from the Eurostat Comext database (Eurostat 2019f) using the CN code 26169000 (precious-metal ores and concentrates, excluding silver ores and

[65] UNEP (2011) estimates the average global EOL recycling rate for gold to be in the range of 15-20%.

concentrates) based on value (EUR). This proxy is used because trade value data are considered more reliable than quantities to show the import distribution among countries.

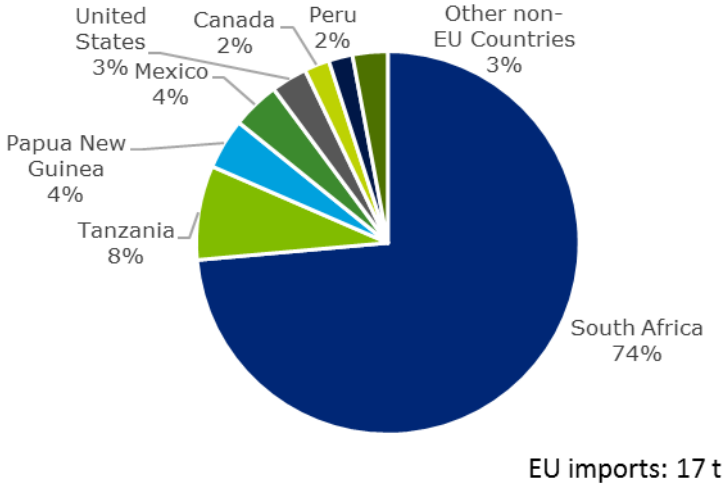


Figure 86: Distribution (%) of EU imports of precious metal ores and concentrates from non-EU countries, based on their value. Average 2012-2016 (Eurostat 2019)

EU imports of precious metals ores and concentrates were dominated in the period 2012-2016 by South Africa (with close to 74 % of the total by value) (see Figure 86). Tanzania was the second most important source of imports (8 % of total), followed by Papua New Guinea and Mexico (4 %, each). The EU has imported in the reference period (2012-2016) 17 tonnes per year, calculated on the basis that the gold content of the ores and concentrates is 0.1% (European Commission 2017b).

9.2.4 Prices and price volatility

Price discovery is crucial for any commodity market. Gold not only has a spot price, but it also has the LBMA Gold Price, as well as several regional prices. The gold price in US dollars per fine troy ounce is set twice daily through the LBMA Gold Price auction. The LBMA Gold Price is used as an important benchmark throughout the gold market, while regional gold prices are important to local markets.

After staying many years in the range USD 200–400 per troy ounce, the gold price increased steadily from 2003 to 2012 when the average annual price reached USD 1,669 per troy ounce (Figure 87). However, since 2012 the price has declined to the average annual price of USD 1,160 per troy ounce in 2015. In the first half of 2016 the gold price began to recover rapidly and peaked in the third quarter at about USD 1,335 per troy ounce, an increase of nearly 25% since the end of 2015. This price rise was due to increased investor demand resulting from global political uncertainties associated in particular with the UK's vote on EU membership and the US presidential elections. Very low interest rates across the world also provided a significant incentive for increased investment in gold. Since then, however, the price fell back to around USD 1,130 per troy ounce at the end of 2016, but recovered to about USD 1,230 per troy ounce in mid-February 2017. After small fluctuations, the price gradually increased again until end-January 2018 when it reached USD 1,353 per troy ounce. A few months later, the price of gold started to decline in May 2018 down to USD 1,180 per troy ounce in August of that year. Since then the price started increasing again to new historical highs. At the beginning of September 2019, the price of gold was USD 1,538 per troy ounce as illustrated in Figure 87 (World Gold Council 2019c).



Figure 87: Prices of gold, January 2000 to September 2019 (quarterly average prices from LBMA, World Gold Council, 2019b)

Volatility of the gold market is important for analysing current and future expectations or uncertainty for the price of gold itself as well as risk in the global markets. The gold price exhibited low volatility during 2018, mostly due to the improving economy and steady political situation worldwide, indicating the power of gold over politics and how this precious metal is directly related to global finances. Nevertheless, after the pause of 2018, prices started rising again, indicating that gold appeals as a safe investment asset in times of geo-political tensions. Since the US announced additional tariffs on Chinese goods, there has been a rout in global equity markets, lending support to prices of precious metals preceded by gold.

Global gold prices are still below the 2011 peak of USD 1877 per fine troy ounce. Nevertheless, the political instability worldwide and tense relations between dominant nations may cause a new sky-rocketing of the price of gold.

The long-term prices of gold are shown in Figure 88. The price curve shows real prices.

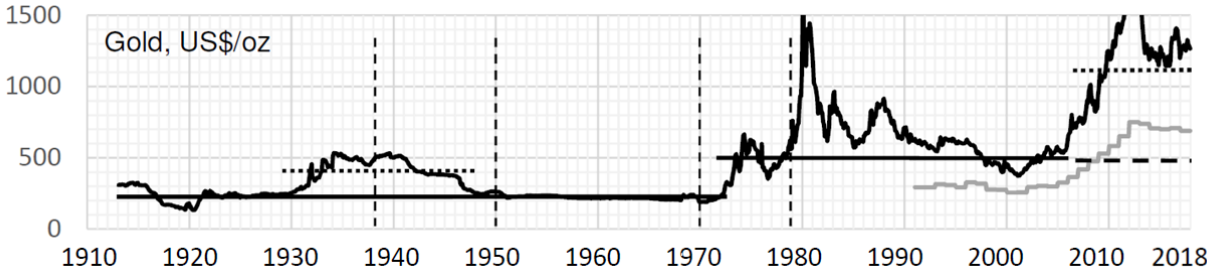


Figure 88: Gold prices. Vertical dashed line indicate breaks in price specification.(Buchholz et al., 2019)

9.3 EU demand

9.3.1 EU consumption

On average for the period 2012-2016, the EU consumed about 300 tonnes per year of gold for the production of jewellery and for technology and dentistry uses (World Gold Council 2019d). In 2018, consumption decreased to approximately 245 tonnes per year (World Gold Council 2019d). The above figures are equal to 8.2% and 7.4% of apparent global consumption respectively.

European demand for gold in jewellery was approximately 76.8 tonnes per year on average over 2012-2016, or 3.2 % of the world total (World Gold Council 2019d). In 2018, the respective figures were 73.4 tonnes per year, or 3.3% of the global consumption. The UK dominates EU demand for jewellery, accounting for about 30.7 % of the EU total, while Italy accounts for 26.5%, followed by France (18.7%), Germany (13.4%) and Spain (10.7%).

Technology demand for gold (electronics, other industrial and dentistry) is comparatively small. Data on the consumption for such uses in Europe is not available in the public domain, but it is apparent that the use of gold in electronics is dominated by Asian countries, including China, Taiwan and South Korea.

9.3.2 Uses and end-uses of gold in the EU

The end uses of gold products in the EU are multiple; both monetary and non-monetary. As already mentioned, for the purposes of criticality assessment, it is the non-monetary, industrial uses that are of interest. Accordingly, as in previous assessments that have been carried out on the basis of gold demand, only these applications for which data is available will be taken into consideration.

The most important non-monetary use of gold is in jewellery. Between 2012 and 2016 gold jewellery accounted for about 51 % of total gold demand and 86 % of its non-monetary use (Figure 89) (World Gold Council 2019d). India and China are the two largest markets for gold jewellery, together representing over half of global consumer demand in 2018.

About 11% of the global non-monetary demand for gold is in technical applications (Figure 89). The majority of this is used in electronic devices, where gold's conductivity and resistance to corrosion make it the material of choice for many high-specification and high-quality components. Gold is used in connectors, switch and relay contacts, soldered joints, connecting wires and connection strips.

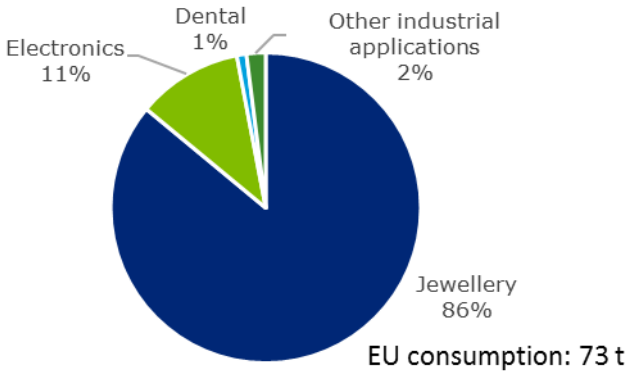


Figure 89: Global non-monetary end uses of gold, averaged over 2012–2016 (World Gold Council, 2019)

Gold is also used in dentistry because it is chemically inert, non-allergenic and malleable. Either pure gold or gold alloys are used for fillings, crowns, bridges and orthodontic appliances. The latter are more preferable since pure gold is rather soft (HV 25) and has a large elongation (45%). In recent years, pure gold has also been used through the electroforming process (Knosp et al, 2003). Tooth restorations such as porcelain veneered copings for crowns and bridgework can be electroformed with pure gold. Nevertheless, alloys including gold are nowadays more and more used.

There are numerous other minor industrial uses of gold. These include long-established applications such as coatings on various substrates to prevent corrosion and gas diffusion and for decorative purposes. On account of its very high malleability gold can be beaten into very thin sheets, so-called beaten gold, that are used to decorate picture frames, mouldings, furniture and parts of buildings. Small amounts of gold are also used in various high-technology industries, in complex and difficult environments, including the space industry, in fuel cells, in auto catalysts and in the manufacture of chemicals. The relevant industry sectors and their 2- and 4-digit NACE codes are summarised in Table 43.

Table 43: Gold applications, 2-digit and associated 4-digit NACE sectors, and value added per sector (World Gold Council, 2019a).

Applications	2-digit NACE sector	4-digit NACE sectors	Value-added of NACE 2 sector (M€)
Jewellery	C32 - Other manufacturing	C3212 - manufacture of jewellery and related articles	39,160
Electronics	C26 - Manufacture of computer, electronic and optical products	C2611 - manufacture of electronic components. Gold is used in connectors, switch and relay contacts, soldered joints, connecting wires and connection strips.	65,703
Dental	C32 - Other manufacturing	C3250 - manufacture of medical and dental instruments and supplies. Gold alloys are used for fillings, crowns, bridges, and orthodontic appliances.	39,160
Other industrial	C32 - Other manufacturing	coating, electrical engineering, medicine, space technology, nanotechnology, etc.	39,160

9.3.3 Substitution

Manufacturers are continually looking for ways to reduce the amount of gold (or other precious metals) required to make an object or substitute less expensive. In jewellery, gold has no technical function and could theoretically be replaced by other precious metals such as silver or platinum, or by cheaper alloys. However, this is likely to be minimal in practice because the importance of gold in jewellery is long established and unlikely to change. The use of gold is so deeply entrenched for thousands of years in many cultures, especially in China and India, that it is very unlikely that consumers would accept these alternative materials and effect large scale substitution of gold.

In its monetary uses, for investment and reserve holdings by central banks, gold cannot generally be substituted with alternatives because it is gold itself that is the particular material specified for these purposes. While exchange-traded funds, coins and bars based on platinum,

and to a lesser extent palladium and silver, have become well established in recent years, their market shares remain very small by comparison with gold.

In electronic devices, platinum, palladium and silver are possible substitutes for gold, but their uptake has been limited in the past, partly by their high prices. However, as gold prices have risen in recent years while those of the platinum group metals (PGMs) have been less buoyant, this price differential has been eroded and substitution has taken place in increasing volumes. Similarly, the use of base metals clad with gold alloys has long been employed as a way to reduce the amount of gold used in electronic devices. In some applications, copper may be a suitable alternative, but there is no data on sub-shares (Kamikoriyama et al. 2019).

In dentistry gold is increasingly being replaced by ceramics and cheaper base metal alloys.

9.4 Supply

9.4.1 EU supply chain

The supply chain for gold in the EU is complex and difficult to quantify. Gold supplies are derived from primary sources (mines), both within and outside the EU, and from secondary sources (refineries), both within and outside the EU. Refineries in the EU process a wide range of gold-bearing materials including impure gold, end-of-life products and manufacturing waste (new scrap). By-products from the mining, processing and manufacturing industries, related chiefly to gold, silver, copper and lead extraction, also contribute to the EU supply of gold. These include a wide range of materials such as concentrates, slags, mattes, flue dust, ash, slimes and other residues.

Primary gold production (mine production) in the EU is about 27 tonnes per year on average over the years 2012-2016 and takes place primarily in Finland, Sweden, Bulgaria, Spain and Turkey (World Gold Council 2019d). Mined gold is further refined in processing installations located in these countries or in other European countries, such as in Poland.

Gold mining projects are at the permitting stage across Europe in the United Kingdom, Portugal, Romania, Slovakia and Greece. Exploration of gold deposits is also underway in other countries, for example, France, Italy and Austria.

Apparently, Europe is rich in economically viable gold mining deposits. Despite its gold mining potential, Europe is still lagging behind the rest of the world. In 2018, EU's gold mine production accounted for less than 1% of world's gold production (nearly 2% when including the Turkish gold mine production) (World Gold Council 2019d). As a result, Europe is still heavily dependent on gold imports (>90%) from other countries.

Various gold mines exist in the EU countries, in particular in Sweden (8 Boliden mines, Blaiken mine, Svartliden mine and Faboliden mine), Finland (Pahtavaara mine, Kittila mine, Orivesi mine), Spain (2 Rio Narcea mines), Greenland (Nalunaq mine), Ireland (Omagh mine) and Portugal, with large mining projects and important gold exploration projects (TGM 2019).

In the Balkans, Bulgaria operates the Chelopech mine, the Kardzhali mine has been licensed and the Krumovgrand mine is expected to get its license. In Romania, the gold mine of Rosia Montana is expected to get its license, while in Serbia it has been announced that three state mines have been conceded to a major gold mining company for further exploration. The same happened recently in Kosovo (TGM 2019). In Greece, Hellas Gold has been given the mining license quite recently (September 2019) and the company is beginning operations.

In neighboring Turkey, the Turkish Gold Miners Association presents in its 2014 data at its website ten active gold mines. The gold mines of Cayeli, Mastra, Kisladag and Efemcukuru are operating, while two more mines are under development. There are currently approximately 70 active gold research and exploration projects in Turkey. Eldorado Gold, Thracean Gold Mining's parent company, developed and operates the Kisladag and Efemcukuru gold mines in Turkey.

9.4.2 Supply from primary materials

9.4.2.1 Geological occurrence/exploration:

Gold can be concentrated by a variety of geological settings and consequently occurs and is extracted from a number of different deposit types. Early mining mainly worked surface deposits of stream gravels, known as placers, also referred to as secondary deposits. From the second half of the nineteenth century, increased gold demand led to significant innovation in mining, beneficiation and extraction technologies that allowed the economic mining of gold from deposits in bedrock, referred to as primary deposits or lode gold deposits. Today the majority of gold is mined from primary deposits in which gold is the main product, but significant quantities are also produced as a co-product or by-product of base metal mining (chiefly copper, but also lead).

Gold deposits have been classified in many ways by different authors. Robert et al. (1997) distinguished sixteen common types of bedrock gold deposits based on their geological setting, the host rocks, the nature of the mineralisation and its geochemical signature. Among the most important types in terms of current production are:Orogenic gold, palaeoplacers, epithermal deposits, porphyry gold deposits, carlin type deposits, iron formation hosted deposits, gold-rich massive sulphides.

Extraction from placer deposits remains widespread. Where gold is extracted as the main product it is generally present in the ore at concentrations in the range 1-10 g/t (ppm). However depending on the size, location and type of deposit, grades considerably less than 1 ppm may be exploited, particularly if the gold is produced as a by-product of other metals. Porphyry deposits are particularly important in this regard: Some of the largest porphyry copper deposits are also important producers of gold. For example, the Grasberg deposit in Indonesia produces more than 330,000 t of copper per annum but also produces 1.2 million ounces of gold, making it one of the largest gold producing mines in the world (Freeport-McMoran 2016).

In primary deposits gold occurs chiefly as native metal, commonly alloyed with silver. The gold occurs in very small grains, rarely visible to the naked eye. Various gold telluride minerals are also known but these are seldom economic to mine.

Gold accounts for the major share of global exploration expenditure for non-ferrous metals. From an all-time high in 2012 of USD 10,500 million gold exploration, expenditure fell by about 60% to USD 4,200 million in 2015 (Schodde 2016). Latin America was the top destination for gold exploration with 27% of the total. This was followed by China, Africa and Canada, each with about 13% of the total exploration budget. About 3% of the total was spent in Western Europe. It is notable that of the 55 gold deposits containing more than 1,000,000 ounces of gold discovered in the period 2010-2013, only one was located in Europe, i.e. the Timok copper-gold deposit in Serbia (Schodde 2015).

9.4.2.2 Resources and reserves[66]

Global resources and reserves
USGS (2019) reports known global reserves of gold of approximately 54,000 tonnes. These are widely dispersed on all continents, with the largest amounts in Australia, Russia and South Africa (see Table 44).

Table 44: Global reserves of gold in 2018. (USGS, 2019; BGS, 2019b)

Country	Gold reserves (t)	Percentage of the total (%)
USA	3,000	5.5
Australia	9,800	18.1
Brazil	2,400	4.4
Canada	2,000	3.7
China	2,000	3.7
Ghana	1,000	1.9
Indonesia	2,500	4.6
Kazakhstan	1,000	1.9
Mexico	1,400	2.6
Papua New Guinea	1,300	2.4
Peru	2,600	4.8
Russia	5,300	9.8
South Africa	6,000	11.1
Uzbekistan	1,800	3.3
Other countries	12,000	22.2
World total	54,000	100

EU resources and reserves[67]*:* Resource data for some countries in Europe are available at Minerals4EU (2019) (see Table 45) but cannot be summed up as they are partial and they do not use the same reporting code.

[66] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of gold in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

[67] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for gold. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for gold, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for gold at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019). Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However a very solid estimation can be done by experts.

Data on known gold reserves in the EU and adjacent countries were collected in the EU FP7 project Minerals Intelligence Network for Europe (Minerals4EU 2019). Data for gold were obtained from eight of the countries surveyed (see Table 46). However, the data were reported according to eight different reporting systems and therefore cannot be aggregated to provide a partial total for Europe. We have no data on gold reserves in the other 31 countries that were surveyed during the Minerals4EU project.

The JORC-compliant resources of gold are located in the Scandinavian countries, as well as in the UK, Greenland, Ireland and Turkey. The resources in several Eastern European countries are based on national codes or on the Russian Classification. Some are based on the Canadian NI43-101 code, whereas for some others there is no known classification system.

Table 45: Gold resource data for the EU compiled in the European Minerals Yearbook at Minerals4EU (2019)

Country	Classification	Quantity (million t of ore)	Grade	Reporting code
Finland	Measured	16	0.83 g/t	JORC
	Measured	363	0.16 g/t	NI43-101
Sweden	Measured	32.45	1.08 g/t	JORC
	Measured	0.21	2.23 g/t	NI43-101
	Measured	513.4	0.12 g/t	FRB-standard
Norway	Indicated	7.86	0.53 g/t	JORC
Greenland	Indicated	5.08	1.25 g/t	JORC
UK	Measured	0.06	15 g/t	JORC
	Measured	0.161	9.1 g/t	NI43-101
Ireland	Indicated	4.927	1.64 g/t	JORC
Ukraine	P1	407.7	-	Russian Classification
Czech Republic	P1	60.2	-	Nat. Rep. Code
Slovakia	Verified (Z1)	7.335	1.59 g/t	None
Hungary	C1	34.59	-	Russian Classification
Romania	333	760	Ag + Au	UNFC
Serbia	Indicated	46.3	1.56 g/t	NI43-101
North Macedonia	A	37.16	0.64 g/t	Ex -Yugoslavian
Albania	A	0.01	1-4 g/t	Nat. Rep. Code
Greece	Indicated	81	0.06-0.08%	USGS
Turkey	Measured	32.8	2.4 g/t	JORC
	Measured	96.1	0.97 g/t	NI43-101
France	Historic resource estimate	0.17	-	None
Spain	Measured	17.3×10^{-6}	3.99 g/t	NI43-101
Portugal	Indicated	4.233	1.57%	NI43-101

Table 46: Gold reserves data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU 2019)

Country	Classification	Quantity (million t of ore)	Grade (% Cr)	Reporting code
Spain	Proven	8.479×10^{-6}	-	NI43-101
Greece	Proven	0.2027	-	CIM
Turkey	Proven	20.51	2.51 g/t	JORC
	Proven	92.726	0.96 g/t	NI43-101
Northern Macedonia	A	37.161	0.64 g/t	Ex-Yukoslavian
Slovakia	Verified (Z1)	7.335	1.59 g/t	None
Czech Republic	Economic explored	0.0487	0.00019%	Nat. Rep. Code
Finland	Proven	8.9	1.3 g/t	JORC
	Proven	190	0.92 g/t	NI43-101
Sweden	Proven	0.41	2.2 g/t	JORC
	Proven	0.09	0.71 g/t	NI43-101
	Proven	517.1	0.16 g/t	FRB-Standard

9.4.2.3 World and EU mine production

Gold is mined in numerous countries and on every continent apart from Antarctica. Between 2012–2016, global annual production averaged 3,197 tonne. China is the leading producer, accounting for 14% of global production per annum between 2012–2016 (see Figure 90).

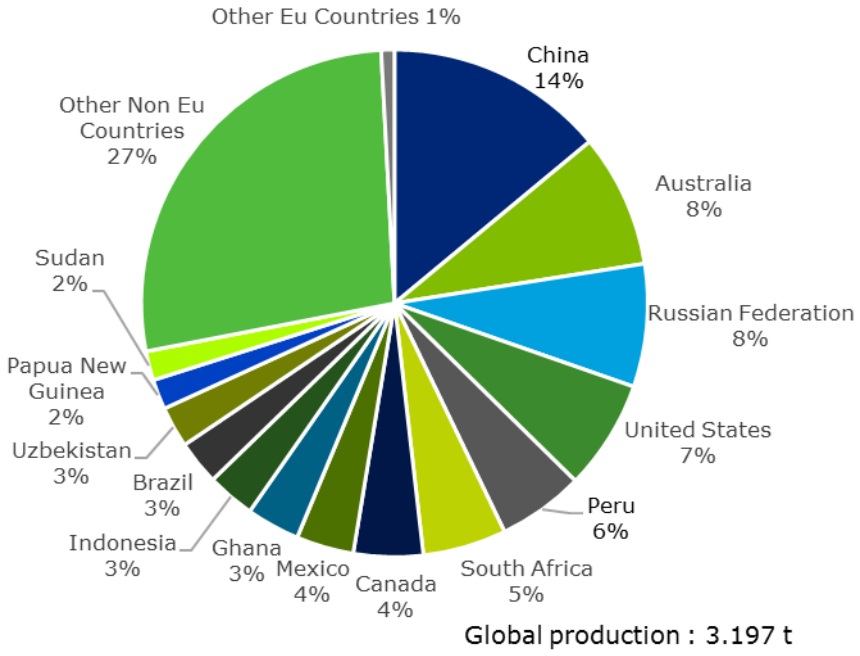


Figure 90: Global mine production of gold. Average 2012-2016 (WMD, 2019; BGS, 2019b; USGS, 2019; World Gold Council, 2019c)

Gold production in the EU averaged 27 tonnes per annum between 2012–2016, equivalent to 0.85% of the global total production. The top three EU producers were Finland (32% of EU total), Bulgaria (27%) and Sweden (24%).

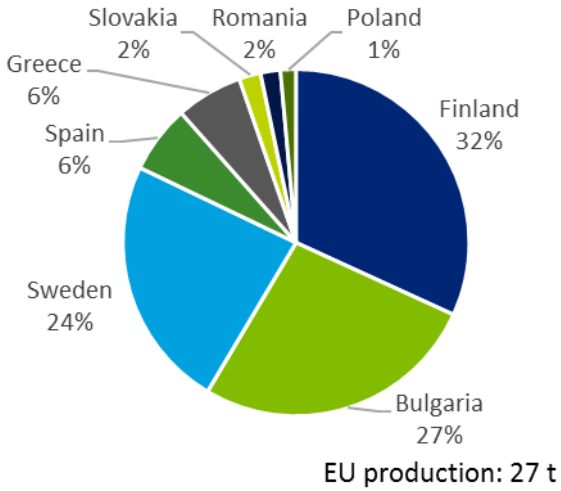


Figure 91: EU mine production of gold. Average 2012-2016. (WMD, 2019)

9.4.3 Supply from secondary materials/recycling

While there are substantial stocks of gold in use comprising jewellery, central bank holdings, private investment and industrial fabrication, it is unlikely that much of this will ever re-enter the supply chain. The reasons for this are many and varied, but in general jewellery and religious artefacts are viewed either as sacred or as precious assets handed down from one generation to another. Central banks view gold as an important reserve asset and, in recent years, they have been more likely to buy than sell gold. In electronic devices, much of the gold is not recovered because they are not efficiently collected at the end of their lifetime.

The contribution of recycling to gold supply varies markedly with gold price. In 2009, as a result of high prices and global economic disruption, it peaked at 1,728 tonnes, equivalent to 42 % of total gold supply (Boston Consulting Group 2015). Since then, however, as prices have fallen and global economic recovery began, gold recycling has decreased. In 2014 it accounted for 26% of total supply.

The majority of gold recycling, about 90%, is from high-value source materials such as jewellery, gold bars and coins which contain a significant proportion of gold alloyed with one or more other metals (Boston Consulting Group 2015). The techniques involved in recovering the gold from these materials are relatively simple and well established; although for some purposes where the desired purity of the output is critical, the techniques are available only in large-scale specialist refineries.

Gold derived from recycling industrial source materials, such as waste from electrical and electronic equipment (WEEE), provided the other 10% of secondary supply, up from about 5% in 2004 (Boston Consulting Group 2015). In printed circuit boards and mobile phones, the gold concentration is estimated to be between 200 and 350 g/t. Apart from the challenge of efficient collection of these devices at the end of their life, it is technically very difficult to extract the gold and other precious metals (palladium and silver). Although the technology required to handle these materials is now both technically efficient and environmentally friendly, it is highly specialised and not widely available.

Gold is also recycled from a wide variety of intermediate products and by-products from mining and metallurgical operations. These include, for example, anode slimes and flue dusts

from copper and lead smelters, complex concentrates of lead, zinc, silver and gold, and by-products from gold mining such as sludges and residues.

UNEP (2011)estimates the average global end-of-life (EoL) recycling rate for gold to be in the range of 20%. This estimate does not include recycling of jewellery and coins because there is typically no end of life management for these products. On the other hand, the (World Gold Council 2019b) estimates that the recycling rate of gold is approximately 29%.

9.4.4 Processing of gold

Gold-bearing ores may be extracted from either surface (open pit) or underground mining operations depending on many variables, chiefly the grade, size, shape and location of the deposit. Some gold-bearing ores are exploited at very big depths, exceeding 3 km from the surface. For example, AngloGold Ashanti's Mponeng gold mine in South Africa is currently the deepest mine operation in the world, at a depth of 4km.

In a free milling ore gold is found in native form and can be extracted directly by dissolution, generally cyanide leaching. The ground ore is treated with sodium cyanide solution which dissolves the gold and silver. The gold is then collected from the solution by activated carbon pellets, typically made from charred coconut husks. This is referred to as the carbon-in-pulp process. The pellets are then recovered and the gold stripped from them by washing with hot cyanide solution. The gold and silver are recovered from the solution by electrochemical deposition. The cathode deposit is then refined into impure bullion or doré, a mixture of mostly gold and silver.

Following conventional mining operations, some ores may be treated by heap leaching in which a weak cyanide solution is sprinkled onto an open pile of ore stacked on an impervious base (typical example is the Chovdar gold mine in Azerbaijan). Free milling gold can also be recovered by direct flotation (since gold is naturally hydrophobic).

In a refractory ore, very fine grained gold is enclosed in the bearing mineral (usually sulphides or carbonaceous material) that is impervious to cyanide leaching. The gold cannot therefore be dissolved directly and some form of pre-treatment is required before the gold can be liberated. Roasting, bacterial oxidation and pressure oxidation are the most common forms of pre-treatment of refractory gold ores (Coetzee et al. 2011).

In gold-silver doré, the gold is recovered at a precious metals refinery. This typically involves two stages of processing, chlorination which yields gold of 99.5% to 99.8% purity, followed by electrorefining which produces gold with a purity of 99.9% or greater.

By-product gold in base metal ores is normally recovered with the other metallic minerals by flotation. The flotation concentrates are shipped to smelters where the gold is ultimately recovered as a by-product of smelting or refining. Gold is smelted in a crucible furnace to oxidise the base metal impurities. The resulting ingots are refined to produce pure gold.

9.5 Other considerations

9.5.1 Environmental issues

The production of gold is highly energy-intensive and the processing of the ore involves toxic substances and chemical components. However, no environmental restriction on placing on the market and using gold is known. Regulatory issues are linked with conflict minerals legislation issues (EU 2017).

Contribution to low-carbon technologies and climate change

Gold's downstream uses – gold in bullion, jewellery, and electronic products – have little material impact on either gold's overall carbon footprint or greenhouse gas (GHG) emissions, which are very small and relatively insignificant in terms of its likely contribution to climate change.

Refining and broadening their understanding of gold's overall emissions profile, the World Gold Council has released a new report (World Gold Council 2019a) in which an extended analysis is described with a focus on the potential decarbonisation of the gold supply chain and climate-related investment impacts. This analysis suggests that there are substantial opportunities for the gold supply chain, and particularly gold mining, to adapt to a net zero carbon future (World Gold Council 2019a).

9.5.2 Health and safety issues

Gold itself is an inert metal that can cause no health and safety issues. Nevertheless, its processing could involve hazardous substances that can be harmful to man and nature. Especially when it comes to small scale and artisanal mining, miners, who have used elemental mercury to amalgamate and extract gold, are potentially heavily contaminated with mercury (Eisler 2003).

9.5.3 Socio-economic issues

Gold falls within the scope of Regulation (EU) 2017/821 (sometimes referred to as the Conflict Minerals Regulation)[68].

The Regulation sets out legally binding due diligence requirements for EU importers of tin, tantalum, tungsten and gold that will apply as of 1 January 2021. The main objective of the Regulation is to break the link between the trade in these minerals and metals and armed conflict and associated human rights abuses. The Regulation will also provide transparency and certainty as regards the supply practices of EU importers sourcing from conflict-affected and high-risk areas.

The Regulation's due diligence requirements are aligned with the 5-step framework for risk-based due diligence developed by the Organisation for Economic Co-operation and Development (OECD) 'Due Diligence Guidance for Responsible Supply Chains from Conflict-Affected and High-Risk Areas' (OECD 2013).

Legislation to address similar concerns with regard to the DRC and neighbouring countries was enacted in the US in 2010 through the Dodd-Frank Act.

9.6 Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. Supply risk has been analysed at the mine stage. The results of this review and earlier assessments are shown in Table 47.

[68] Regulation (EU) *2017/821* of the European Parliament and of the Council of 17 May 2017 laying down supply chain due diligence obligations for Union importers of tin, tantalum and tungsten, their ores, and gold originating from conflict-affected and high-risk areas, OJ L 130, 19.5.2017, p. 1–20

Table 47: Economic importance and supply risk results for gold in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014); 2017 (European Commission, 2017a; 2017b) and 2020.

Assessment	2011			2014			2017			2020	
Indicator	EI	SR		EI	SR		EI	SR		EI	SR
Gold	n/a	n/a		3.78	0.15		2.0	0.2		2.11	0.19

9.7 Data sources

While the World Gold Council (WGC) provides through its website an extensive archive of statistics on supply, demand, prices and other variables, the majority of such information deals with the global situation and very little data specific for Europe or the EU are available from these sources.

The monetary uses (investment and central bank gold reserves), which account for about 41 % of global gold demand, are not considered in this criticality assessment. The assessment methodology measures the economic importance of the raw material based on its use in manufacturing. Accordingly, as in the previous EU criticality assessment (European Commission 2014), only the non-monetary uses of gold are considered.

Production data for gold are dynamic and are changing every year, while previous years announcements are always corrected (especially in the annual series of the USGS Mineral Yearbooks). For this reason, data from four different sources (WMD, 2019; World Gold Council, 2019d; BGS, 2019b; USGS, 2019) were cross-compared to validate the actual production figures. The data from the four sources do not match perfectly, but there is significant consistency and the minor differences can be attributed to the dynamic nature of the data. On this basis, the data from the World Gold Council is implemented in the calculations.

Trade data for 'precious metal ores and concentrates, excluding silver ores and concentrates' were extracted from the Eurostat COMEXT online database (Eurostat 2019) using the Combined Nomenclature (CN) code 2616 9000. There are some concerns over the reliability of the Eurostat data available for trade in precious metal ores and concentrates. These data are reported in value and no information is given on the actual gold concentration within the 'ores and concentrates'. Without this information it was not possible to determine EU consumption and import reliance of gold in this form.

The recycling rate for gold is difficult to quantify because of the lack of reliable data. This part of the supply chain is also extremely sensitive to the gold price, increasing rapidly when the price is high, but falling back when it is low. Furthermore, it is generally considered that a very large proportion of gold in use in high-value applications (jewellery, religious artefacts, coins, bars, etc.) will rarely become available for recycling and will therefore not be able to make a major contribution to the supply. Recycling rates from technological applications are low because of inefficient collection at the end of life and because the technology for gold recovery is highly specialised and not widely available. The EOL recycling rate for gold was estimated by UNEP to be 20 %, whereas the World Gold Council (2019) determines a recycling rate of 29%.

9.7.1 Data sources used in the factsheet

BGS (2019a) World mineral statistics data, British Geological Survey . Available at: https://www.bgs.ac.uk/mineralsuk/statistics/wms.cfc?method=searchWMS (Accessed: 30 July 2019).

BGS (2019b) World mineral statistics data, British Geological Survey .

Boston Consulting Group (2015) The Ups and Downs of Gold Recycling. Boston Consulting Group and World Gold Council. Available at: http://www.gold.org/supply-and-demand/ups-and-downs-gold-recycling (Accessed: 1 September 2019).

Coetzee, L. L. et al. (2011) 'Modern gold deportments and its application to industry', Minerals Engineering, 24(6), pp. 565–575. doi: 10.1016/j.mineng.2010.09.001.

Eisler, R. (2003) 'Health Risks of Gold Miners: A Synoptic Review', Environmental Geochemistry and Health, 25(3), pp. 325–345. doi: 10.1023/A:1024573701073.

EU (2017) '791 Regulation (EU) 2017/821 of the European Parliament and of the Council of 17 May 2017 laying down supply chain due diligence obligations for Union importers of tin, tantalum and tungsten, their ores, and gold originating from conflict-affected and hig'.

European Commission (2014) Report on critical raw materials for the EU - Critical raw materials profiles. Available at: https://ec.europa.eu/docsroom/documents/11911/attachments/1/translations/en/renditions/pdf.

European Commission (2017a) Study on the review of the list of critical raw materials. Critical Raw Material Factsheets. European Commission. doi: 10.2873/398823.

European Commission (2017b) Study on the review of the list of critical raw materials. Non-critical raw materials factsheets. European Commission. doi: 10.2873/876644.

Eurostat (2019) Easy Comext database. Available at: http://epp.eurostat.ec.europa.eu/newxtweb/.

Freeport-McMoran (2016) 'Driven by Value: Annual report'. Available at: http://www.annualreports.com/HostedData/AnnualReportArchive/f/NYSE_FCX_2016.pdf.

Hainfeld, J. F. et al. (2008) 'Radiotherapy enhancement with gold nanoparticles', Journal of Pharmacy and Pharmacology, 60(8), pp. 977–985. doi: 10.1211/jpp.60.8.0005.

Kamikoriyama, Y. et al. (2019) 'Ambient Aqueous-Phase Synthesis of Copper Nanoparticles and Nanopastes with Low-Temperature Sintering and Ultra-High Bonding Abilities', Scientific Reports, 9(1), p. 899. doi: 10.1038/s41598-018-38422-5.

Knosp, H., Holliday, R. J. and Corti, C. W. (2003) 'Gold in dentistry: Alloys, uses and performance', Gold Bulletin, 36(3), pp. 93–102. doi: 10.1007/BF03215496.

Lide, D. R. (2008) 'CRC Handbook of Chemistry and Physics, 88th edition'.

Minerals4EU (2019) European Minerals Yearbook. Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html (Accessed: 9 July 2019).

OECD (2013) Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas. Available at: https://www.oecd-ilibrary.org/ governance/oecd-due-diligence-guidance-for-responsible-supply-chains-of-minerals-from-conflict-affect.

Robert, F., Poulsen, K. H. and Dube, B. (1997) 'Gold Deposits and Their Geological Classification', Proceedings of Exploration 97: Fourth Decennial International Conference on Mineral Exploration, pp. 209–220.

Schodde, R. (2015) 'Long term trends in gold exploration. Presented at NewGenGold 2015'. Available at: http://www.minexconsulting.com/publications.html.

Schodde, R. (2016) 'Long term trends in gold exploration: Is the love affair over or is it just warming up? Technical presentation to the Melbourne Branch of the AusIMM'. Available at:

http://www.minexconsulting.com/publications.html.

TGM (2019) Thracean Gold Mining S.A. - Gold mines in the EU. Available at: https://www.tgm.gr/project-information/gold-mines-in-the-eu/?lang=en (Accessed: 16 September 2019).

UNEP (2011) Recycling rates of Metals - A status Report, A Report of the Working Group on the Global Metal Flows to the International Resource Panel.

USGS (2019) Mineral Commodity Summaries 2019. U.S Geological Survey. doi: 10.1007/978-3-540-47108-0-4.

World Gold Council (2019a) Gold and climate change: Current and future impacts. Available at: https://www.gold.org/goldhub/research/gold-and-climate-change-current-and-future-impacts (Accessed: 16 July 2019).

World Gold Council (2019b) Gold Demand Trends Full Year 2018. Available at: http://www.gold.org/supply-and-demand/gold-demand-trends/back-issues/gold-demand-trends-full-year-2015 (Accessed: 16 July 2019).

World Gold Council (2019c) Historical prices. Available at: http://www.gold.org/statistics#historical-prices (Accessed: 16 July 2019).

World Gold Council (2019d) Supply and demand data. Available at: http://www.gold.org/statistics#supply-and-demand-data (Accessed: 16 July 2019).

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

9.7.2 Data sources used in the criticality assessment

Aindow, M., Alpay, S. P., Liu, Y., Mantese, J. V. and Senturk, B.S. (2010). Base metal alloys with self-healing native conductive oxides for electrical contact materials, Applied Physics Letters, 2010; 97 (15): 152103 DOI: 10.1063/1.3499369

Argus Media (2019). Weekly price updates. Available at: https://www.argusmedia.com/

BGS (2019). BGS- World Mineral Statistics database; World Mineral Production 2012-2016 reports

Donaldson, J.A. (1980). *The use of gold in dentistry*, Gold Bulletin, 160-165

European Commission (2011) *Critical raw materials*. Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en (Accessed: 8 July 2019).

European Commission (2014) *Report on critical raw materials for the EU - Critical raw materials profiles.* Available at: https://ec.europa.eu/docsroom/documents/11911/attachments/1/translations/en/renditions/pdf.

European Commission (2017a) *Study on the review of the list of critical raw materials. Critical Raw Material Factsheets*. European Commission. doi: 10.2873/398823.

European Commission (2017b) *Study on the review of the list of critical raw materials. Non-critical raw materials factsheets.* European Commission. doi: 10.2873/876644.

European Commission (2019). DG Trade website "Agreements", Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/

Eurostat (2019a) *Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E)*. Available at: https://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_ R2 (Accessed: 7 July 2019).

Eurostat (2019b) *Easy Comext database*. Available at: http://epp.eurostat.ec.europa.eu/ newxtweb/ (Accessed: 7 July 2019).

Greenwood, N. N. and Earnshaw, A. (1997). Chemistry of the Elements, 2nd edition. Oxford: Butterworth-Heinemann

Hainfeld, J.F., Dilmanian, F.A., Slatkin, D.N. and Smilowitz, H.M. (2008). Ra*diotherapy enhancement with gold nanoparticles*, Journal of Pharmacy and Pharmacology. 60(8): 977–85. doi:10.1211/jpp.60.8.0005. PMID 18644191

Kamikoriyama, Y., Inamura, H., Muramatsu, A. and Kanie, K. (2019). Ambient Aqueous-Phase Synthesis of Copper Nanoparticles and Nanopastes with Low-Temperature Sintering and Ultra-High Bonding Abilities, Scientific Reports, 9(899). DOI: 10.1038/s41598-018-38422-5

Knosp H., Holliday, R.J. and Corti, C.W. (2003). *Gold in Dentistry: Alloys, Uses and Performance*, Gold Bulletin, 36(3): 93-102

Lide, D. R. (2008) *CRC Handbook of Chemistry and Physics*, 88th edition. Boca Raton, Florida: Taylor & Francis Group.

OECD (2019a) *Export restrictions on Industrial Raw Materials*. Available at: https://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials (Accessed: 5 July 2019).

OECD (2019b) *Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas*. Available at: https://www.oecd-ilibrary.org/ governance/oecd-due-diligence-guidance-for-responsible-supply-chains-of-minerals-from-conflict-affected-and-high-risk-areas_9789264185050-en (Accessed: 5 July 2019).

Stock, V., Schmidlin, P.R., Merk, S., Wagner, C., Roos, M., Eichberger, M. and Stawarczyk, B. (2016). PEEK Primary crowns with cobalt-chromium, zirconia and galvanic secondary crowns with different tapers - A comparison of retention forces, Materials, 187(9):1-10

USGS (2019). Mineral Commodity Summaries - Gold reports (2012; 2013; 2014; 2015;2016)

World Gold Council. (2019a). World Gold Council - compiled from various reports on Gold Demand Trends - Full Year 2012, Full Year 2013, Full Year 2014, Full Year 2015, Full Year 2016

World Gold Council. (2019b). Gold Mining Production Volumes (2012-2016)

9.8 Acknowledgments

This factsheet was prepared by the JRC in collaboration with Mr. Georgios Barakos (TU Bergakademie Freiberg, Germany). The authors would like to thank the Ad Hoc Working Group on Critical Raw Materials as well as experts participating in SCRREEN workshops for their contribution and feedback.

10. GYPSUM

10.1 Overview

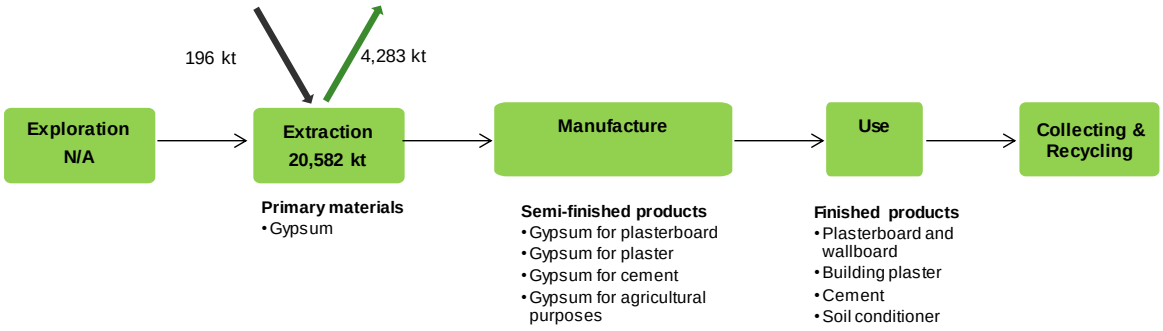


Figure 92: Simplified value chain for gypsum in the EU[69] (average 2012-2016).

Gypsum ($CaSO_4.2H_2O$) is an evaporite mineral formed by precipitation, commonly from lake or sea water. It can also form in hot springs or precipitate from volcanic gases. Anhydrite is a dehydrated variety of the same mineral (chemical formula: $CaSO_4$). Gypsum plaster, also called plaster of Paris is a calcined variety (heated to remove water) which is also known as a hemihydrate. This calcined gypsum is the main semi-product for further manufacturing of plaster based products. Alabaster is a fine-grained, white or lightly tinted, gypsum which has been used since ancient times for sculpture. Gypsum has a hardness of 2.0 on Mohs scale (and is used to define that point on this relative scale), is moderately water soluble and if pure will be white or colourless.

Trade data refer to CN code 2520 1000 – "gypsum; anhydrite" (Eurostat Comext, 2019).

The future demand for gypsum is driven by the plasterboard sector. Use of plasterboard has tripled in the past 25 years and on the assumption that the building construction sector continues to grow, it is expected that the plasterboard and gypsum sector will grow too in the near future.

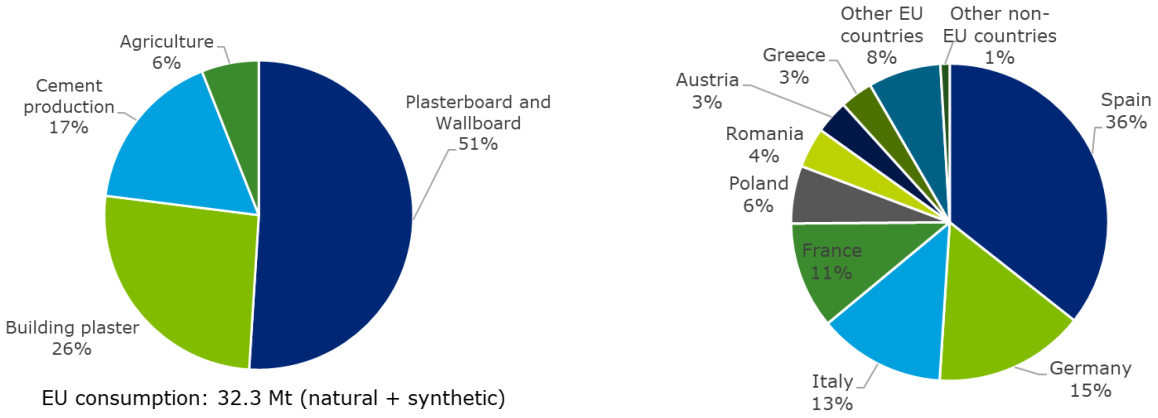


Figure 93: End uses (Eurogypsum, 2020; NERA, 2016) and EU sourcing of Gypsum (BGS, 2019; Eurostat, 2019) (2012-16).

[69] JRC elaboration on multiple sources (see next sections)

The average unit price of gypsum in the period 2014-2018 reported by USGS (2019) and U.S. producers was around EUR 7.2 per tonne of crude gypsum. The prices of the different gypsum products vary widely depending on its type, for example EUR 27 per tonne for calcined gypsum, EUR 38 per tonne for gypsum used in agricultural uses and EUR 385 per tonne for plaster.

The EU apparent consumption in the period 2012-2016 (5-year average) is estimated at 32.3 Mt per year (natural + synthetic). The majority of the EU production is consumed within the European area and can sufficiently satisfy EU industry demand for gypsum without import reliance issues.

Gypsum is used in the production of plasterboard and wallboard products, in the manufacture of building plaster, in cement production and in agriculture as a soil conditioner. Substitutes for gypsum used in plasterboard and wallboard include synthetic gypsum and recycled gypsum. Wood based wall panels, renewable material wall panels, plastic and metal panels, brick and glass may also be used to construct wallboards. In applications such as building plaster and stucco, gypsum may be substituted by cement and lime plaster. Synthetic gypsum (mainly FGD gypsum) is used as an alternative material in the production of cement and as a soil conditioner in agriculture.

Reserves are believed to be large, but data for several countries are not available or reliable. The gypsum reserves in China are estimated at 17 billion tonnes and in Iran at 2.2 billion tonnes. Other countries with large reserves are the US, Canada, Brazil and Turkey. A global reserve figure cannot be estimated as data from several major producing countries (Thailand, Iraq, Mexico, etc.) are missing. Reserve data for some European countries are available at Minerals4EU website (2019) but cannot be summed as they are incomplete and they do not use the same reporting code.

The trade of gypsum is relatively low when compared to production. Europe does not rely on gypsum imported from other countries, but on the availability of domestic resources, thus, there is no import reliance on gypsum in EU.

World mine production of gypsum is 265.5 Mt. China is the largest producer of gypsum with a share of 48.7% of the global production, followed by the United States and Iran who both have around 6% share of the global production. Many more countries, more than 80, produce gypsum around the world. The 5 years average EU production of gypsum between 2012 and 2016 was 21.8 Mt/y, which accounts for 8.2% of the global production, down from 14% for the period 2010-2014. Producing countries include Spain, Germany, France, Poland, Italy and others.

The European Union follows a strong "decarbonisation" route regarding energy generation and has set long-term objectives for reducing dependency on coal/lignite power stations. Based on this, the production and availability of flue gas desulphurization (FGD) gypsum, a major substitute to gypsum, is expected to decrease substantially, by 40 to 50% until 2035. Recycled gypsum is produced from the processing of gypsum waste products, namely plasterboard waste. Gypsum recycling varies considerably across Europe. Only 1% of the total gypsum used by the European industry is obtained from recycling of gypsum products at end-of-life.

Information on export restrictions are accessed by the OECD Export restrictions on Industrial Raw Materials database (OECD, 2019). There are no export restrictions, quotas or prohibitions identified that may impact on the availability of gypsum.

10.2 Market analysis, trade and prices

10.2.1 Global market analysis and outlook

The future demand for gypsum is driven by the plasterboard sector. Plasterboards are widely used in buildings. Use of plasterboard has tripled between 1995 and 2020 and on the assumption that the building construction sector will continue to grow, it is expected that the plasterboard and gypsum sector will grow too. The same trend is foreseen for building plaster and cement production, as they are closely linked to the construction sector (British Geological Survey, 2006; DG Environment, 2010; Eurogypsum, 2009; Roskill, 2014; Mordor Intelligence, 2019).

The prediction of future supply of gypsum is more complicated due to interlinkages of the flows of natural gypsum and synthetic gypsum[70]. The uncertainties surrounding the future supply of FGD gypsum influence the future need for natural gypsum. The European Union follows a strong "decarbonisation" route regarding energy generation and has set long-term objectives for reducing dependency on coal/lignite power stations. Based on this, the availability of FGD gypsum is expected to drop the following years, thus FGD gypsum production is anticipated to decrease by 40 to 50% until 2035 (Eurogypsum, 2020).

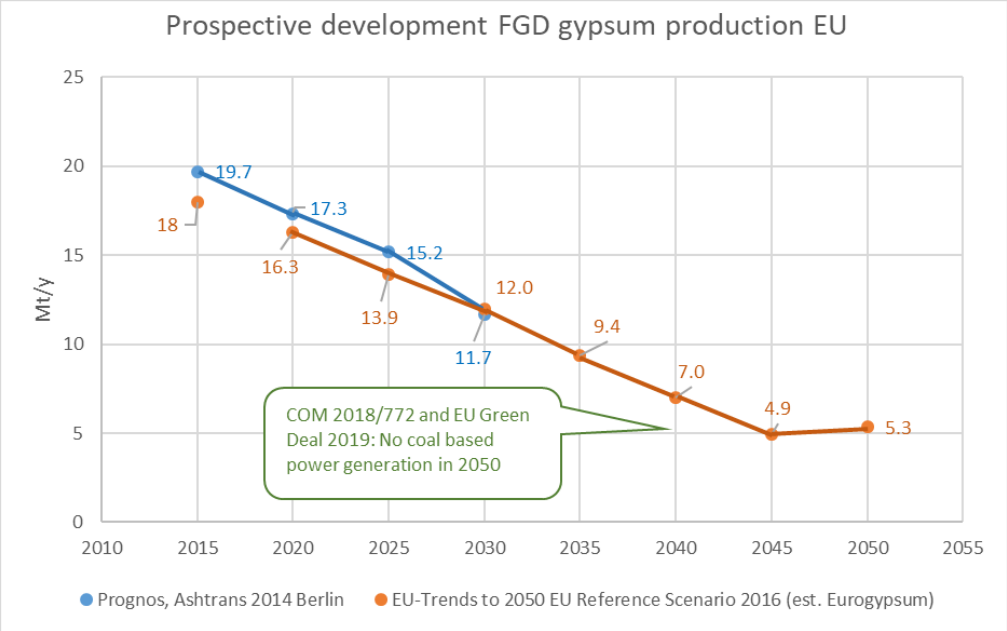


Figure 94: Prospective development of FGD gypsum production (in million tonnes) in the EU, (1) Prognos-report: Supply of gypsum to industry in the context of energy turnaround in Europe, Ashtrans Europe 2014, Berlin; (2) European Commission: EU trends to 2050 – EU reference scenario (2016) (EUROGYPSUM, 2020)

Boosting the recycling of waste gypsum (e.g. waste plasterboard) may compensate for a small part of the FGD gypsum reduction, but not for all. In that case the requirement for natural gypsum may grow to satisfy demand (Eurogypsum, 2020; Demmich, 2015).

[70] The assessment on gypsum should incorporate synthetic gypsum, in particular FGD gypsum, which is an important contributing material to the sector. However, there is no official data on FGD gypsum, only estimates.

Table 48: Future supply and demand for gypsum

Material	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Gypsum		x	+	+	?	+	+	+

10.2.2 EU trade

The low unit value of gypsum means that transportation cost has a high impact on the final price of products and, therefore, most of them are consumed where they are extracted. This becomes apparent also from the trade data). For example, the EU has produced on average, on an annual basis for the period 2012 to 2016 21.8 Mt of natural gypsum per year, whilst the imports to the EU in the same period were approximately 196 kt per year.

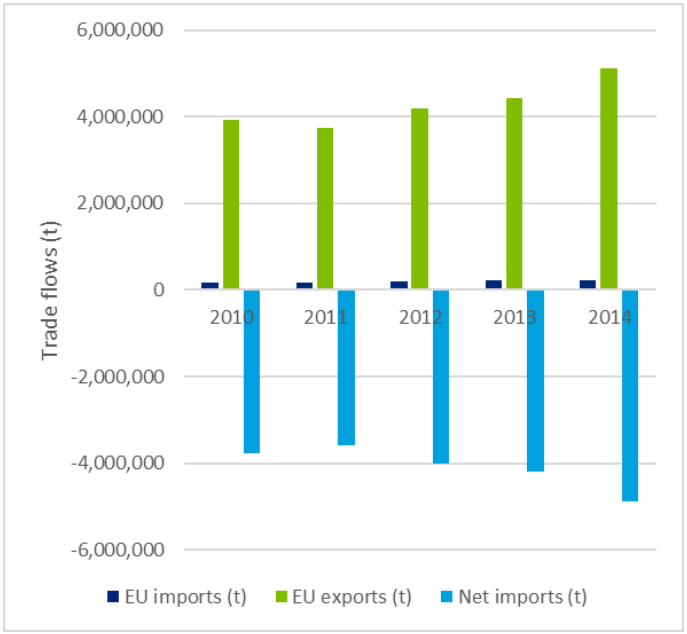


Figure 95: EU trade flows for gypsum (Eurostat, 2019a).

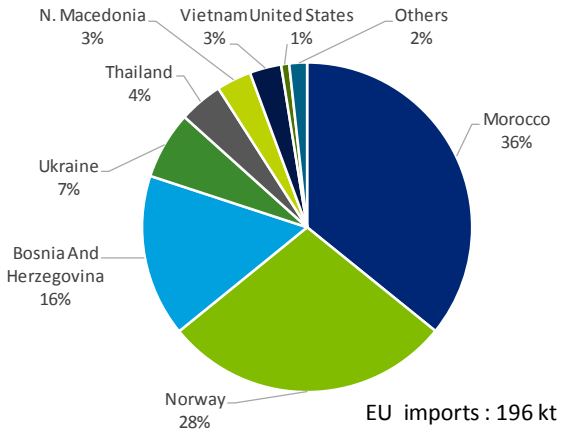


Figure 96: EU imports of gypsum, average 2012-2016 (Eurostat, 2019a)

Therefore, imported gypsum represents only a small flow to the EU. Gypsum exported from Europe in the same period accounts for approximately 4.28 Mt, 23.7% more compared to the period 2010-2014, thus Europe is a net exporter of gypsum.

Spain is the most important exporter of gypsum in EU accounting for 80% of the European gypsum exports. Most of the Spanish gypsum is exported to the US. Imports of gypsum to the EU appear to be mainly from Morocco and Norway[71]. It has to be mentioned that imports from Morocco in 2017 and 2018 have increased by 50% compared to the period 2012-2016 to 130 kt/y. In 2018 big imports from Tunisia were also noted (65 kt/y) (Eurostat, 2019a).

10.2.3 Prices and price volatility

The average unit price of gypsum in the period 2014-2018 reported by USGS and U.S. producers was around EUR 7.2 per tonne of crude gypsum. The prices of the different gypsum products vary widely depending on their type; for example, EUR 27 per tonne for calcined gypsum, EUR 38 per tonne for gypsum used in agriculture and EUR 385 per tonne for plaster (USGS, 2019).

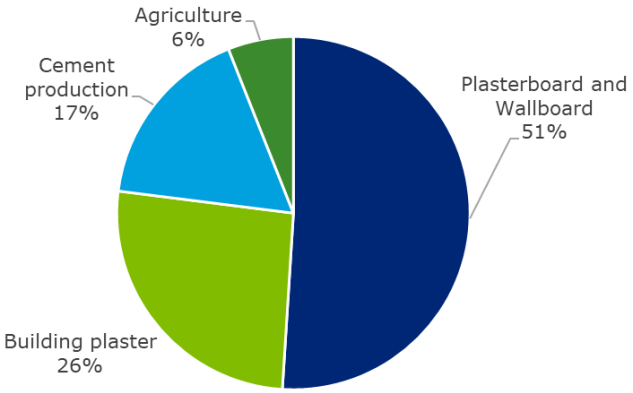
10.3 EU demand

10.3.1 EU demand and consumption

The European apparent consumption in the period 2012 and 2016 (5-year average) is estimated at 32.3 Mt per year, of which 21.8 Mt is the domestic production of natural gypsum, 18.0 Mt tonnes is the domestic production of synthetic FGD gypsum (NERA, 2016), 195 kt is the imports to the EU from extra EU countries and 4,280 kilotonnes is the exports from the EU to extra EU countries. The above figures suggest that the majority of the domestic production is consumed within the EU and it can sufficiently satisfy the industry demand for gypsum.

10.3.2 Uses and end-uses

The gypsum industry in Europe is vertically integrated and consists of companies that mine gypsum, but also manufacture plasterboard, wallboard, plaster and other gypsum products. Gypsum is also used in cement production and in agriculture as soil conditioner.



EU consumption: 32.3 Mt (natural + synthetic)

[71] Imports from Norway are mainly of synthetic gypsum

Figure 97: EU end uses of gypsum. Average 2012-2016 (Eurogypsum, 2020).

Plasterboard, plaster blocks, ceiling tiles and gypsum fibreboard are used for partition and lining of walls, ceilings, roofs and floors. The properties of plasterboard can be modified to meet a specification or requirement. Building plaster is commonly used for walls and ceilings, whereas decorative plaster is used to produce aesthetic effects on brick and block walls and on ceilings. Plasterboard properties can provide several advantages to buildings, such as fire resistance, sound insulation, thermal insulation, impact resistance and humidity control (Eurogypsum, 2020). Gypsum in cement is used to control the setting rate of cement. Circa 15 kt of gypsum are used as ornamental stones (e.g. alabaster) (SCRREEN CRM workshop, 2019).

Relevant industry sectors are described using the NACE sector codes in Table 49.

Table 49: Gypsum applications, 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2019b).

Applications	2-digit NACE sector	Value added of NACE 2 sector (millions €)	4-digit NACE sectors
Plasterboard and Wallboard	C23 - Manufacture of other non-metallic mineral products	57,255.0	C2362 - Manufacture of plaster products for construction purposes
Building plaster	C23 - Manufacture of other non-metallic mineral products	57,255.0	C2352 - Manufacture of lime and plaster
Cement production	C23 - Manufacture of other non-metallic mineral products	57,255.0	C2351 - Manufacture of cement
Agriculture	C23 - Manufacture of other non-metallic mineral products	57,255.0	2399 Manufacture of other non-metallic mineral products n.e.c.

10.3.3 Substitution

Substitutes with a similar functionality in comparison to gypsum are available for the applications of plasterboard, wallboard and building plaster. Substitutes are assigned a 'sub-share' within a specified application and considerations of the cost and performance of the substitute, as well as the level of production, whether the substitute has a 'critical' status and is produced as a co-product/by-product.

Substitutes for gypsum used in plasterboard and wallboard include synthetic gypsum and recycled gypsum. All these materials have similar properties with natural gypsum and are used in the same way. Wood based wall panels, renewable material wall panels, plastic and metal panels, brick and glass may also be used to construct wallboards. In applications such as building plaster and stucco, gypsum may be substituted by cement and lime plaster. Synthetic gypsum (mainly FGD gypsum) is used as an alternative material in the production of cement and as a soil conditioner in agricultural applications.

There are no quantified 'market sub-shares' for the identified substitutes of gypsum and the ones used are based on hypotheses made through expert consultation (SCRREEN workshops, 2019) and literature findings (Eurogypsum, 2015).

10.4 Supply

10.4.1 EU supply chain

The 5 years average EU production of natural gypsum between 2012 and 2016 was 21.8 Mt per year, which accounts for 8.2% of the global production, down from 14% in the period 2010-2014. Producing countries include Spain, Germany, France, Poland, the United Kingdom, Italy and others (BGS, 2019). The production in Italy dropped from a range of 3.8 to 5.9 Mt per year in the period 2012-2015 to around 0.5 Mt in the period 2015-2017. Gypsum is a "high place – value" industrial mineral therefore most of the gypsum produced is consumed in the country of production.

FGD gypsum EU production is estimated approximately at 18 Mt per year, thus FGD gypsum is an important input material to the European gypsum industry. Recycled gypsum is produced from the processing of gypsum waste products, namely plasterboard waste. Gypsum recycling varies considerably across Europe. Only 3% of the total gypsum used by the European industry is recycled gypsum.

The trade of gypsum is relatively low when compared to production. Europe does not rely on gypsum imported from other countries, but on the availability of domestic resources. There is no import reliance on gypsum in EU.

Europe is a net exporter of gypsum and the primary destinations of the European gypsum are the United States, Nigeria, Colombia and Venezuela. Spain is the most important EU exporting country, and the second largest exporter of gypsum in the world, covering about 80% of the European gypsum exports.

At global level, the United States is the world largest importer of gypsum accounting for almost 15% of the world imports per annum for the period 2012 to 2016. India and Japan are also major importers with shares equivalent to 15% and 9% of the world total imports in the same period. Thailand and Canada are also large exporters of gypsum globally.

There are no export restrictions, quotas or prohibitions identified that may impact on the availability of gypsum.

10.4.2 Supply from primary materials

10.4.2.1 Geology, resources and reserves

Geological occurrence:

Gypsum ($CaSO_4.2H_2O$) is an evaporite mineral formed by precipitation, commonly from lake or sea water. It can also form in hot springs or precipitate from volcanic gases. Anhydrite ($CaSO_4$) is a dehydrated variety of the same mineral. Gypsum plaster, also called plaster of Paris is a calcined variety (heated to remove water) which is also known as a hemihydrate, $CaSO_4 \cdot 0.5H_2O$. This calcined gypsum is the main semi-product for further manufacturing of plaster based products. Alabaster is a fine-grained, white or lightly tinted, gypsum which has been used since ancient times for sculpture. Gypsum has a hardness of 2 on Mohs scale (and is used to define that point on this relative scale), is moderately water soluble and if pure will be white or colourless. Natural deposits typically contain impurities and can appear grey, yellow, red or brown. Although it is often found as thick beds in sedimentary sequences, it rarely occurs as sand but White Sands National Monument in the US is a notable exception. Often gypsum is formed by the hydration of anhydrite at or near surface, which was uplifted to

the near surface by geological processes. Gypsum usually passes into anhydrite below 40-50 m, although this varies according to local geological conditions.

Gypsum in nature occurs as beds or nodular masses up to a few metres thick and is formed as chemical sediments of evaporating marine or terrestrial water bodies. Common country rocks of the calcium sulphates include dolomite, saline claystone and salt rocks (e.g. halite). When the concentration of seawater increases, the calcium sulphates are precipitated after carbonate rocks and before rock salt. The primary precipitate of calcium sulphate is gypsum, only when temperature is higher than 56 to 58°C. Anhydrite is the thermodynamically stable phase. In sabkhas [72] conditions of gypsum and anhydrite stability switch easily and multiple transformations are often taking place (Pohl, 2011; British Geological Survey, 2006).

Global resources and reserves[73]*:*

According to the USGS (2016 and 2019), the gypsum reserves in China are estimated at 17 billion tonnes and in Iran at 2.2 billion tonnes. A global reserve figure cannot be estimated as data from several major producing countries are missing (Thailand, Iraq, Mexico, etc.). Reserves are believed to be large, but data for most countries are not available. Reserve data for some countries in Europe are also available at Minerals4EU (2019).

Table 50: Global reserves of gypsum (USGS 2019).

Country	Gypsum Reserves (kilotonnes)
United States	700,000
Canada	450,000
Brazil	340,000
Turkey	200,000
India	36,000
Oman	4,900
Iran	2,200,000
China	17,000,000

[72] An area of coastal flats subject to periodic flooding and evaporation which result in the accumulation of clays, evaporites and salts

[73] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of gypsum in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly count reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template (www.crirsco.com), which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

EU resources and reserves[74]*:*

Resource data for some countries in Europe are available at Minerals4EU (2019) but cannot be summed as they are partial and they do not use the same reporting code.

Table 51: Resource data for the EU (Minerals4EU, 2019)

Country	Reporting code	Quantity	Unit	Grade	Code Resource Type
Spain	None	60,000	Million m^3	-	Resource
Greece	UGSG	70	Mt	-	Indicated
Serbia	JORC	11.89	Mt	-	Total
N. Macedonia	Ex-Yugoslavian	178,738	t	-	A
Albania	Nat. Rep. Code	1,000,000	Million m^3	85%	A
Turkey	None	1,800	Mt	-	Historic Resource Estimates
Hungary	Russian Classification	?	Million m^3	2.4 t/m^3	-
Slovakia	None	1.127	Mt	68.4% economic	Z1
Czech Republic	Nat. Rep. Code	82,137	kt	-	Potentially economic
Ukraine	Russian Classification	56,770	kt	-	P2
Poland	Nat. Rep. Code	192.39	Mt	-	A+B+C1
Latvia	Nat. Rep. Code	47.7	Mt	-	Stock of explored deposits
Lithuania	Nat. Rep. Code	16.82	Million m^3	-	Mesaured
UK	None	>2,000	Mt	-	Estimate
Ireland	None	8	Mt	78%	Historic Resource Estimates

The only country reporting reserve data on gypsum using the United Nations Framework Classification (UNFC) is Romania, which indicated 113 Mt of reserves for UNFC 111 code and 200 Mt of reserves for UNFC 121 code (Minerals4EU, 2019).

[74] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for gypsum. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for gypsum, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for gypsum at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU, 2019). Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However, a very solid estimation can be done by experts.

Table 52: Reserve data for the EU (Minerals4EU, 2019)

Country	Reporting code	Quantity	Unit	Grade	Code Reserve Type
Spain	Other	2,645	Mt	-	Proven
Romania	UNFC	113	Mt	-	111
Croatia	Nat. Rep. Code	51.22	Mt	-	-
N. Macedonia	Ex-Yugoslavia	178,738	t	-	A
Switzerland	None	3	Mt	-	Total
Slovakia	None	1.127	Mt	68.4% economic	Z1
Czech Republic	Nat. Rep. Code	119,100	kt	-	Economic explored
Ukraine	Russian Classification	39,836	kt	Gypsum and anhydrite, total	A
Poland	Nat. Rep. Code	109.11	Mt	-	Total
UK	None	> 50	Mt	-	Total

10.4.2.2 World and EU mine production

Gypsum/anhydrite are produced predominantly in Europe using open cast mining techniques (80%) and (20%) by underground mining using pillar and stall mining methods that give extraction rates of up to 75%. These mining methods do not cause subsidence and no significant waste is produced. The impact of the workings is confined to the surface facilities at the mine. Continuous mining is becoming increasingly common in underground gypsum mines too. In open cast mines, mineral to overburden/interburden ratios can be as high as 1:15. Overburden is used to reclaim the void, which may also be used for landfilling (British Geological Survey, 2006).

Gypsum is normally only screened to remove fines (mainly mudstone), then crushed and finely ground. Gypsum/anhydrite for cement manufacture is supplied in crushed form for further fine grinding with cement clinker. For plaster manufacture, the finely ground gypsum is heat treated in calcination facilities to remove three-quarters of the combined water to produce hemi-hydrate plaster. Emissions consist only of steam. There is, therefore, little or no waste associated with the extraction and processing of natural gypsum (British Geological Survey, 2006). Furthermore, it is mentioned that gypsum products can be counted amongst the very few construction materials where *"closed-loop" recycling* is possible, i.e. where the waste is used to make the same product again. Gypsum as such is 100% and eternally recyclable (Eurogypsum, 2020). To a relatively large extent, the source of Gypsum are mineral sulphides forming SO_2 during roasting.

Approximately 8.2% of the global production, for the period 2012-2016, of natural gypsum is European. This figure is 6% lower compared to the previous assessment period, due to the three-fold increase in production by China between 2012-2016; the accuracy of the Chinese data is uncertain though. Europe is a net exporter of gypsum hence the sector is a positive contributor to the European economy. Exports by the EU the period 2012-2016 have increased by 20% compared to the previous assessment period; imports were similar in both periods.

In the reported period (2012-2016), the world mine production of gypsum was 265.5 Mt, 63% higher compared to the previous assessment period (2010-2014). China is the largest producer of gypsum with a share of 48.7% of the global production, followed by the United States and Iran who both account for a 6% share of the global production. In total, more than 80 countries produce gypsum around the world.

However, because of the depletion of deposits of natural gypsum and anhydrite, the use of synthetic gypsum and recycled gypsum will increase. As there are still a significant number of synthetic gypsum landfills, manufacturers will start to recycle it (Lushnikova and Dvorkin, 2016).

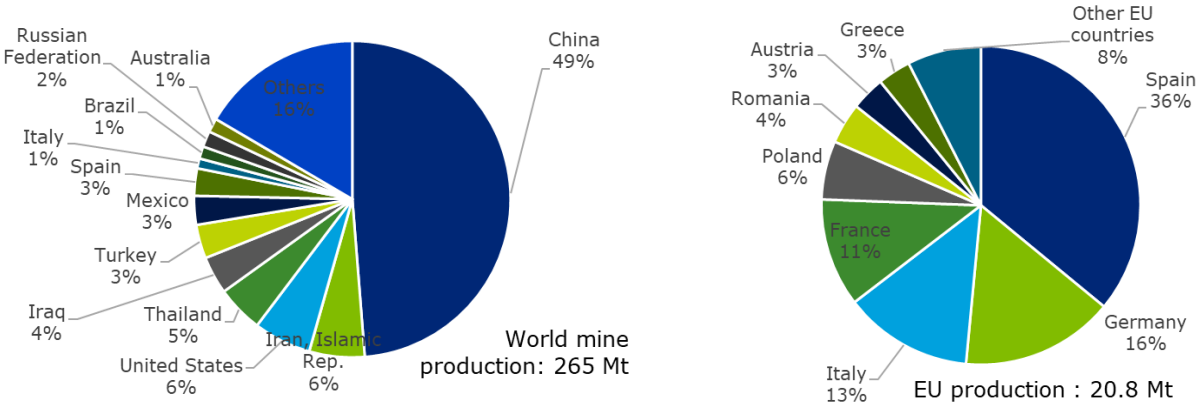


Figure 98: Global and EU mine production of gypsum, average 2012–2016 (BGS, 2019).

The European production of natural gypsum between 2012 and 2016 is estimated at 20.8 Mt per year and 18 countries are reporting production. According to Eurogypsum, 154 gypsum quarries are currently in operation in Europe (EUROGYPSUM, 2020). Spain, Germany, Italy and France are the largest producers of gypsum in Europe with 7.4 Mt, 3.2 Mt, 2.7 Mt and 2.3 Mt production reported respectively.

Spain produced 3%, Germany 1.2% and Italy 1% of the global production. In Spain, gypsum is produced by numerous quarries using open cast mining methods. In Germany and Italy several different mine and quarries exist that produce gypsum from a variety of locations. The remaining European countries produce in total 4% of the global production.

10.4.3Supply from secondary materials/recycling

The EU industry does not solely rely on natural gypsum. The use of FGD gypsum, recycled gypsum and other synthetic gypsum is also important to the sector (Lee et al., 2011; Kubba, 2017). In the reported period, approximately 38% of consumption was met by FGD gypsum, 3% by recycled gypsum and 2% by other synthetic gypsum, with the remaining 57% by natural gypsum. Regarding FGD, US Environmental Protection Agency (EPA) concludes that the use of FGD in gypsum board has significant environmental and economic benefits (Eurogypsum, 2014 and 2020).

The global synthetic gypsum market is expected to reach 220Mt/y by 2027, from a 151 Mt/y in 2017. A modest growth in the US, a decline in Europe and growth in China is forecasted over the next 10 years. The current supply of synthetic gypsum is mostly based in these countries and has accounted for 96% of worldwide supply in 2014 (Global Gypsum, 2017).

10.4.3.1 FGD gypsum

FGD gypsum is a by-product of coal fired power station, while flue gas desulphurisation takes place in scrubbing towers. When flue gas comes into contact with an aqueous suspension containing limestone or slaked quicklime, SO_2 present in the flue gas is oxidised to SO_3 and precipitates to form finally gypsum dihydrate. The gypsum crystals are separated from the suspension with the use of centrifuges or filtering technology. FGD gypsum production in the

EU is estimated approximately at 18 Mt per year. FGD gypsum, which is directly usable, is used similarly to natural gypsum in the production of plaster and plasterboard. The quantity of FGD gypsum is closely related to the sulphur content of the coal used in coal powered electricity plants and its operation time. Low sulphur coal will produce lower quantities of FGD gypsum. Eurogypsum, Ecoba and VGB Powertech have determined harmonized quality criteria and analysis methods to ensure the utilisation in the European gypsum industry.

The growth in the construction industry in Asia Pacific, North America, and Europe is anticipated to boost the global FGD gypsum market in the near future. Demand for gypsum is high in the construction industry, which accounts for 10% share of the GDP of European Union, due to wide applications in wallboard, cement, and plaster of Paris (Transparency Market Research, 2019).

The main FGD gypsum producing country is Germany due to the presence of coal fired power plants stations (around 7 million tonnes produced every year) (Figure 99). Plasterboard plants in countries with no or poor natural gypsum deposits (Scandinavia, Belgium, the Netherlands, and the United Kingdom) rely up to 100% on this substitute to produce plasterboard. FGD gypsum is of higher purity than most natural gypsum. This means that lower quality gypsum can be blended with high purity FGD gypsum, allowing material that would not have been mined in the past to be exploited.

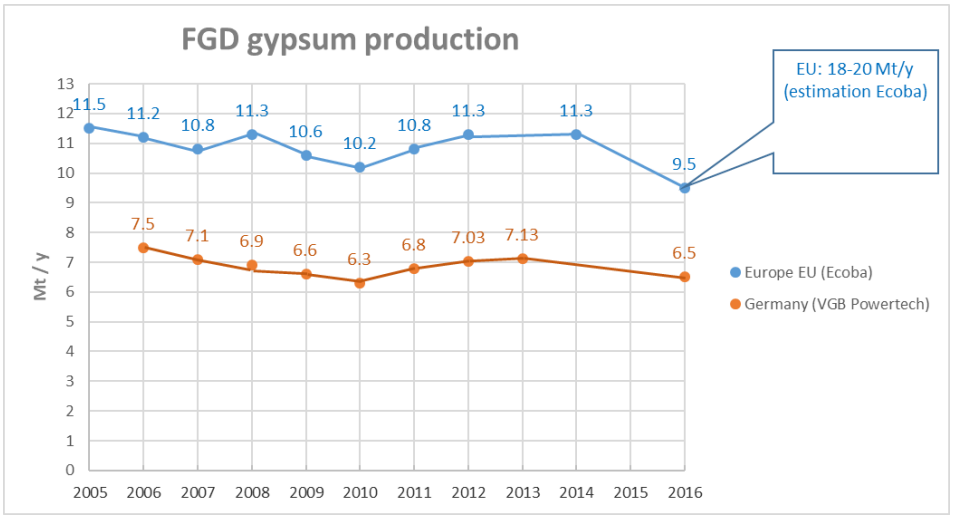


Figure 99: FGD gypsum production figures in million tonnes (2005 – 2016) for Germany and Europe[75]. (Eurogyspum, 2017)

10.4.3.2 Recycled gypsum

Recycled gypsum is produced from processing of gypsum waste products, namely plasterboard waste. Three categories of gypsum waste can be differentiated based on their origin:

- Production waste (e.g. gypsum boards which do not meet specifications and waste from the manufacturing process). Production waste currently recycled is approximately 3.5-5%.
- Waste resulting from construction sites (called construction waste). The gypsum construction waste currently recycled is estimated, at current market volumes, at ca. 7%.
- Demolition waste. The last category includes both demolition and renovation waste and is the most complex to address because it adheres to other construction materials (such as

[75] Former EU-15 countries

plasters, paints & screeds etc). The demolition waste does not depend on market volumes and its recycling rate is estimated at ca. 1%.

Although gypsum products are indefinitely and fully recyclable, only a small percentage of construction and demolition material is recycled in Europe[76]. One reason for the low amount of gypsum waste recycled from demolition activities is due to the common practice of demolishing and mixing different kinds of waste in same bins on job sites rather than deconstructing and segregating waste by nature during a deconstruction activity. This common practice also leads to potential problems of contamination with hazardous substances, which can affect the recycling efficiency. The recycling of plasterboard waste includes several activities (dismantling and separation of suitable waste, processing of plasterboard recovered and re-incorporation into new manufacturing processes) and different parties are involved to facilitate the process.

A Life Project GypsumtoGypsum[77] initiative was promoted by Eurogypsum with the overall aim to achieve higher recycling and reuse rates of gypsum, thus transforming the European gypsum market in a resource efficient and circular economy. The study demonstrates feasibility of re-incorporation (up to 30% according to current state of the art technology) of recycled gypsum in manufacturing of Type A plasterboard with a face to which suitable gypsum plasters or decoration may be applied (EN-520 Standard), without noticeably affected basic performance characteristics. It highlighted potential production bottlenecks in terms of recipe modifications (e.g. in additives) and production process equipment (e.g. storage, feeding conveyors, recycled gypsum pre-processing etc.) that may arise when the increased percentage becomes standard practice in the plasterboard manufacturing. It concluded on the fact that several actions were possible to increase significantly the circularity of this industry, by favoring deconstruction versus demolition, by pushing the correct implementation of the current EU waste legislation in a harmonized way across Europe, by fostering the economic competitiveness of the recycling route compared to other currently permitted routes and by turning waste into a resource.

The recycling of gypsum is controlled by national and commercial specifications, but in reality recycling across Europe varies considerably from country to country, mainly according to local gypsum waste landfilling costs and constraints. No end-of-life criteria exist at the moment at European level that could promote gypsum recycling further. The UK is the only country, which has adopted a quality protocol for the recycling of gypsum from plasterboard waste accompanied also by a specification for the production of reprocessed gypsum (WRAP & BSI, 2013; WRAP & Environment Agency, 2011). Hence the current low production and use of recycled gypsum in Europe is not unexpected (only 3% of the total gypsum used).

Recently a new recycling facility commenced operation in Holmestrand, Norway, approximately 70km south of the capital Oslo. Construction of the building and installation of the processing equipment was completed during July 2018 and the commissioning of the new equipment was carried out in August 2018. The new recycling facility has sufficient capacity to process up to 100,000t/yr, providing sufficient capacity to service the local gypsum wallboard plants (Global Gypsum, 2018).

[76] http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4191

[77] "From production to recycling: a circular economy for the European gypsum industry with the demolition and recycling Industry" http://gypsumtogypsum.org/

10.4.3.3 Other synthetic gypsum

Several other industries produce gypsum as a by-product, but their use by the European gypsum industry is very low. Other types of synthetic gypsum include phosphogypsum, titanogypsum, citrogypsum and other (Eurogypsum, 2020).

The most important potential of other synthetic gypsums than FGD gypsum lies in the use of purified phosphogypsum, but apart from a few exceptions its radioactivity still remains a problem. There is also some potential in the use of purified titanogypsum. In the past, both the phosphoric acid and the titanium dioxide industries have systematically closed down production facilities in Europe (Eurogypsum, 2020; Gypsum Association, 2019).

10.5Other considerations

10.5.1Environmental and health and safety issues

It is known that one of the most commonly encountered forms of dust during construction activities is the one associated with plaster and related plastering materials . Inhaling plaster dust can lead to respiratory complaints, including asthma and chronic obstructive pulmonary disease (COPD). In addition, serious illness can result if the plaster mix contains any silica, or if old plaster walls being sanded contain any asbestos (Azarov et al., 2016; RTVGROUP, 2019).

Based on the results of several available studies there is no indication of any major risk to occupational exposure to gypsum dust, if all precautions are taken (Oakes et al., 1982). Typical symptoms of prolonged exposure may include irritation of eyes, skin, mucous membrane, upper respiratory system; cough, sneezing, rhinorrhea (discharge of thin nasal mucus) (NIOSH, 2019). Gypsum core board products normally do not entail any risk (CertainTeed, 2018).

Gypsum association has carried out LCA studies for gypsum products to assess their production environmental impact by considering several impact categories as indicators (Gypsum Association, 2011 and 2016).

It is however underlined that companies should always use all apropriate means (personal protective equipment, workplace practices, engineering controls, continuous medical surveillance etc) to ensure that workplace exposure complies with applicable occupational exposure limits (OELs) (Brun et al., 2013). Special emphasis should be paid on monitoring and controlling exposure to respirable crystalline silica associated with all mined minerals, since this make cause autoimmune disorders, chronic renal disease, and other adverse health effects (NIOSH, 2002).

On the other hand, flue gas desulpurization (FGD) gypsum may exhibit some risk pertinent to leaching of heavy metals such as Hg (Fu et al., 2019; Hao et al., 2016). Nevertheless, no health risk has been noticed when using FGD gypsum as compared to natural gypsum (Beckert et al., 1991).

Finally, it has to be mentioned that despite its great potentiality, most of gypsum waste (GW) in EU is currently landfilled. Besides the loss of valuable resources, gypsum landfilling may result in potential leaching of sulfates; moreover, hydrogen sulfide and greenhouse gases can be emitted due to degradation processes occurring in landfills. Thus, efficient management systems need to be developed to minimize environmental issues and improve economics of gypsum waste management (Pantini et al., 2019).

10.5.2Socio-economic issues

Gypsum is widely used in construction, the biggest sectorial employer in EU (Global Gypsum Magazine, 2018). The gypsum industry has a turnover of around 7.7 billion Euro. It operates 154 quarries and 160 factories, which generate employment directly for 28,000 and indirectly for 300,000 people. The number of plasterboard installer in Europe is around 1 million persons. The industry trains 25,000 people per year. Important socio-economic benefits are also anticipated from the emergence of a market for gypsum recycling (GtoG Life project, 2011).

Minerals such as gypsum offer a lot in terms of job opportunities and economic growth along the value chain. They are indispensable to secure a low-carbon future for buildings and are an integral part of the circular economy (ZKG, 2019).

Socio-economic issues are very important for the areas (and the countries) where gypsum is mined or processed since such activities contribute to social welfare and economic growth. On the other hand, in order to meet the criteria of sustainable growth and environmental protection, sustainable development indicators (SDIs) need be used at all stages, including exploration, mining, processing and post-mining so that social, economic and environmental improvement is achieved in the areas of concern (Tzeferis et al., 2013; Blengini et al., 2013; Komnitsas et al., 2013).

Despite good practices record of quarrying in line with nature, the permitting procedures for mining gypsum in European countries are long (up to 10 years), costly and burdensome (scattered administrative requirements between national, regional and local level) with a low social acceptance of mining in Europe (pillar 2 of the Raw Material Initiative) (European Commission 2017). Access to gypsum deposits is also becoming more difficult as Natura 2000 areas expands and the Guidelines on Extraction into such areas allows extraction under specific conditions. However, in practice, those guidelines are not well known at national level. The common views of national authorities is that Natura 2000 areas are "no go areas". The forthcoming action plan of the Commission on the implementation of the Birds and Habitat Directive will provide tools to support and enhance access to natural gypsum at a time when the substitute for natural gypsum in Europe, FGD gypsum, is decreasing due to the closure of coal power plant stations (Eurogypsum, 2020).

In the absence of opening of new quarries, some EU countries are likely to lack gypsum in the forthcoming years. The importance of transportation costs relatively to gypsum price limits its transport over long distance. Hence, gypsum has to be produced locally. Access to gypsum deposits could also be enhanced by a land use planning taking into account the gypsum deposits close to urban areas.

10.6Comparison with previous EU assessments

A revised methodology, similar to the one used in the 2017 assessment for critical raw materials in Europe, was followed in this study. Both the calculations of economic importance and supply risk are different therefore the results with previous studies (2011 and 2014) are not directly comparable.

The results of this review and earlier assessments are shown in Table 53.

Table 53: Economic importance and supply risk results for gypsum in assessments of 2011, 2014 (European Commission, 2011-2014-2017).

Assessment	2011		2014		2017	2020

Indicator	EI	SR		EI	SR		EI	SR	EI	SR
Gypsum	5.04	0.36		5.54	0.47		2.2	0.5	2.6	0.5

Although it appears that the economic importance of gypsum has been reduced after 2014, this is a rather false impression due to the revised methodology used that implies refined EI calculations. The value added used in this study corresponds to a 2-digit NACE sector rather than a 'megasector' used in the previous studies and the economic importance figures are therefore reduced. The supply risk indicator is similar to the previous two assessments. The changes observed in Table 53 6 are in general not major and it is not possible to quantify what proportion of this changes is due to the methodology alone, as new data have been used more recent assessments.

10.7Data sources

Market shares are based on the statistical data provided by EUROGYPSUM and they represent the European market. Production data for gypsum are from World Mineral Statistics dataset published by the British Geological Survey (BGS, 2019). Trade data was extracted from the Eurostat Easy Comext database (Eurostat, 2019a). Data on trade agreements are taken from the DG Trade webpages, which include information on trade agreements between the EU and other countries (European Commission, 2016). Information on export restrictions are accessed by the OECD Export restrictions on Industrial Raw Materials database (OECD, 2019).

For trade data the Combined Nomenclature (CN) code 2520 1000 – GYPSUM; ANHYDRITE has been used. The end-of-life recycling input rate for gypsum was calculated with data provided by EUROGYPSUM. The calculation is based on data available for gypsum recycling for selected countries only (France, the United Kingdom, the Netherlands, Belgium and Luxembourg).

The production figure as well as the reserves for China, who is the global leading producer, varies significantly between different data providers (BGS, 2019; USGS, 2019). It is believed that some bigger production data reported for China may include other forms of gypsum, for example, FGD gypsum.

Other data sources used in the criticality assessment are listed in section 1.7.2.

10.7.1Data sources used in the factsheet

Azarov, A.V., Zhukova, N.S., Kalyuzhina, E.A. (2016). Environmental and working area dust emission from the gypsum warehouse, Procedia Engineering, 150, 2080-2086.

Beckert, J., Einbrodt, H. J., Fischer, M. (1991). Comparison of natural gypsum and FGD gypsum, VGB Kraftwerkstechnik 1/1991

Blengini, G.A., Moltrer, A., Valbusa, M., Komnitsas, K., Agioutantis, Z., Garbarino, E., (2013). Data and methodologies for a resource-efficient planning of primary and secondary aggregates in South East Europe (SEE) countries, Proceedings 6th International Conference "Sustainable Deveoplemt in the Minerals Industry (SDIMI)", 30 June - 3 July 2013, Milos, Greece, http://sdimi2013.conferences.gr/sdimi2013-home.html

Brun, P., Kunz, A., Funke, M. (2013). Buried under gypsum powder, a rear respiratory complication, Respiratory Medicine Case Reports, 8, 36-39.

CertainTeed, (2018). Safety data sheet for gypsum core board products, https://www.certainteed.com/resources/SDS%20USA%20CT5-19%20Gypsum%20Boards.pdf

British Geological Survey (2006). Gypsum - Mineral Planning Factsheet [online] Available at: http://www.bgs.ac.uk/mineralsuk/planning/mineralPlanningFactsheets.html

BGS (2019). World Mineral Production 2013-2017. British Geological Survey, Available at: https://www.bgs.ac.uk/mineralsuk/statistics/worldStatistics.html

Demmich, J. (2015). The Future of FGD Gypsum in Europe. ASHTRANS EUROPE 2015, Copenhagen KNAUF, http://ashtrans.eu/onewebmedia/7%20ASHTRANS%20EUROPE%202015%20Demmich.pdf

DG Environment (2010). Green Public Procurement. Wall Panels Technical Background Report. [online] Available at: http://ec.europa.eu/environment/gpp/pdf/wall_panels_GPP_background_report.pdf

Eurogypsum (2014). https://gypsum.org/press-roomfgd-gypsum-board/ (accessed Aug. 6, 2019)

Eurogypsum (2020). https://www.eurogypsum.org

European Commission (2016). DG Trade. Agreements [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/

European Commission (2017). Legal framework for mineral extraction and permitting procedures for exploration and exploitation in the EU, MinPol and partners, May 2017, https://publications.europa.eu/en/publication-detail/-/publication/18c19395-6dbf-11e7-b2f2-01aa75ed71a1/language-en

Eurostat (2019a). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2019b). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

Fu, B., Liu, G., Manik Mian, M., Sun, M., Wu, D. Characteristics and speciation of heavy metals in fly ash and FGD gypsum from Chinese coal-fired power plants, Fuel, 251, 593-602.

Global Gypsum Magazine (2018), https://www.eiif.org/sites/default/files/inline-files/eGGSept2018ns.pdfGypsumtoGypsum (2016). Gto G Project - EU Life programme. [online] Available at: http://gypsumtogypsum.org/

Global Gypsum (2018), https://www.globalgypsum.com/magazine/articles/762-new-west-gypsum-recycling-commissions-norwegian-plant (1 Sep. 2018)

Global Gypsum (2017), https://www.globalgypsum.com/news/itemlist/tag/synthetic%20gypsum (28-3-2017)

GtoG – GtoG (2019): From Production to Recycling, a Circular Economy for the European Gypsum Industry with the Demolition and Recycling Industry, Life project, LIFE11 ENV/BE/001039, http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4191

Gypsum Association (2011). A Cradle-to-Gate Life Cycle Assessment of ½" Regular and 5 /8" Type X Gypsum Wallboard, by Dr. Lindita Bushi and Mr. Jamie Meil, Athena Sustainable Materials Institute, https://gypsum.org/wp-content/uploads/2019/05/15_Gypsum_Wallboard-1_2-in-Regular-5_8-in-Type-X.pdf

Gypsum Association (2016). An Industry Average Cradle-to-Gate Life Cycle Assessment of Glass Mat Gypsum Panels for the USA and Canadian Markets, Athena Sustainable Materials Institute, https://gypsum.org/wp-content/uploads/2019/05/GMGP_LCA-Report-Final_Athena-8.30.2016_GA-3.pdf

Gypsum Association (2019). https://gypsum.org/ (assessed July. 5, 2019)

Hao H., Wu, S., Pan, W., Li Q., Zhou, J., Xu, Y., Qian, G. 2016. Characterization and leaching toxicities of mercury in flue gas desulfurization gypsum from coal-fired power plants in China, Fuel, 177, 157-163.

Komnitsas, K., Agioutantis, Z., Shields, D., Blengini, G.A., Tzeferis, P.G. (2013). Stakeholder identification in the planning phase of aggregate and quarrying projects, Proceedings 6th International Conference "Sustainable Deveoplemt in the Minerals Industry (SDIMI)", 30 June - 3 July 2013, Milos, Greece, pp. 294-301, http://sdimi2013.conferences.gr/sdimi2013-home.html

Lee, J.C., Bradshaw, S.L., Edil, T.B., Benson C.H. (2011). Quantifying the benefits of flue gas desulphurization gypsum in sustainable wallboard production, World of Coal Ash (WOCA) Conference, May 9-12, 2011, Denver, CO, USA, http://www.flyash.info/2011/068-Bradshaw-2011.pdf

Minerals4EU (2019). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

National Institute for Occupational Safety and Health (NIOSH, 2019), https://www.cdc.gov/niosh/npg/npgd0308.html

National Institute for Occupational Safety and Health (NIOSH). (2002). Health effects of occupational exposure to respirable crystalline silica. Department of Health and Human Services, Centers for Disease Control Prevention, National Institute for Occupational Safety and Health, Atlanta, Georgia, 145 p, https://www.cdc.gov/niosh/docs/2002-129/pdfs/2002-129.pdf?id=10.26616/NIOSHPUB2002129.

NERA (2016). The access to gypsum raw material by 2050: challenges, obstacles and levers. Report prepared for Eurogypsum.

Oakes, D., Douglas, R., Knight, K., Wusteman, M., McDonald, J.C. (1982). Respiratory effects of prolonged exposure to gypsum dust, The Annals of Occupational Hygiene, 26(8), 833–840.

OECD (2019). OECD Export restrictions on Industrial Raw Materials database. [online] Available at: http://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

Pantini, S., Giurato, M., Rigamonti, L. (2019). A LCA study to investigate resource-efficient strategies for managing post-consumer gypsum waste in Lombardy region (Italy), Resources Conservation and Recycling 147, 157-168.

Pohl, W. L. (2011). Economic Geology. Principles and Practice. UK: Wiley-Blackwell.

Roskill (2014). Gypsum and Anhydrite: Global Industry Markets and Outlook. [online] Available at: https://roskill.com/product/gypsum-and-anhydrite-global-industry-markets-and-outlook-11th-edition-2014/

RTVGROUP (2019). https://rvtgroup.co.uk/cmsrvt/uploads/rvt_whitepaper_hazards-of-plasterboarding.pdf (accessed July 4, 2019)

Tzeferis, P., Kavalopoulos, Komnitsas, K., (2013). Production data and Sustainable Development Indicators (SDIs) for the Greek Mining/Metallurgical Industry in the period 2007-2011, Proceedings 6th International Conference "Sustainable Deveoplemt in the Minerals Industry (SDIMI)", 30 June - 3 July 2013, Milos, Greece, pp. 269-276, http://sdimi2013.conferences.gr/sdimi2013-home.html

USGS (2014). Gypsum. 2014 Minerals Yearbook. [online] Available at: https://minerals.usgs.gov/minerals/pubs/commodity/gypsum/

USGS (2016). Mineral Commodity Summary. Gypsum. [online] Available at: https://minerals.usgs.gov/minerals/pubs/commodity/gypsum/

USGS (2019). Mineral Commodity Summary. Gypsum. [online] Available at: https://minerals.usgs.gov/minerals/pubs/commodity/gypsum/

WRAP and BSI (2013). PAS 109:2013. Specification of the production of reprocessed gypsum from waste plasterboard. [online] Available at: http://www.wrap.org.uk/sites/files/wrap/PAS109%20(2013).pdf.

WRAP and Environment Agency (2011). Recycled gypsum from waste plasterboard. End of waste criteria for the production and use of recycled gypsum from waste plasterboard. [online] Available at: http://www.wrap.org.uk/sites/files/wrap/Gypsum_Quality_Protocol_0.pdf

ZKG (2019). EU gypsum industry is part of "European Minerals Day" 2019, https://www.zkg.de/en/news/eu-gypsum-industry-is-part-of-european-minerals-day-2019_3412665.html (accessed 20 Aug. 2019).

10.7.2Data sources used in the criticality assessment

BGS (2016). World Mineral Production 2010-2014. [online] Keyworth, Nottingham British Geological Survey, Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.html

BGS (2019). World Mineral Production 2013-2017. British Geological Survey, Available at: https://www.bgs.ac.uk/mineralsuk/statistics/worldStatistics.html

DG Environment (2010). Green Public Procurement. Wall Panels Technical Background Report. [online] Available at: http://ec.europa.eu/environment/gpp/pdf/wall_panels_GPP_background_report.pdf

Eurogypsum (2009). Criticality of Raw Materials: Gypsum Data, http://www.eurogypsum.org/wp-content/uploads/2015/05/091109CriticalityGypsumData.pdf

Eurogypsum (2018). Symposium on availability of raw materials from secondary resources: a key aspect of circular economy Geneva, 24 April 2018, https://www.unece.org/fileadmin/DAM/energy/se/pp/unfc_egrm/egrc9_apr2018/24.04_RM/07_Christine.Marlet.pdf

European Commission (2016). DG Trade. Agreements [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/

European Commission (2014). Report on Critical Raw Materials for the EU. [online] Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

Eurostat (2019a). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2019b). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

GypsumtoGypsum (2016). Gto G Project - EU Life programme. [online] Available at: http://gypsumtogypsum.org/

Kubba, S. (2017). Green Building Materials and Products, in Handbook of Green Building Design and Construction (Second Edition), Butterworth-Heinemann, ISBN 978-0-12-810433-0, pp. 257-351, https://doi.org/10.1016/B978-0-12-810433-0.00006-X

Lushnikova, N., Dvorkin, L. (2016). Sustainability of gypsum products as a construction material, in Sustainability of Construction Materials (Second Edition), Woodhead Publishing, ISBN 978-0-08-100995-6, https://doi.org/10.1016/C2014-0-02849-3

Mordor Intelligence (2019), GYPSUM BOARD MARKET - GROWTH, TRENDS, AND FORECAST (2019-2024), https://www.mordorintelligence.com/industry-reports/gypsum-board-market

OECD (2016). OECD Export restrictions on Industrial Raw Materials database. [online] Available at: http://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

Roskill (2014). Gypsum and Anhydrite, Global industry, markets and outlook, https://roskill.com/market-report/gypsum-and-anhydrite/

SCRREEN CRM validation workshop (2019). Expert's comment, Brussels, 11 Sep. 2019.

Transparency Market Research (2019). FGD Gypsum Market - Global Industry Analysis, Size, Share, Growth, Trends, and Forecast 2017 – 2025, https://www.transparencymarketresearch.com/fgd-gypsum-market.html (accessed July 25, 2019).

USGS (2019). Mineral Commodity Summary. Gypsum [online] Available at: https://minerals.usgs.gov/minerals/pubs/commodity/gypsum/USGS (2016). Mineral Commodity Summary - Pumice and Pumicite. [online] Available at: https://minerals.usgs.gov/minerals/pubs/commodity/pumice/

10.8 Acknowledgments

This factsheet was prepared by the JRC in collaboration with Prof. Konstantinos Komnitsas (Technical University Crete). The authors would like to thank the Ad Hoc Working Group on Critical Raw Materials, in particular Mr. Tristan Suffys of Eurogypsum, as well as experts participating in SCRREEN workshops for their valuable contribution and feedback.

11. HELIUM

11.1 Overview

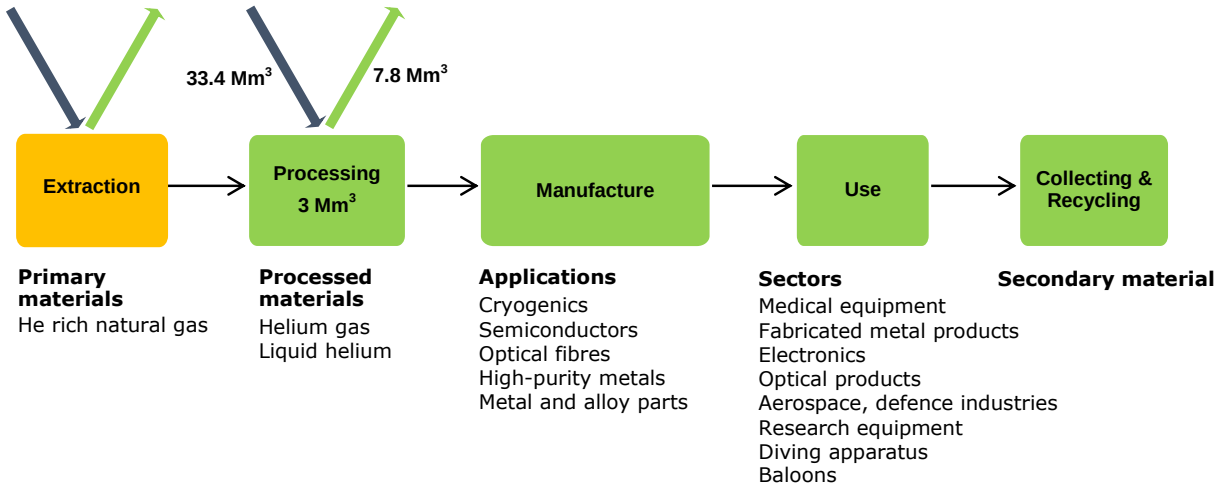


Figure 100: Simplified value chain for helium (2012-2016 average values for EU)[78]

Helium (chemical symbol He) is a chemically inert, noble gas. It is second lightest after hydrogen and its boiling point is the lowest among all the elements (–269°C).

Helium constitutes about 23% of the mass of the universe and is thus second in abundance to hydrogen in the cosmos. Below 2.17 kelvin (-270.98°C), the isotope ^{4}He becomes a superfluid (its viscosity nearly vanishes). Most helium on Earth is ^{4}He, which is produced by radioactive decay deep inside the planet. Over hundreds of millions of years, it migrates up to the crust, where it is released during periods of tectonic activity.

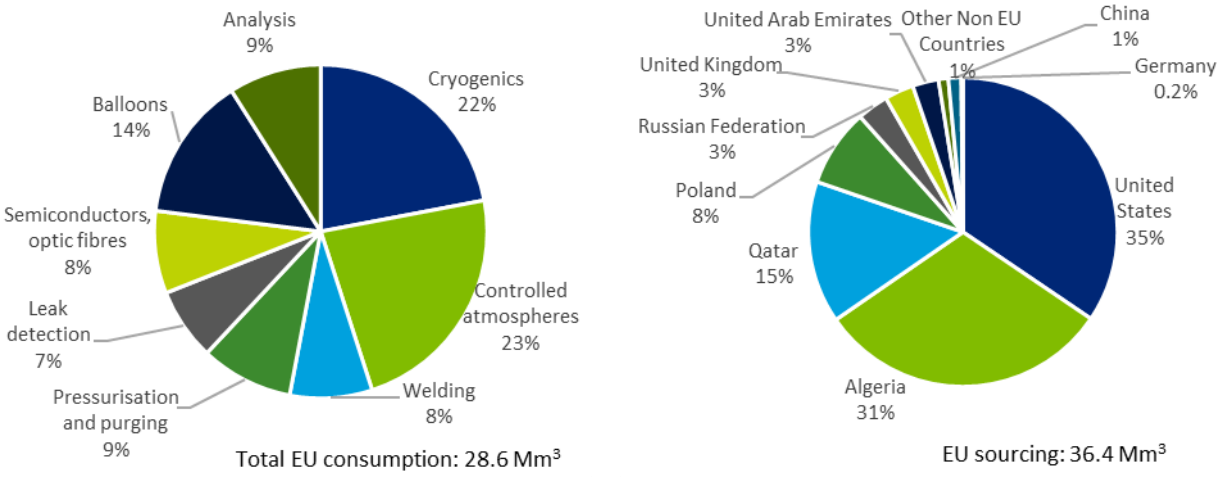


Figure 101: End uses (CRM Experts, 2019) and EU sourcing of helium, averaged over 2012-2016[79]

[78] JRC elaboration on multiple sources. See next sections.

[79] The EU sourcing figure is an elaboration from production and EU imports figures.

Helium is produced as a by-product of natural gas processing and Liquid Natural Gas (LNG) production and the market is highly consolidated. Helium extraction is seldom economical without natural gas production and even with natural gas production, the companies' profit margin is very low.

Data source for trade was COMEXTwith the CN code 28042910. Original data were in kg of He and were converted to m^3 using the conversion 1 kg = 5.988 m^3 He.

The world average annual production of helium between 2012 and 2016 was about 169.3 Mm^3 per year (28.3 kt), with 63% of production taking place in the United States, 17% in Qatar and 13% in Algeria (USGS 2019).

The European production of helium is located mainly in Poland (around 3 Mm^3). In Germany the average annual production is 60 Km^3. These two countries account for 2% of the world production, respectively 8% of the EU sourcing (Eurostat database).

The EU imports of processed helium are more than 11 times higher than the domestic production. The value of the import reliance calculated for the period 2012-2016 is 89%. The EU average consumption is about 28.6 Mm^3 of helium per year (4.77 kt). It is sourced mainly through imports from the United States (35% of the total sourcing) and Algeria (31%) (Figure 101).

Helium is used as a coolant liquid in cryogenics, as an inert gas atmosphere for welding metals, in the manufacturing of semiconductors and optical fibre cables, in rocket propulsion to pressurise fuel tanks, as a lifting gas, and in high-pressure breathing operations. Helium is also used as a tracer gas to check for leaks in containers, pressure vessels, etc. In research analysis, helium is used in mixtures with other gasses for i.e. calibration of instruments.

For some applications, helium has substitutes, but other uses rely on helium unique properties and there are no existing alternatives.

Helium used in large-volume applications is rarely recycled. The end-of-life recycling input rate (EoL-RIR) has been estimated at 1% for the purpose of the assessment.

Helium is listed in REACH and is exempted from registration (ECHA, 2019). Inhalating of helium gas can cause high voice, dizziness, dullness, headache and suffocation. The contact of liquit helium effect frostbites.

11.2 Market analysis, trade and prices

11.2.1 Global market analysis and outlook

The helium production and distribution market are highly consolidated, with numerous mergers and acquisitions taking place. The helium distribution business is run mostly by industrial gas companies having direct access to sources of helium. The world leaders on this market are Air Products and Chemicals (US), Air Liquide (France), Linde plc (registered in Ireland and resulted from the merger in October 2018 of Linde AG–Germany with Praxair-US), Matheson Tri-Gas (US, the largest subsidiary of TNSC Japan), ExxonMobil (US) and RasGas (Qatar).

Helium is traded on contract based with long term (10+ years) take-or-pay supply contracts with industrial gas companies. Because of the nature of the supply and the contract structure of the industry, storage is particularly important in helium market, having also a big influence in helium price.

Helium supply had several fluctuations, the most remarkable being the supply constraints during the period 2011-2013 . With the implementation of Qatar Helium 2 project, by the end of 2013, the global supply switched from shortage to excess-supply and stayed above the demand until beginning of 2017. Throughout 2018, helium was in tight supply caused primarily by the reduction of US helium production that started with the Qatar embargo in June 2017. However, large projects announced in Qatar and Russia should secure the helium supply during the forecast period.

The major factors playing on the supply side are the ongoing privatisation of US-based Federal Helium Reserve under the Helium Privatization Act of 1996 and the new players announced for the global helium market: Renergen (2019), Qatar 3 (2020), Irkutsk (2021) and Amur (2021-2026), a Gazprom project of gas processing plant in Siberia. Gazprom estimates that Amur facility will add to the world supply 60 Mm^3 once fully operational and thus Russia will become an important global supplier of helium.

Overall, the enlarged capacity production of the new facilities is likely to smooth the production fluctuations and secure a supply that can follow better the demand trends.

Table 54: Qualitative forecast of supply and demand of helium

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Helium		x	+	+	+	-+	+	+

Despite the high cost of extraction and transportation of the gas, the demand for helium will continue to grow, following the increasing demand for the gas from medical applications such as magnetic resonance imaging (MRI) and nuclear magnetic resonance (NMR) and growth in the electronics and semiconductor industries across the Asia-Pacific region.

Another factor that might influence the increasing demand for helium is related to the dynamics of research and development (R&D) for helium-based devices. For instance, there are the ongoing research of NASA and the National Science Foundation to employ supercooled helium for making sensitive gyroscopes for better navigation in submarines and airplanes. New applications of helium might include also hybrid air vehicles (such as Airlander and Lockheed Martin's LMH-1), helium filled hard drives, and Google X Project Loon.

11.2.2 EU trade

For helium, the EU is heavily reliant on imports. Over the 2012-2016 period, the EU imports are originating mainly in the United States (38% of the total imports) and Algeria (34%) (Figure 103).

No export restriction is in place for helium (OECD, 2019). A free trade agreement exists between the EU and Algeria since 2007 (within Euro-Med). On 18 June 2018, EU and Australia launched negotiations for a comprehensive trade agreement (European Commission, 2019).

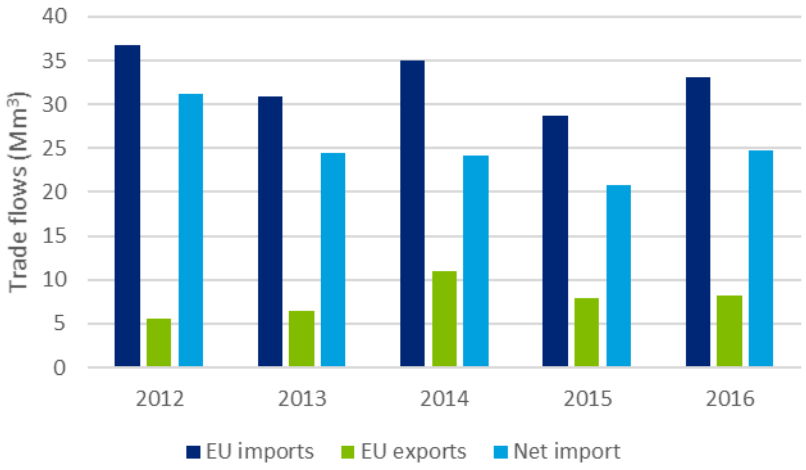


Figure 102: EU trade flows for helium (Eurostat 2019b)

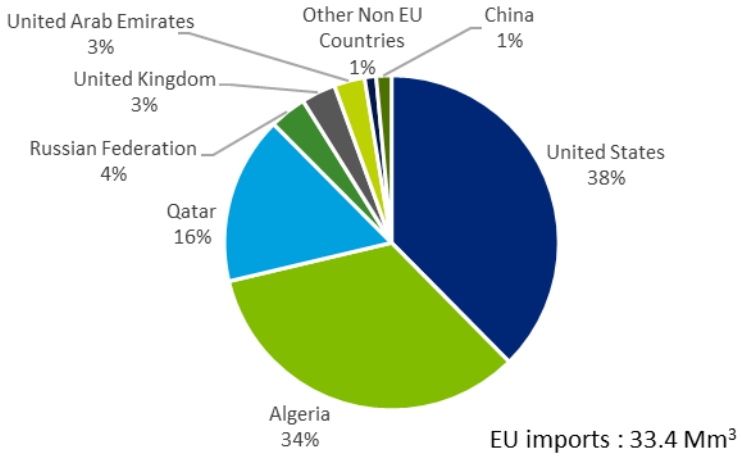


Figure 103: EU imports of helium, average for the 2012-2016 period (Eurostat 2019b)

11.2.3 Prices and price volatility

The US Bureau of Land Management (BLM) started to sell crude helium from the federal helium reserve on the open market in 2005, at a formula-driven price. This price became the de-facto crude helium price, and the basis of the price of refined liquid and refined gas in the US and worldwide. The unit price of in-kind helium has an increasing trend and has doubled over the last 20 years. The highest increase took place between 2014 and 2016, as a reaction to the supply constraints during the period 2011-2013 (Figure 104).

In fiscal year 2018, the price for crude helium to Government users was USD 3.10 per m^3 and to non-government users was USD 4.29 per m^3.

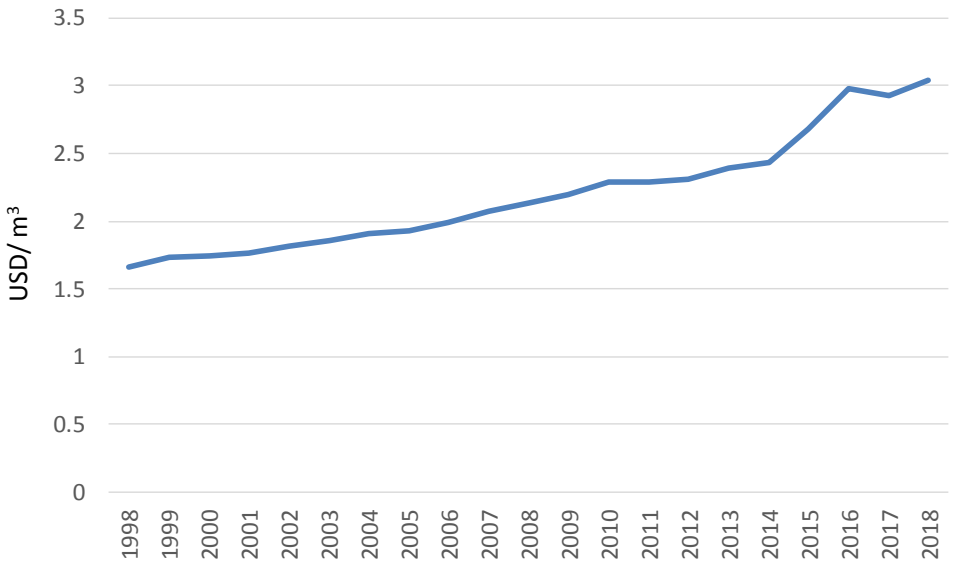


Figure 104. Prices of helium in-kind[80] from 1998 to 2018 (BLM,2019)

Over the period 2012-2016, the unit value of both EU imports and exports were quite stable, around 1 euro per m^3 for imports and 2.7 euro per m^3 for exports, respectively (Figure 105).

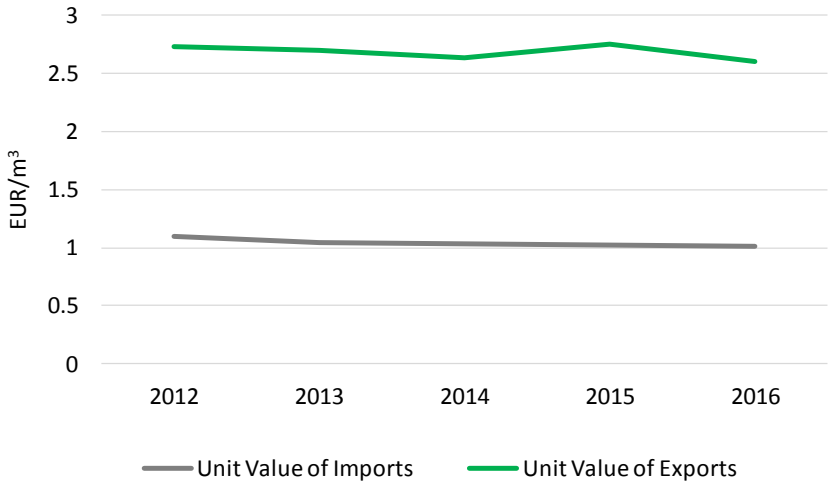


Figure 105. Helium EU unit value prices of imports and exports (Eurostat 2019b)

11.3EU demand

11.3.1EU demand and consumption

The EU net consumption amounted to about 28.6 Mm^3 per year on average during the period 2010-2016 (USGS, 2019).

[80] Original data converted from cubic feet to cubic metre

11.3.2Uses and end-uses of helium in the EU

Helium is important for scientific research, medicine and defence. The main categories of end uses for helium are shown in Figure 106 and the relevant industry sectors are described using the NACE sector codes in Table 55.

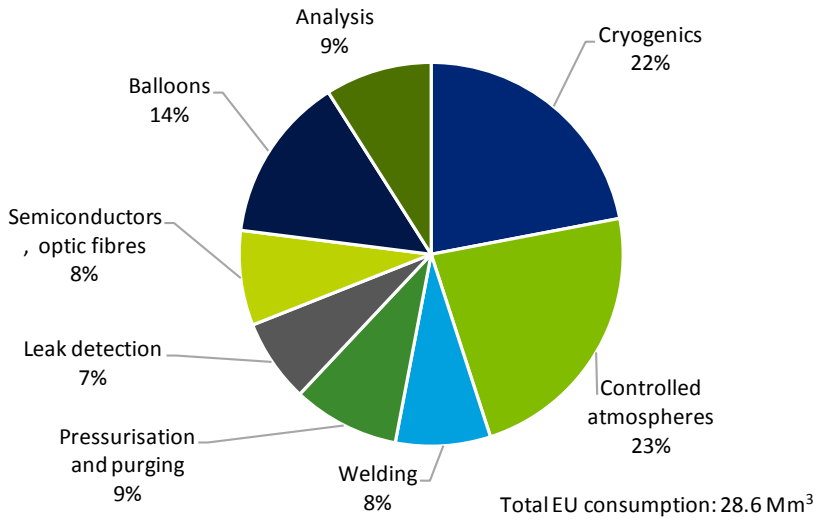


Figure 106: EU end uses of helium. Average figures for 2012-2016 (CRM Experts, 2019)

The largest use for liquid helium is in cryogenics where it is used mostly to cool superconductive magnets of MRI (Magnetic Resonance Imaging) scanners and, to a much less extent, in particle physics research facilities.

In 2018, an estimated 25% of global helium was consumed in liquid form, with this share being higher in developed regions (HIS Markit, 2019). In the major consuming regions—the United States, Western Europe, Japan, China, and Other Asia — MRI was the largest application for liquid helium, followed by fibre optics, semiconductors/electronics, and metals processing (welding cover gas).

The major use for gaseous helium is in arc welding, where it provides an inert gas shield to prevent oxidation during welding of aluminium, magnesium, copper, and stainless steels. Depending on the type of weld and the metal, helium will usually be blended with argon (in a share of 25% to 75% in the gas mix). Pure helium is generally only used for some specialized tungsten inert gas (TIG) welding applications (Air liquid, 2019).

Helium gas is also used:

- In semiconductor wafer and chip fabrication for its inertness, heat conducting and cooling properties. It is used as a cooling gas in the strand spinning operations in the manufacture of optical fibre cables.
- As purging and/or pressurising gas in aerospace, defence, and nuclear industries (e.g. NASA, Ariane).
- To create controlled atmospheres when gas inertness is necessary: heat treatment and manufacture of high-purity metals etc. It is a component of breathing gas in deep diving activities in offshore oil and gas exploration and underwater pipe maintenance.

- In leak detection as a tracer gas to check for leaks in containers, pressure vessels etc. because of the He atom small size.
- As a lifting gas in party balloons, weather balloons, advertising blimps, balloons for upper atmosphere studies.

Helium is also applied in advanced R&D projects in areas such as: nuclear technology, magneto hydrodynamics studies and behaviour of materials at very low temperatures.

Helium could be demanded also for producing the precooler heat exchanger of the Synergetic Air-Breathing Rocket Engine (SABRE), that cools the hot airstream generated by air entering the engine intake at hypersonic speed (Mach 5) (ESA, 2019).

Future applications of helium might include also hybrid air vehicles Airlander 10 and Airlander 50 in perspective (Hybrid air vehicles, 2019).

Relevant industry sectors are described using the NACE sector codes (Eurostat 2019a).

Table 55: Helium applications, 2-digit and associated 4-6-digit NACE sectors, and value added per sector (Eurostat 2019a)

Applications	Shares	2-digit NACE sector	6-digit CPA
Cryogenics	22%	C32 - Other manufacturing	32.50
Controlled atmospheres	23%	C24 - Manufacture of basic metals	24.45
Welding	8%	C25 - Manufacture of fabricated metal products, except machinery and equipment	25.62.20 25.11
Pressurisation and purging	9%	C32 - Other manufacturing	32.99.11
Leak detection	7%	C33 - Repair and installation of machinery and equipment	33.12
Semiconductors, optic fibres	8%	C26 - Manufacture of computer, electronic and optical products	27.31.1 26.11.22 26.30
Balloons	14%	C32 - Other manufacturing	32.99
Analysis	9%	C32 - Other manufacturing	32.99

11.3.3Substitution

Due to its unique properties (the best refrigerant, superfluidity below 2.18 Kelvin: viscosity-free fluid flow and extraordinarily high thermal conductivity, the highest ionization potential, very high specific heat and thermal conductivity, chemically and radiologically inert), helium can be substituted only in some of its applications, as following:

- **Cryogenics**: There is no substitute for liquid helium in cryogenic applications if temperatures below 17°K (-256°C) are required. Other cryogenic substances are used in other temperature conditions.
- **Purge and pressurization:** There is no substitute for applications requiring inertness and ultra-low temperature.

- **Welding**: Argon can be used for both gas metal arc welding and gas tungsten arc welding.
- **Semiconductor and optical fibre manufacturing**: For semiconductor industry, helium can be substituted by argon or hydrogen or nitrogen depending on its application. There is presently no substitute for helium in optical fibre production process (Borersen, 2013).
- **Lifting gas:** Hydrogen is sometimes substituted if safety concern can be met (Chan, 2013).
- **Controlled atmospheres and breathing gas:** Argon can be used as a substitute. There is no substitute for breathing mixtures.
- **Leak detection:** Some helium users could use a mix of 5% hydrogen and 95% nitrogen -which is classified as non-flammable - as an alternative.
- **Analysis:** Hydrogen and nitrogen are used as carrier gas for chromatography. Hydrogen provides the fastest analysis time over a broad linear velocity range, but safety concerns must be addressed. Nitrogen is a slow carrier gas, so its use is limited to situations where longer analysis times are acceptable (Wallace, 2011).

11.4Supply

11.4.1EU supply chain

The EU is a net importer of helium and the import reliance is 89% (averaged over 2012-2016), slightly lower as compared to the previous estimation within the criticality exercise.

In Europe, the extraction of helium occurs mainly in Poland.

11.4.2Supply from primary materials

11.4.2.1 Geology, resources and reserves of helium

Geological occurrence: Helium is concentrated in stars, where it is synthesised from hydrogen by nuclear fusion. Helium occurs in the Earth's atmosphere only to the extent of 1 part in 200,000 (0.0005%), and small amounts occur in radioactive minerals, meteoric iron, and mineral springs. Great volumes of helium are found as a component in natural gases. The helium that is present on Earth is not a primordial component of the Earth but has been generated by radioactive decay. Helium is produced in the natural environment continually by the radioactive decay of uranium specifically within uranium and thorium-rich sedimentary sequences in the earth's crust e.g., black shales (Selley, 1985) and escapes into the atmosphere.

Since the concentration of helium in air is very minimal, extraction of helium from air is not economically viable. Helium is mainly extracted from helium-bearing natural gas.

Global resources and reserves: There are no recent and reliable global or EU resource and reserve estimates for helium. Existing data should be treated with caution as direct comparison between countries may not be possible due mainly to different reporting systems.

In December 2006, the total helium reserves and (probable, possible and speculative) resources in the United States were estimated to be 20,600 million cubic metres (Mm^3).

Helium resources in the rest of the world were estimated at about 31,300 Mm^3, with the third of these resources located in Qatar (10,100 Mm^3) followed by Algeria (8,200 Mm^3), Russia (6,800 Mm^3), Canada (2,000 Mm^3) and China (1,100 Mm^3) (USGS, 2019).

Table 56: Global reserves of helium[81] (USGS, 2019)

Country	million cubic metres (Mm^3)
USA	3,900
Algeria	1,800
Russia	1,700
Poland	25
Other countries: Australia, Canada, China, Qatar	Not available
World	Not available

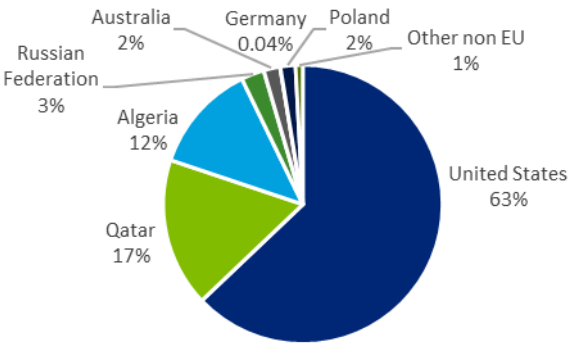
The exploration project of the Helium One company revealed big resources of helium available in Tanzania Rukwa basin (98.9 billion standard cubic feet, equal to 2800 Mm^3). Aside from the large quantity, the basin where the helium seeps are located is also relatively unique in the concentration of helium it produces, ranging between 2.5% and 10% (Helium one, 2019).

EU resources and reserves*:* Poland helium reserves are estimated at 23.88 Mm^3 in 2018, available in a total of 16 fields: 10 exploited fields (20.76 Mm^3) and 6 non-exploited fields (3.16 Mm^3) (Polish geological institute, 2019).

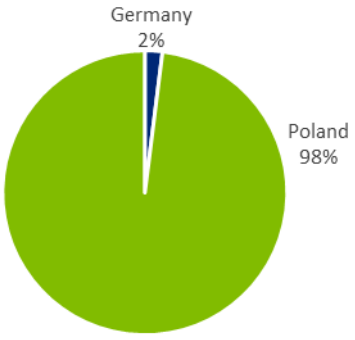
11.4.2.2 World and EU production

The world annual average supply of helium was approximatively 169.3 Mm^3 (28.3 Kt) over the period 2012-2016, with 63% of the global supply coming from the US, followed by Qatar (17%), Algeria (13%), Russia (3%), Australia (2%) and Poland (2%) (USGS, 2019), see Figure 107.

The US supply came from active natural gas wells and from the federal government National Helium Reserve which is an underground stockpile known as the Bush Dome Reservoir in the Cliffside gas field, in Texas. Large amounts of helium had been stored in this reservoir from the early 1960s to the mid-1990s. The Helium Privatization Act of 1996 and the Helium Stewardship Act of 2013 mandated the resell of most of the federal stockpiles. The Bureau of Land Management (BLM) manages the federal helium reserve (USGS,2019).



Global production 169.3 Mm^3



EU production 3 Mm^3

[81] Note: Data as for December 2006. Updates are expected to be published in 2020

Figure 107: Global and EU helium production in Mm^3 and percentage. Average for the years 2012-2016 (USGS, 2019).

According The Central Geological Database of Poland, in this country the recovery of helium from ten fields reached 750 km^3 in 2018. The volume does not include the recovery from the fields in which a helium admixture has not been documented. The total pure helium production by Polish Oil and Gas Company (POGC – in Polish PGNiG) – Odolanów Branch, recovered from the exploited natural gas in Poland, amounted to 3.08 m^3 in 2018 (Polish geological institute, 2019).

According to DERA (Elsner, 2018) helium is supplied:

a) **In the liquefaction of natural gas to liquefied natural gas** (LNG) in LNG facilities - In Algeria, Australia and Qatar. In the majority of cases the helium is also liquefied, to make easier its transportation and commercialisation.
b) **During denitrification of natural gas** - in the US, Russia and Poland. In order to reduce the excessive levels of non-combustible nitrogen in some natural gas reservoirs, nitrogen and helium are converted by pressure swing adsorption or separated at low temperatures by cryogenic fractionating distillation.
c) **In the purification of natural carbon dioxide gas**. Carbon dioxide is used in fracking in the US, and gas producer Air Products and Chemicals, Inc. decided to process a highly CO_2-rich natural gas, thereby producing helium as a saleable product.
d) **From the nitrogen fraction in air separation** - in Leuna in Germany, Ukraine and China. Helium is obtained as a by-product of neon production, where it is present in the crude neon–helium fraction at up to 24%. Because helium and neon levels in air are very low, this form of helium production is highly complex and expensive. The volume of helium produced compared to helium production methods a) and b) is very low. Large quantities of ^3He are therefore created in nuclear reprocessing plants, nuclear weapons factories and nuclear reactors.

There are several exploration projects worldwide, but no detailed information for EU has been found.

11.4.3Supply from secondary materials/recycling

Cost issues and uncertainties about helium supply have led to the development of recovery and recycling technologies in certain end-user applications and an increasing usage of helium recovery and purification systems in both scientific R&D and industrial applications. However, USGS (2019) reports that helium used in large-volume applications is rarely recycled. Overall, the end-of-life recycling input rate has been estimated at 1%.

Several German universities and research institutes also collect the gaseous helium they use and return it to the respective gas suppliers, partly in the gaseous state, partly liquefied, for a fee. Here, good recovery rates are between 90% and 95%. The price for a complete plant such as this, with liquefaction, is said to be around 2 million euro (Elsner, 2018).

11.4.4 Processing of helium

Helium is extracted from natural gas of average content 0.1%-0.5%, usually produced as a by-product of natural gas processing. Natural gas contains methane and other hydrocarbons and smaller quantities of nitrogen, water vapour, carbon dioxide, helium and other non-combustible materials. Crude helium containing about 50-70% helium is extracted from the stream of natural gas usually using a cryogenic distillation method after removing the impurities which might solidify during the process. Once separated from the natural gas, crude

helium which contains nitrogen along with smaller amounts of argon, neon, and hydrogen is purified to commercial grades (99.99+%). This is typically done using either activated charcoal absorbers at liquid-nitrogen temperatures and high pressure or pressure-swing adsorption (PSA) processes (US National Research Council, 2010).

For natural gas fields with sufficient concentrations of helium and other non-fuel gases such as CO_2 and sulphur, helium may be directly processed. Helium could be recovered during the production of liquefied natural gas (LNG) which consists mainly of liquefied methane. The helium is extracted from the gases that remain after the methane has been liquefied. These tail gases, which have a high helium concentration similar to that of crude helium, are then purified. The end product of the purification process is liquefied helium. In this case, helium can be economically recovered from natural gas with very low helium content (U.S. National Research Council, 2010).

11.5Other considerations

11.5.1 Environmental and health and safety issues

Helium is listed in EC Inventory of ECHA under the code 231-168-5, and is exempted from registration in REACH (ECHA, 2019). Nevertheless, its labelling should include ”Contains gas under pressure; may explode if heated”.

Under standard conditions, neutral helium is non-toxic. Helium-gas can be absorbed by inhalation with following effects (depends on the amount of inhalated gas): high voice, dizziness, dullness, headach and suffocation. Contact with liquit helium can cause frostbites.

11.5.2 Socio-economic issues

No specific socio-economic issues are related to helium.

11.6Comparison with previous EU assessments

Helium was assessed for the first time in 2017 using a revised methodology. The 2020’s criticality assessment was performed at the processing stage of the value-chain, following the methodology adopted for the 2017 assessment.

The results of this and earlier assessments are shown in Table 57.

Table 57: Economic importance and supply risk results for helium in the assessments of 2011, 2014, 2017, 2020 (European Commission, 2011-2014-2017).

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Helium	Not assessed		Not assessed		2.8	1.6	2.63	1.16

Both economic importance and supply risk have diminished slightly compared to previous CRM assessment.

11.7Data sources

11.7.1Data sources used in the factsheet

Air liquide. (2019). Helium. Retrieved from https://industry.airliquide.com.au/sa-spec-helium

BLM. (2019). Bureau of Land Management Crude Helium Price. Retrieved from https://www.blm.gov/sites/blm.gov/files/FY2019%20Posted%20Price_Interim.pdf

Boersen, B. (2013). The Past, Present and Future of the Federal Helium Program. [online] Available at:. Retrieved from http://docs.house.gov/meetings/II/II00/20130214/100266/HHRG-113-II00-Wstate-BoersenB-20130214.pdf

Chan, M. (2013). Up in the Air: The BLM's Disappearing Helium Program. Retrieved from https://www.blm.gov/congressional-testimony/air-blms-disappearing-helium-program

ECHA. (2019). Registered substances. Retrieved from https://echa.europa.eu/

Elsner, H. (2018). Edelgase – Versorgung wirklich kritisch? (D. R. S., Ed.) Retrieved from https://www.deutsche-rohstoffagentur.de/DE/Gemeinsames/Produkte/Downloads/DERA_Rohstoffinformationen/ro

ESA. (2019). ESA greenlight for UK's air-breathing rocket engine. Retrieved from https://www.esa.int/Enabling_Support/Space_Engineering_Technology/ESA_greenlight_for_UK_s_air-breathing_rocket_engine

European Commission. (2019). Overview of the FTA and other trade negotiations – updated November 2019. Retrieved from https://trade.ec.europa.eu/doclib/docs/2006/december/tradoc_118238.pdf

Eurostat. (2019a). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). Retrieved from http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

Eurostat. (2019b). International Trade Easy Comext Database. Retrieved from http://epp.eurostat.ec.europa.eu/newxtweb/

Gas World. (2019). Globa Helium Summit 2018. Retrieved from https://www.gasworld.com/global-helium-summit-2018-closes/2015512.article

Helium One. (2019). Retrieved from http://www.helium-one.com/projects/rukwa/

Hybrid air vehicles. (2019). Retrieved from https://www.hybridairvehicles.com/our-aircraft/airlander-10/

IHS Markit. (2019). Helium Chemical Economics Handbook. Retrieved from https://ihsmarkit.com/products/helium-chemical-economics-handbook.html

Polish Geological Institute. (2019). Mineral Resources of Poland. Retrieved from http://geoportal.pgi.gov.pl/surowce/energetyczne/hel/2018

Selley, R. (1985). Elements of Petroleum Geology. San Francisco.

US National Research Council. (2010). Selling the Nation's Helium Reserves. Washington, DC, US: The National Academies Press. Retrieved from https://www.nap.edu/read/12844/chapter/1

USGS. (2019). Mineral Commodity Summaries. (A. C. Tolcin, Ed.) Retrieved from https://www.usgs.gov/centers/nmic/helium-statistics-and-information

Wallace, R. a. (2011). Hydrogen: A Carrier Gas Alternative to Helium. Retrieved from http://www.sigmaaldrich.com/content/dam/sigma-aldrich/articles/reporter-us/pdf/hydrogen-a-carrier.pdf

11.7.2Data sources used in the criticality assessment

BGR (2016). Helium (Gubler et al.)

European Commission (2019). Free trade agreements. [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/

Eurostat (2019a). International Trade Easy Comext Database. [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2019b). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

Gazprom (2019). www.gazprom.com

Hydrogen Europe (2019). Hydrogen production, available at: https://hydrogeneurope.eu/hydrogen-production-0

Linde Group (2015)a. Gases & Applications eBook. [online] Available at: http://www.linde-gas.com/internet.global.lindegas.global/en/images/Gases-and_Applications_eBook_144dpi17_168809.pdf?v=2.0

Linde Group (2015)b. Gas units converter : The Linde Group. [online] Available at: http://hiq.linde-gas.com/en/specialty_gases/gas_units_converter.html

OECD (2019) Export restrictions database on Industrial Raw Materials. [online] Available at: https://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

Polish Geological Institute (2019). Helium [online] Available at: http://geoportal.pgi.gov.pl/surowce/energetyczne/hel

The Essential Chemical Industry (2016). Oxygen, nitrogen and the rare gases. [online] Available at: http://www.essentialchemicalindustry.org/oxygen.html

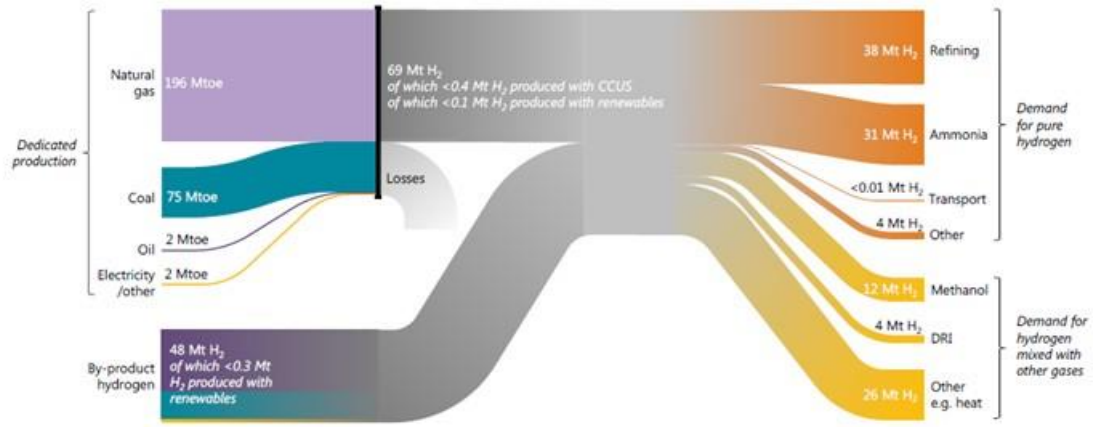
USGS (2019). Mineral Commodity Summaries. Helium (2012 to 2016). [online] Available at: https://minerals.usgs.gov/minerals/pubs/commodity/helium/mcs-2017-heliu.pdf

11.8Acknowledgments

This factsheet was prepared by JRC. The authors would like to thank to IFEU, Germany (which conducted the MSA assesment for helium), the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this Factsheet.

12. HYDROGEN

12.1 Overview



Notes: Other forms of pure hydrogen demand include the chemicals, metals, electronics and glass-making industries. Other forms of demand for hydrogen mixed with other gases (e.g. carbon monoxide) include the generation of heat from steel works arising gases and by-product gases from steam crackers. The shares of hydrogen production based on renewables are calculated using the share of renewable electricity in global electricity generation. The share of dedicated hydrogen produced with CCUS is estimated based on existing installations with permanent geological storage, assuming an 85% utilisation rate. Several estimates are made as to the shares of by-products and dedicated generation in various end uses, while input energy for by-product production is assumed equal to energy content of hydrogen produced without further allocation. All figures shown are estimates for 2018. The thickness of the lines in the Sankey diagram are sized according to energy contents of the flows depicted.

Source: IEA 2019. All rights reserved.

Figure 108: Hydrogen value chain globally (IEA, 2019)

Hydrogen is the most abundant and lightest of the elements; it is odourless and nontoxic. It has the highest energy content of common fuels by weight - nearly three times that of gasoline. Hydrogen is not found free in nature and must be "extracted" from diverse sources: fossil energy, renewable energy, nuclear energy and the electrolysis of water. A separate energy source (electricity, heat or light) is required to "produce" (extract or reform) the hydrogen.

Hydrogen is an "energy carrier". It can be used in a full range of applications in all sectors of the economy: transportation, power, industry, and buildings. As an "industrial gas**,**" hydrogen is already a big global business with strong basis. Hydrogen is used in several industrial processes: in the refining industry as a petrochemical for hydrocracking and desulphurization, in the chemical industry**,** it is used for ammonia production and fertilizer for agriculture. It is also used for applications in the metal production & fabrication (production of steel, special metals and semiconductors)**;** methanol production (used in the manufacture of many polymers); food processing and electronics sectors. In the electronics industry, it is widely employed as a reducing agent and as a carrier gas. High-purity hydrogen is also used as a carrier gas in gas chromatography.

The value chain of hydrogen is shown in Figure 108. Supplying hydrogen to industrial users is now a major business globally. Demand for hydrogen (around 70 million tonnes per year pure hydrogen) has grown more than threefold since 1975 and continues to rise. Further 45 million tonnes per year were used in industries such as steel and methanol production without prior separation of the hydrogen from other gases. Hydrogen is almost entirely supplied from fossil fuels, with 6 % of global natural gas and 2 % of global coal going to hydrogen production. In

energy terms, total annual hydrogen demand worldwide is around 330 million tonnes of oil equivalent (toe), which is larger than the primary energy supply of Germany (IEA, 2019).

In future, besides the common industrial applications, hydrogen will have an important role for storage of renewable electricity as a result of the growth of renewable energy sources. The electricity grid must sometimes restrict uptake of renewable electricity when the grid is full (saturated) in order to balance electricity supply and demand. Consequently, renewable electricity production is curtailed. However, use of hydrogen for storage of renewable electricity (converted via water electrolysis) can be a game changer. Hydrogen and electricity are in fact complementary energy carriers: hydrogen can be converted to electricity, and electricity can be converted to hydrogen.

Hydrogen use in 2018 globally was dominated by industry: oil refining, ammonia production, methanol production and steel production. Around 33 % is used in Refineries to process crude oil into refined fuels, such as gasoline and diesel, and for removing contaminants (e.g. sulphur) from these fuels (Figure 109). Refinery demand for hydrogen has increased as demand for diesel fuel has risen both domestically and internationally, and as sulphur-content regulations have become more stringent. Roughly 27 % of the hydrogen is used for ammonia and 10 % for methanol production. Around 80 % of ammonia is mostly used in the manufacture of fertilisers such as urea and ammonium nitrate. The remainder is used for industrial applications such as explosives, synthetic fibres and other specialty materials, which are an increasingly important source of demand. Methanol is used for a diverse range of industrial applications, including the manufacture of formaldehyde, methyl methacrylate and various solvents. Methanol is also used in the production of several other industrial chemicals, and for the methanol-to-gasoline process that produces gasoline from both natural gas and coal, which has proven attractive in regions with abundant coal or gas reserves but with little or no domestic oil production. Around one third of the hydrogen is used for metal refining, chemicals production, food processing and electronics manufacturing (IEA, 2019).

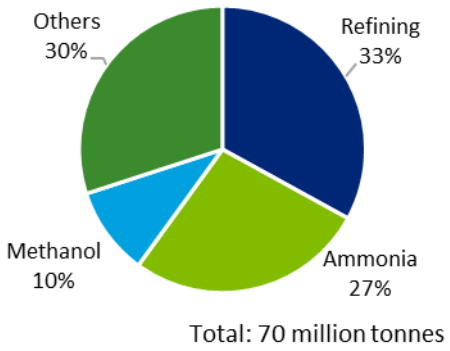


Figure 109 End uses of hydrogen globally in 2018 (IEA, 2019)

Hydrogen can be used much more widely. Hydrogen can be adopted in sectors where it is almost completely absent in 2019, such as transport, buildings and power generation:

- Transport. The competitiveness of hydrogen fuel cell cars depends on fuel cell costs and refuelling stations while for trucks the priority is to reduce the delivered price of hydrogen. Shipping and aviation have limited low-carbon fuel options available and represent an opportunity for hydrogen-based fuels.
- Buildings. Hydrogen could be blended into existing natural gas networks, with the highest potential in multifamily and commercial buildings. Particularly in dense cities

while longer-term prospects could include the direct use of hydrogen in hydrogen boilers or fuel cells.

- Power generation. Hydrogen is one of the leading options for storing renewable energy, and hydrogen and ammonia can be used in gas turbines to increase power system flexibility. Ammonia could also be used in coal-fired power plants to reduce emissions.

Hydrogen is produced in large quantities both as a principal product and as a by-product. Large consumers are also producing hydrogen on-site at the consumption site. This is mainly done for refineries, fertilizer plants (ammonia), methanol, and hydrogen peroxide production plants. Hydrogen producers may consume the product captively, sell it to end users, sell it to a company that specializes in marketing industrial gases, burn it for fuel, or vent it to the atmosphere. Consumers may buy hydrogen from an industrial gas company or a by-product producer, use internally generated by-product hydrogen or install a hydrogen plant on-site. In some cases, a company will generate crude by-product hydrogen that is purchased and purified by an industrial gas company and then sold back to the original generating company.

More than 70% of the hydrogen worldwide is produced by the steam reforming of methane or natural gas, in 2018 (Figure 110). The production of hydrogen from natural gas is the cheapest source. This process consists of heating the gas to between 700 and 1100 °C in the presence of steam and a nickel catalyst. Almost the rest of the hydrogen is generated by gasification of coal. Less than 2% is generated by oil reforming or electrolysis (IEA, 2019).

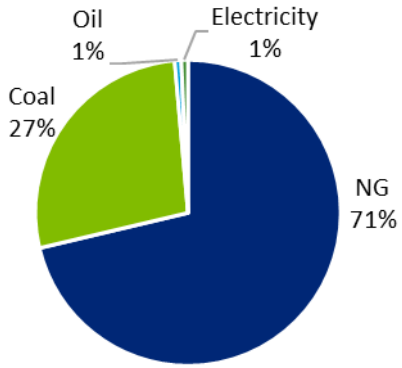


Figure 110: Raw materials used for production of hydrogen worldwide (IEA, 2019)

In Europe, more than 90% of the industrial hydrogen is produced by steam reforming of natural gas and the rest is generated by oil reforming (Figure 111) (IEA, 2019).

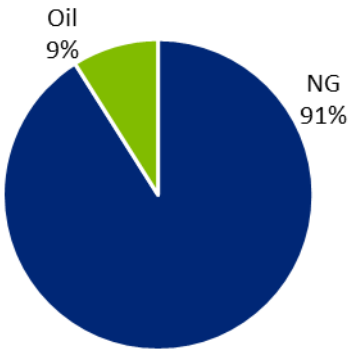


Figure 111: Raw materials used for production of hydrogen in Europe (IEA, 2019)

Hydrogen, produced by water electrolysis using carbon-free electricity or from natural gas steam reforming using Carbon Capture and Storage can contribute to decarbonise various sectors in future. First, as storage in the power sector to accommodate for variable energy sources. Second, as an energy carrier option used in heating, transport and industry and, finally, as a feedstock for industry such as steel, chemicals and e-fuels in those sectors that are most difficult to decarbonise (COM, 2018; 773 final).

In future it is expected that a significant share of the hydrogen will be produced by electrolysers and that automotive market will become an important consumer of hydrogen. Hydrogen is considered a sustainable fuel for the future automotive sector and a promising large-scale electricity storage option.

Use of electrolysis to split water into hydrogen and oxygen is on the increase. The 2015 IEA Technology Roadmap for Hydrogen and Fuel Cells recognizes that hydrogen with a low-carbon footprint has the potential to facilitate significant reductions in energy-related CO_2 emissions. Thus, use of renewable feedstocks for hydrogen production is very attractive from the environmental perspective. If the electricity used in electrolysis is produced from fossil fuels, then the pollution and carbon dioxide emissions produced from those fuels are indirectly associated with electrolysis.

The Regulation on Hydrogen (GTR, 2013) regulates in particular safety requirements in hydrogen vehicles, and in particular, fuel cell electric vehicles (FCEVs).

Recycling rate of hydrogen is considered as 0 %. The waste of hydrogen gas has typically not been recovered for reuse, especially in smaller scale applications. There are two solutions for the waste hydrogen: purchase more from industrial gas suppliers or generate on-site.

12.2Market analysis, trade and prices

12.2.1Global market analysis and outlook

According to market consultants, overall global demand for hydrogen is expected to increase at around 4 to 5% per year between 2020 and 2025. Primarily as a result of demand from petroleum refinery operations, and the production of ammonia and methanol. Asia will continue to lead demand growth in line with the increasing growth of its domestic economies.

Production of ammonia has been on the rise with lower natural gas prices providing an advantage. The methanol market is also experiencing robust growth. Demand for distillate is steadily on the increase. Refineries are large-volume producers and consumers of hydrogen for distillate. Refinery hydrogen by-product covers however only a third of hydrogen requirements, with the gap filled by dedicated on-site production and commercial supply. Most dedicated on-site production uses natural gas feedstock, but light fractions of oil distillation and heavier feedstocks – petroleum coke, vacuum residues and coal – are also used in some regions. Use of heavier feedstocks is mostly restricted to India and China, where gas needs to be imported. Coal gasification is routinely included in new refinery setups in China as a main or auxiliary hydrogen production unit.

Market supply of hydrogen is an option in densely industrialised areas where developed hydrogen pipeline infrastructure exists, such as the US Gulf Coast and Europe's Amsterdam-Rotterdam-Antwerp hub. As with dedicated on-site production, commercially available hydrogen is mostly produced from natural gas. The amount not coming from natural gas is generated through chemical processes: a by-product of operations such as steam cracking and chlorine production. In regions such as the US Gulf Coast, the commercialised hydrogen can meet over a third of total hydrogen demand.

In general, environmental regulations implemented in most industrialized countries result in increased hydrogen requirements at refineries for gasoline and diesel desulfurization because of increased demand for cleaner fuels and tighter engine manufacturer specifications. Ongoing oil sands processing, gas-to-liquids, and coal gasification projects all require enormous amounts of hydrogen and will boost the size of the market significantly until 2025. Alberta, Canada has an enormous area containing oil sands that can be processed to produce oil. Even by conservative estimates, this area is estimated to be the second-largest oil reserve after Saudi Arabia. Desulfurization operations for these sands would consume vast quantities of hydrogen.

Hydrogen is also expected to see a surge in consumption in the manufacture of methanol. Substantial methanol consumption in direct-fuel use as motor gasoline is expected in countries such as China, Russia, South Africa, Venezuela, and several Middle Eastern countries.

The future hydrogen demand (Table 58) growth depends on the evolution of demand for downstream products, notably refined fuels for transport, fertilisers for food production, and construction materials for buildings. Demand for ammonia and methanol is expected to increase over the short to medium term. In the longer term, steel and high-temperature heat production offer vast potential for low emissions hydrogen demand growth. The demand for hydrogen in 2030 is foreseen to increase by 7 % in oil refining sector, around 30 % in the chemical sector and to double in the steel production sector, which accounts for around 30 % increase of the overall hydrogen demand (IEA, 2019).

Higher demand is foreseen according to the European Roadmap for hydrogen for the same timeframe: an increase between 48 % and 105 % in case of 'Business as usual' and 'Ambitious' scenario, respectively. An increase between 140 % and almost 600 % is anticipated by 2050 with respect to the same scenarios (Hydrogen Roadmap, 2019).

The consumption of hydrogen for Industry, Transport, Residential & services and Power sector (storage) in 2050 is expected to increase by 5 Mtoe (2 % increase as of today) according to a 'Baseline' scenario. In a high hydrogen deployment scenario, the consumption of hydrogen is projected to increase by 145 Mtoe for the same year, representing 44 % increase as of today (EC COM 773).

Table 58: Qualitative forecast of supply amd demand of hydrogen

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	30 years	5 years	10 years	20 years
Hydrogen		X	-	30% - 105%	2% - 600%	-	-	-

12.2.2EU trade

According to experts and TrendEconomy (2019), the hydrogen produced in Europe is enough to satisfy Europe's needs and basically no hydrogen is imported in Europe. This also appears from the Roads2Hy study (Roads2Hy, 2007): a potential of between 2 and 10 billions Nm^3 hydrogen might be available as 'surplus hydrogen' in Europe, either in the form of excess capacity or by-product hydrogen

Europe is dependent on import of natural gas and oil, being the main raw materials required for hydrogen generation today in Europe. In 2017, the main global suppliers of natural gas were the US (20 %) and Russia (17 %), see Figure 112A (BP, 2018). The main suppliers of natural gas to the EU in 2017 were Russia with a share of 39 %, Norway with 25 % and Algeria 11 %; see Figure 113A (Eurostat, 2019a). The import reliance of Europe on supply of natural gas was 73 % (Eurostat, 2019b).

With regards to crude oil production, the main suppliers in 2017 were Russia (13%), Saudi Arabia (13%) and US (13%); see Figure 112B (BP, 2018). Leading exporters to the EU in 2017 were Russia (30%), Norway (12%) and Iraq (8%) (Figure 113B) (Eurostat, 2019a). In 2017, the import reliance of Europe on supply of oil products was 87% (Eurostat, 2019c).

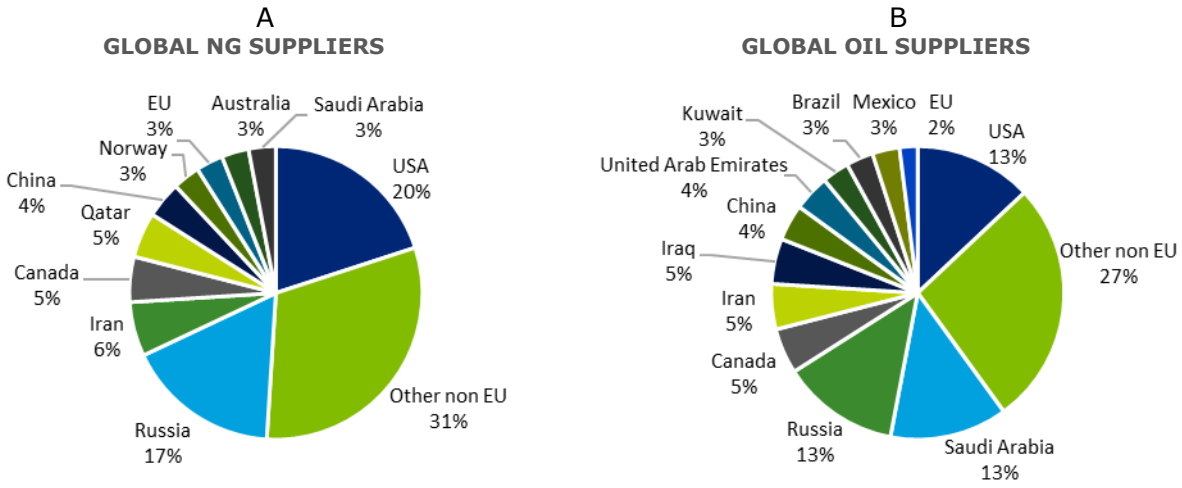


Figure 112: Global suppliers of natural gas (A) and oil (B) in 2017 (BP, 2018)

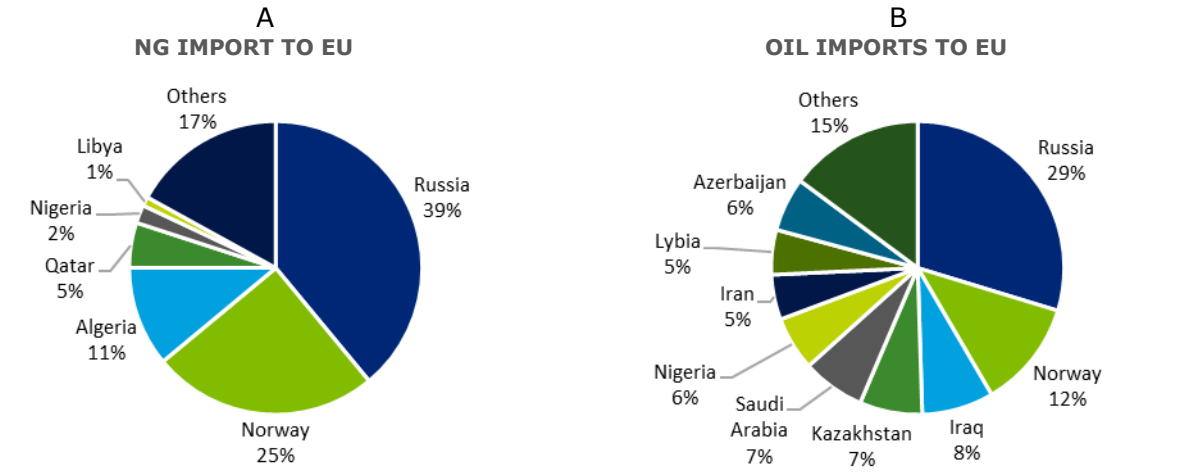


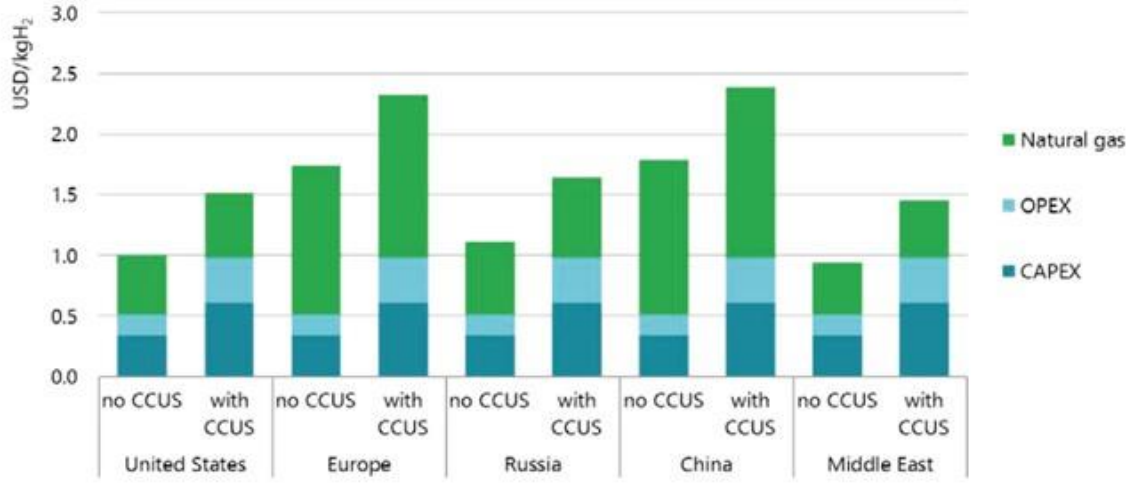
Figure 113: EU imports of natural gas (A) and crude oil (B) in 2017 (Eurostat, 2019a)

12.2.3Prices and price volatility

Production costs of hydrogen vary greatly regionally (Figure 114). The most economic option for hydrogen production in most parts of the world is natural gas without carbon capture utilisation and storage (CCUS), which costs US$ 1 per kilogram hydrogen (Middle East). Among low-carbon options, electrolysis requires electricity prices of US$ 10 to 40 per MWh and full load hours of 3,000–6,000 to become cost-competitive with natural gas with CCUS. Regions with good renewable resources or nuclear power plants may find electrolysis an attractive option, especially if they currently depend on relatively high cost natural gas imports.

The future costs will also depend on factors such as prices for fossil fuels, electricity and carbon that will continuo to vary ragionally. There are several regions where hydrogen imports could be cheaper than domestic production. Domestic production in Japan using electrolysers and its distribution could cost around around US$ 6.5 per kilogram hydrogen in 2030. Hydrogen imported from Australia could cost around US$ 5.5 per kilogram. Similar opportunities may develop in Korea and parts of Europe. Using ammonia directly in end-use sectors could further improve the competitiveness of imports. Even where importing hydrogen is not the cheapest option, some energy-importing countries may wish to consider imports to increase their energy diversity and access to low-carbon energy.

The production cost of hydrogen from natural gas is influenced by various technical and economic factors, with gas prices and capital expenditure (CAPEX) being the two most important. Fuel costs are the largest cost component in all regions and account for between 45 % and 75 % of production costs (Figure 114). Low gas prices in the Middle East, the Russian Federation, and North America give rise to some of the lowest hydrogen production costs. Gas importers such as Japan, Korea, China and India have to contend with higher gas import prices, and that makes for higher hydrogen production costs.



Notes: kgH_2 = kilogram of hydrogen; OPEX = operational expenditure. CAPEX in 2018: SMR without CCUS = USD 500–900 per kilowatt hydrogen (kW_{H_2}), SMR with CCUS = USD 900–1 600/kW_{H_2}, with ranges due to regional differences. Gas price = USD 3–11 per million British thermal units (MBtu) depending on the region. More information on the underlying assumptions is available at www.iea.org/hydrogen2019.

Source: IEA 2019. All rights reserved.

Figure 114: Hydrogen production cost using natural gas in different regions in 2018 (IEA, 2019)

12.3EU demand

12.3.1EU demand and consumption

The refining and chemical sectors (namely ammonia and methanol production), representing around 70 % of the demand for hydrogen globally, are used to estimate the European demand of hydrogen.

The demand for hydrogen in the refinery sector based on global oil refining capacity is shown in Figure 115A (BP, 2018). The US represents the biggest consumer for refinery hydrogen of

almost 20 % of the global demand. EU and China represent the other two major consumers, having 15 % demand share each.

The demand for hydrogen for ammonia and methanol production globally is shown in Figure 115B (IEA, 2019). The biggest consumer is Asia Pacific with more than 20 % of the global demand, followed by Middle East (17 %) and North America (17 %). Europe is the fourth biggest consumer of hydrogen for ammonia and methanol production with 16 % demand share.

On average Europe requires around 15 % of the hydrogen globally for the considered sectors.

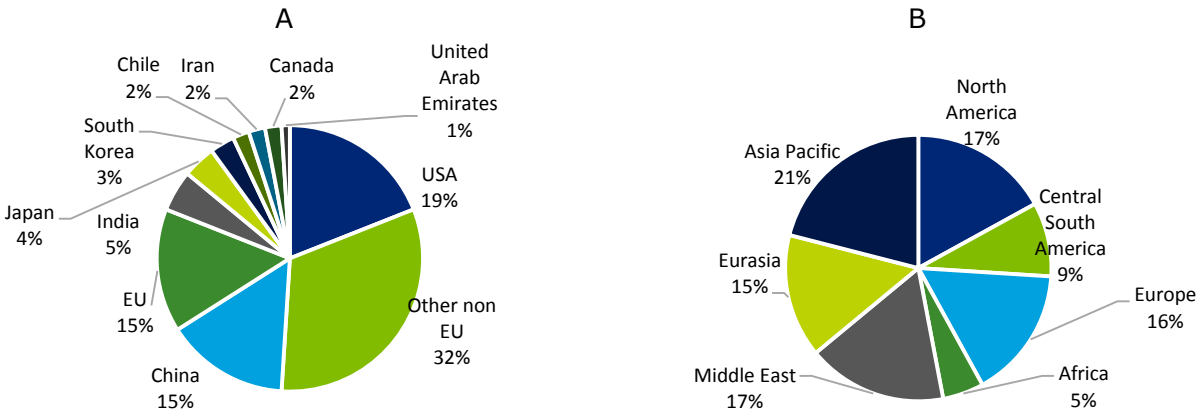


Figure 115 Hydrogen demand for refining (A) (BP, 2018), amonia and methanol production sectors (B) (IEA, 2019)

12.3.2Uses and end-uses of Hydrogen in the EU

In the EU the main sectors requiring hydrogen are the Chemical sector (63 %), most of which (84 %) goes for ammonia production, 12 % for methanol production and only 4 % for the production of polymers and resins (CertifHy, 2015). Refineries are requiring around 30 % of the hydrogen in the EU, Metal Processing industry 6 %, and other sectors consume only 1 % (Figure 116) (CertifHy, 2015).

For instance in Europe in 2018 around 3.8 million tonnes hydrogen per year are required for ammonia production and only 0.35 million tonnes hydrogen per year for methanol production (IEA, 2019). A typical ammonia plant has the capacity to produce between 1,000 to 2,000 tonnes per day of this product, needing a hydrogen feedstock to operate ranging from 57,500 to 115,000 tonnes per year (CertifHy, 2015). The ammonia market in Europe is driven by the biggest fertilizer supplier: Yara. The global ammonia market is expected to be relatively stable with an annum rate growth of 0.1%. Methanol is the second largest hydrogen consumer in the chemical sector in Europe. Since it is a mature market, it is forecasted that it will maintain a stagnant growth.

Refineries represent the second largest consumer of hydrogen in Europe within the Industry segment, with a market share of 30 % (2.1 million tonnes of hydrogen demand annually) (CertifHy, 2015). The hydrogen volume consumption of a refinery site depends strongly on the processes involved and products generated. Therefore, it may change greatly from refinery to refinery and cannot be calculated from the production volumes alone. In general terms a typical plant operates with hydrogen production capacities in a range of 7,200 to 108,800 tonnes per year and for new and complex large scale refineries up to 288,000 tonnes per year.

The main actors in the European market are BP, Total, Shell and EXXON (the latter with a small participation).

Metal processing encompasses the use of hydrogen to yield iron reduction. The market share for the metal processing industry is 6% (410,000 tonnes). The typical hydrogen consumption in this type of plant is rounded between 36 to 720 tonnes per year (CertifHy, 2015). The activity in the metal processing sector has decreased (around 2.7% per year) since 2009 as a result of the financial crisis.

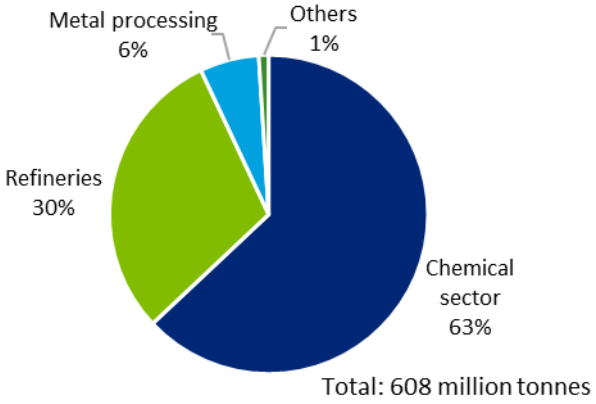


Figure 116: End uses of hydrogen in the EU (CertifHy, 2015)

Relevant industry sectors are described using the NACE sector codes (Eurostat, 2016c).

Table 59: Hydrogen applications and value added per sector (Eurostat, 2019d)

Applications	NACE sector	Value added (M€)
Chemical sector	C20 - Manufacture of chemicals and chemical products	105,514
Refineries	C19 - Manufacture of coke and refined petroleum products	17,289
Metal processing	C24 - Manufacture of basic metals	55,426
Others	C32 - Other manufacturing	39,160

12.3.3Substitution

Hydrogen cannot be substituted in the various industrial applications neither in fuel cells requiring hydrogen as a fuel.

12.4Supply

12.4.1EU supply chain

Roads2HyCom project estimated the total European production to be about 90 billion m^3. Analysis by market sectors showed that the captive[82] industry produces around 64 % of the total, followed by the by-products[83] industry (27 %) and merchant[84] companies (9 %) (Roads2Hy, 2007). The most common method for large hydrogen consumers is on-site (captive) production of hydrogen at the consumption site. This is mainly done for refineries, fertilizer plants (ammonia), methanol, and hydrogen peroxide production plants.

Data from the Hydrogen Analysis Resource Centre were used to estimate the production of hydrogen globally and within Europe (H2tools, 2019). The global independent (i.e. available to the market) and captive hydrogen production capacities are shown in Figure 117. European capacities represent around 16% and 29% of the global merchant and captive capacities respectively. The merchant and captive hydrogen capacities in Europe solely are shown in Figure 118. The combination of both is used to elaborate the EU sourcing of hydrogen.

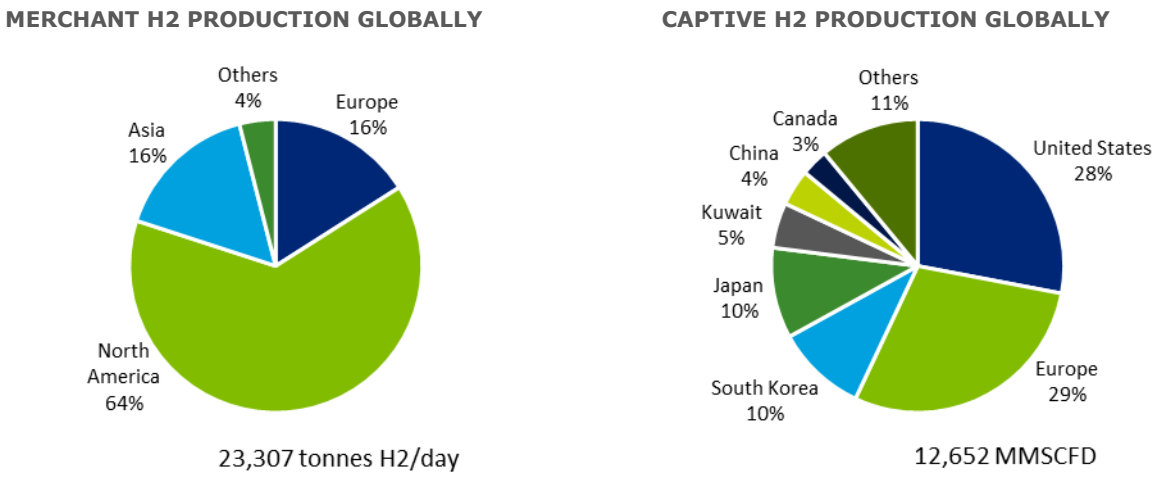


Figure 117: Merchant and captive global hydrogen production (H2tools, 2019)

[82] Hydrogen produced by the consumer for internal use and consumed at the point of usage.

[83] By-product hydrogen, i.e. hydrogen produced inadvertently as a by-product of a chemical process. By-products sources are ethylene, acetylene, styrene, coke oven gas among others. By-product hydrogen is generally either used as a chemical component for downstream processes or as fuel to produce heat.

[84] Hydrogen generated on site or in a central production facility and sold to a consumer by pipeline, bulk tank or cylinder truck delivery.

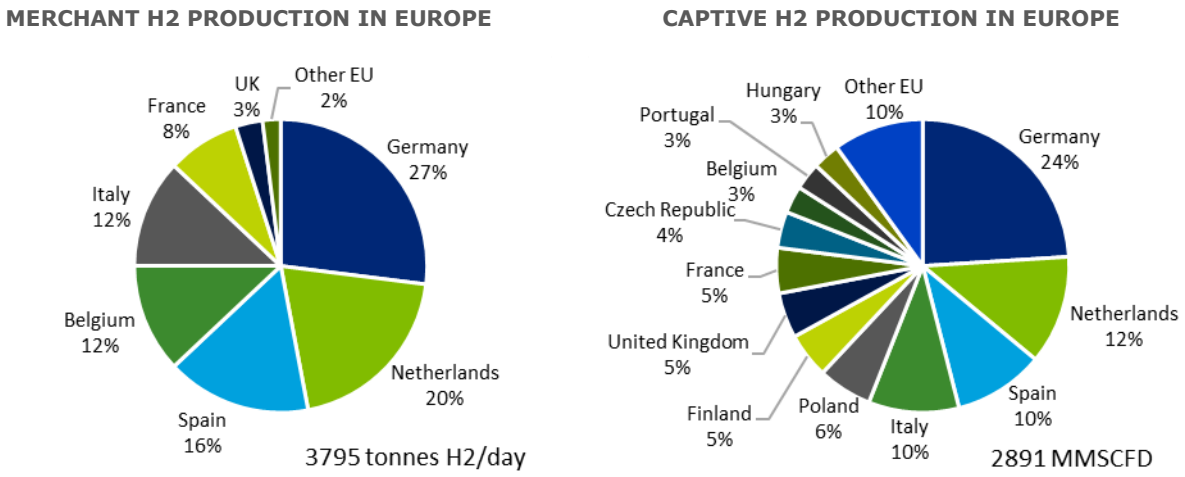


Figure 118: Merchant and captive[85] hydrogen production in Europe (H2tools, 2019)

12.4.2 Supply from primary materials

12.4.2.1 Geology, resources and reserves of hydrogen

Not applicable for hydrogen!

12.4.3 Supply from secondary materials/recycling

Hydrogen is typically vented during industrial processes in the same stream as other waste gas components. The waste hydrogen gas has typically not been recovered for reuse. This is especially true in smaller scale applications, because there is no economical means by which to scrub the gas stream of accumulated impurities, or to compress it in a way that it could be efficiently stored for later use. Hydrogen consumers have traditionally had two solutions to the problem of waste hydrogen: purchase more hydrogen from industrial gas suppliers or generate hydrogen on-site using an electrolyser or a reformer. Recycling rate of 0% can be considered for the calculations.

12.5 Other considerations

12.5.1 Environmental and health and safety issues

Hydrogen is zero-carbon fuel with great potential but the water consumption together with the energy and GHG impacts need to be evaluated in relation to other fuel pathways. In the case of hydrogen produced by electrolysis, its carbon footprint is directly related with the source of electricity. Additionally, the use of fresh water for hydrogen generation via electrolysis could present additional environmental concerns – water consumption is an important metric for evaluating the sustainability of energy systems. The theoretical limit for water electrolysis is a consumption of 9 liter water for one kilogram of hydrogen produced (A. Mehmeti et al., 2018). Recent scientific sources however claim around 10 liter of water for kilogram of hydrogen produced for alkaline electrolysis and 18 liter of water for kilogram of hydrogen produced for Proton exchange membrane (PEM) electrolysis (J.C. Koj and C.W. Zapp, 2019). Water consumption is a complicated topic which needs further attention.

Hydrogen presents certain health and safety risks when used on a large scale. As a light gas of small molecules, hydrogen requires special equipment and procedures to handle it. Hydrogen

[85] Captive capacities expressed in MMSCFD (Milion Standard Cubic Feet per Day)

is so small it can diffuse into some materials, including some types of iron and steel pipes, and increase their chance of failure. It also escapes more easily through sealings and connectors than larger molecules, such as natural gas. Hydrogen is a non-toxic gas, but its high flame velocity, broad ignition range and low ignition energy make it highly flammable. This is partly mitigated by its high buoyancy and diffusivity, which causes it to dissipate quickly. It has a flame that is not visible to the naked eye and it is colourless and odourless, making it harder for people to detect fires and leaks. There are
already many decades of experience of using hydrogen industrially, including in large dedicated distribution pipelines. Protocols for safe handling at these sites are already in place, and they also exist for hydrogen refuelling infrastructure in site-specific forms. However, they remain complex and unfamiliar compared to those for other energy carriers. Widespread use in the energy system would bring new challenges. They would need further development and any public concerns would need to be alleviated (IEA, 2019).

12.5.2 Socio-economic issues

Potential socio-economic issues are related to the use of hydrogen in fuel cells. In principal, the success of new technologies on the market depends to a large part on public acceptance and public understanding of these technologies. With regard to early markets and later on a potential mass market roll-out of hydrogen and fuel cell applications it is thus important to understand public attitudes and consumer preferences and acceptance.

12.6 Comparison with previous EU assessments

Hydrogen was not assessed in the 2017 EU criticality assessments.

Table 60: Economic importance and supply risk results for hydrogen in the assessment 2020

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Hydrogen	Not assessed		Not assessed		Not assessed	Not assessed	3.84	0.39

12.7 Data sources

12.7.1 Data sources used in the factsheet

BP, 2018. BP Statistical Review of World Energy, 2018.

CertifHy, 2019. Overview of the market segmentation for hydrogen across potential customer groups, based on key application areas", 2015.

COM(2018) 773 final. COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN

(EC COM 773, 2018) IN-DEPTH ANALYSIS IN SUPPORT OF THE COMMISSION COMMUNICATION COM(2018) 773; A Clean Planet for all A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy.

Eurostat, 2019a. Energy production and imports, Statistics Explained (https://ec.europa.eu/eurostat/statisticsexplained/)

Eurostat, 2019b. Supply, transformation and consumption of gas; http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_cb_gas&lang=en

Eurostat, 2019c. Oil and petroleum products - a statistical overview; https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Oil_and_petroleum_products_-_a_statistical_overview&oldid=315177#Oil_imports_dependency

Eurostat, 2019d. Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). Available at: https://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

GTR, 2013. Global Technical Regulation No. 13, Global Technical Regulation on Hydrogen and Fuel Cell Vehicles, ECE - United Nations, 2 013.

H2tools, 2019. Hydrogen Tools; Hydrogen Analysis Resource Center, https://h2tools.org/hyarc

(Hydrogen Roadmap, 2019) Hydrogen Roadmap Europe, A sustainable Pathway for the European Energy Transition; https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf

Mehmeti A. et al., 2018. Life Cycle Assessment and Water Footprint of Hydrogen Production Methods: From Conventional to Emerging Technologies, *Environment*, 2018, 5(2), 24; https://doi.org/10.3390/environments5020024

IEA, 2019. The Future of Hydrogen, Seizing today's opportunities. Report prepared by the IEA for the G20, Japan, June 2019.

J.C. Koj and C.W. Zapp, 2019. Environmental impacts of power-to-X systems – A review of technological and methodological choices in Life Cycle Assessments; *Renewable and Sustainable Energy Reviews*, vol.112, pp.865-879, September 2019.

PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE, THE COMMITTEE OF THE REGIONS AND THE EUROPEAN INVESTMENT BANK, A Clean Planet for all A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy, November 2018.

Roads2Hy, 2007. Roads2HyCom, DELIVERABLE 2.1 AND 2.1a "European Hydrogen Infrastructure Atlas" and "Industrial Excess Hydrogen Analysis", PART II: Industrial surplus hydrogen and markets and production, R2H2006PU.1, March 2007.

TrendEconomy, 2019. TrendEconomy database, Hydrogen | Imports and Exports | 2018.

12.7.2Data sources used in the criticality assessment

H2tools, 2019. Hydrogen Tools; Hydrogen Analysis Resource Center, https://h2tools.org/hyarc

CertifHy, 2015. Overview of the market segmentation for hydrogen across potential customer groups, based on key application areas", 2015.

TrendEconomy, 2019. TrendEconomy database, Hydrogen | Imports and Exports | 2018.

12.8Acknowledgments

This factsheet was prepared by the JRC. The authors would like to thank the Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this Factsheet.

13. IRON ORE

13.1 Overview

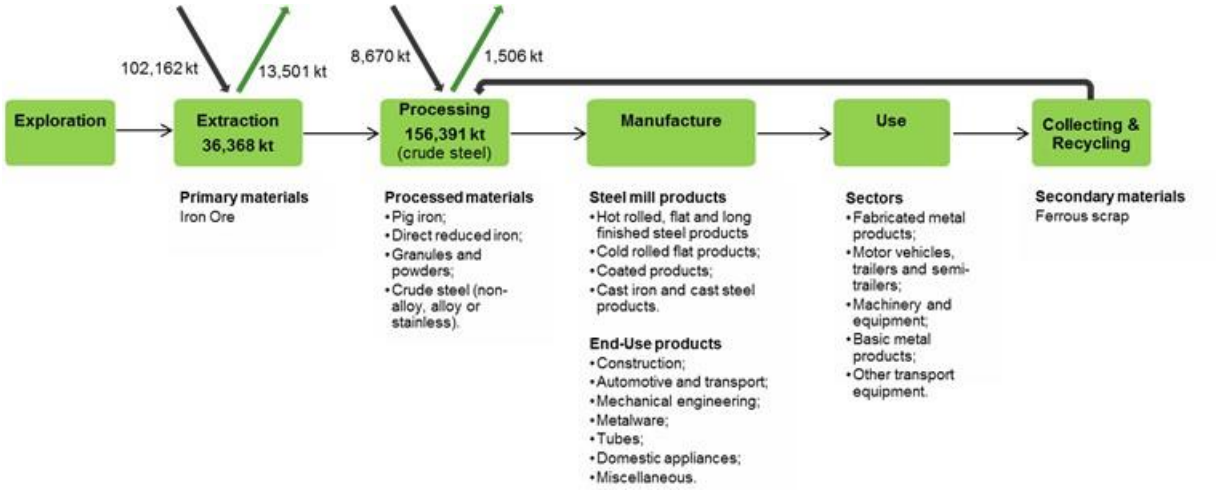


Figure 119: Simplified value chain for iron ore for the EU, averaged over 2012-2016[86]

Iron ore is the source of primary iron for the iron and steel industry. It consists mostly of iron oxides, the primary forms of which are magnetite (Fe_3O_4) and hematite (Fe_2O_3). Iron (chemical symbol Fe, atomic number 26, transition metal group) is a lustrous silver-grey metal with density of 7.87 g/cm^3 and melting point of 1,530°C. Pure iron is rarely used as it is relatively soft (4 in Mohs hardness scale) and oxidises rapidly in air to hydrated iron oxides, commonly known as rust. Iron is commonly used as an alloy with other elements to make thousands of different steel grades and other alloys with a vast range of desirable properties. Iron ore smelting in the presence of a reductant generally yields an alloy of iron and carbon (pig iron) which usually contains 3.5-4.5% carbon along with small amounts of other elements such as silicon, manganese and phosphorus. Although pig iron has specific applications in ferrous castings production, it is mainly an intermediate product in steel production.

Steel is an alloy of iron and carbon and other elements, suited for metal forming in solid-state. Carbon is of fundamental importance for its properties; steel contains up to about 2% of carbon but typically less than 1%. Numerous different types of steel are produced, designed to provide the specific properties required for a great variety of applications. Steels vary not only in the level of contained iron and carbon but also in the content of many alloying elements which are added deliberately in the steelmaking process (e.g. chromium, nickel, molybdenum, manganese). Alloy steel refers to steel with fixed minimum limits for different alloying elements. Alloy steels are broken down into high-alloy steels and low-alloy steels. Low-alloy steels are considered those having a total amount of alloying elements not exceeding 5%. Examples of alloy steel grades are stainless steel, high-speed steel, tool steels, and bearing steels. Non-alloy steel typically refers to steel with a lower content of alloying elements than that required for alloy steel.
Furthermore, the diversity of steels is not only defined by chemical composition but also by a variety of microstructural characteristics. There are more than 3,500 different grades of steel with an enormous range and combinations of achievable properties, even in extreme environments (e.g. high heat or pressure), such as strength, corrosion resistance, workability, toughness. Approximately 75% of modern steels have been developed during the past 20

[86] JRC elaboration on multiple sources. See next sections.

years (WorldSteel 2019c). Besides steel's extreme versatility to meet the specific needs of end-users, steel also has a relatively low cost, is 100% recyclable, gives off no harmful emissions for human health and has a long useful life. All these intrinsic properties have made steel the most widely used material in modern society.

Iron ore is assessed at the extraction stage. At the processing/refining stage, the assessment is performed for crude steel which is defined as steel in its first solid (or usable) form, including ingots, semi-finished products (blooms, billets, and slabs) by continuous casting, and liquid steel for castings. No assessment has been made for the criticality of intermediate stages in the value chain, namely the production of pig iron, direct reduced iron, iron granules and powders. Downstream steel mill products are also not included in the assessment, as they are considered to belong to the manufacturing stage; therefore, their production and trade flows are not analysed. Quantities are expressed in volume for both iron ore and crude steel, and all figures are averaged over 2012–2016 data unless otherwise mentioned.

The trade codes used in this assessment for iron ore are (Eurostat Comext, 2019):

- HS 260111 "iron ores and concentrates; non-agglomerated";
- HS 260112 "iron ores and concentrates; agglomerated (excluding roasted iron pyrites)".

The trade codes corresponding to crude steel are (Eurostat Comext, 2019):

- HS 7206 "iron and non-alloy steel in ingots or other primary forms (excl. remelting scrap ingots, products obtained by continuous casting and iron of heading 7203)";
- HS 7207 "semi-finished products of iron or non-alloy steel";
- HS 7218 "stainless steel in ingots or other primary forms (excl. remelting scrap ingots and products obtained by continuous casting); semi-finished products of stainless steel";
- HS 7224 "steel, alloy, other than stainless, in ingots or other primary forms, semi-finished products of alloy steel other than stainless (excl. waste and scrap in ingot form, and products obtained by continuous casting)".

The world iron ore and steel production have doubled since 2000, growing with a compound annual rate of more than 4%. Australia and Brazil are the most significant exporters of iron ore to the global market with a combined global market share of 82% in 2016. China is driving global demand for iron ore accounting for 70% by volume of the world imports in 2016. As regards crude steel, the leading exporters worldwide are Russia, Brazil, and Ukraine which accounted for 62% of the total crude steel exports by volume in 2016. The EU is the major destination for exports of crude steel with a share of 27% of total imports by volume in 2016. (Eurostat Comext, 2019)

Since 2004, iron ore prices have risen driven by steel demand in China, but with increased volatility due to temporal unbalanced supply and demand growth. The iron ore prices surged in 2019 by more than 70%, advancing to the level of USD 100 per tonne for the first time from 2014, driven by stronger demand from the Chinese steel sector and supply deficits following closures of Brazilian mines related to a major dam disaster, and weather-related supply disruption in Australia.

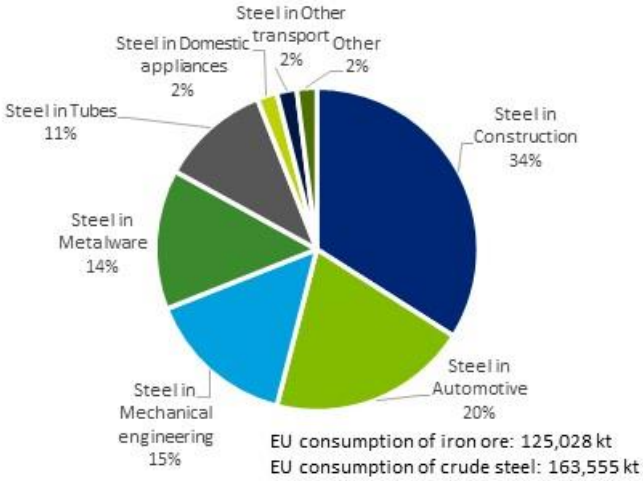


Figure 120: End uses of iron ore (steel) in 2018 (Eurofer 2019c)

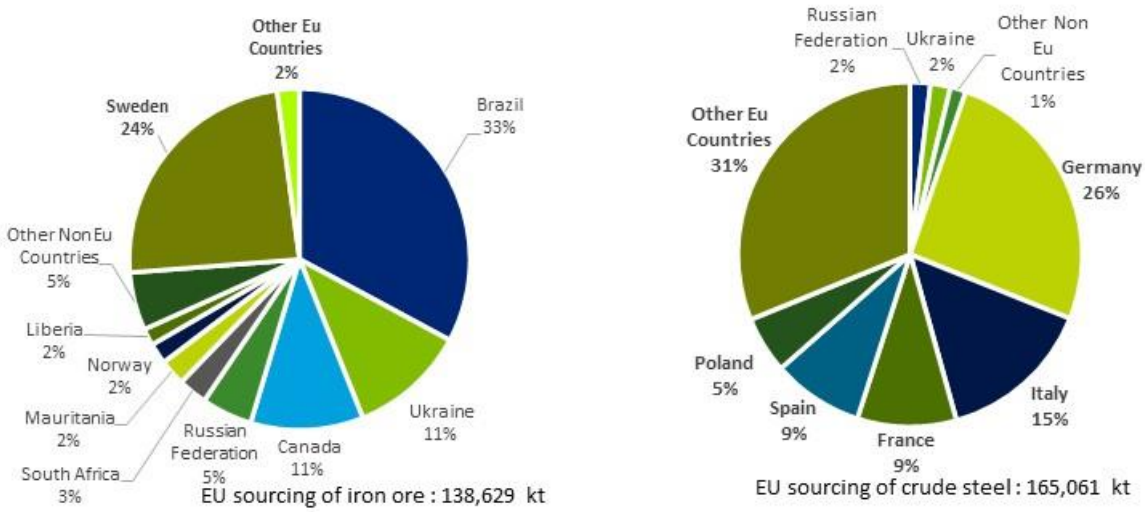


Figure 121: EU sourcing of iron ore (left) and crude steel (right). Average 2012-2016 (BGS 2019)(Eurostat Comext 2019)

The apparent consumption of iron ore in the EU was estimated at 125,000 ktonnes per year, of which 102,100 ktonnes were sourced through imports, and 22,900 ktonnes were supplied by domestic production, mainly from Sweden which stands at (24% of the EU sourcing), averaged over 2012-2016. The largest part of iron ore imported to the EU comes from Brazil (45% of imports), Ukraine (15% of imports), and Canada (14% of imports). The EU apparent consumption for crude steel between 2012 and 2016 was estimated at 163,600 ktonnes annually, most of which is sourced domestically (154,900 ktonnes) with imports contributing 8,700 ktonnes. Germany, Italy, France and Spain are the largest domestic producers of crude steel. The dependency on imports is substantial for iron ore (72% import reliance), while for crude steel the import reliance is 4% (BGS 2019) (Eurostat Comext 2019).

Steelmaking consumes the vast majority of iron ore (98%). Steel is the most commonly used metal in the world in a huge range of applications in every aspect of the economy. The construction sector (buildings and infrastructure) consumes the largest amount of steel globally (more than 50%) and in the EU (34%), followed by the transport sector (automotive

and other transport). The manufacture of mechanical equipment, metal products (metalware and tubes), and domestic appliances are the next most important markets for steel. Substitutes for construction applications include reinforced concrete and other construction materials. For automotive applications, aluminium, magnesium, and carbon fibre composites are potential substitute materials, whereas for steel used in mechanical engineering substitutes include composite materials, aluminium, magnesium and titanium.

The iron and steel production is an energy-intensive process with significant GHG emissions. On average, 1.83 tonnes of CO_2 per tonne of steel were produced in 2017. Breakthrough technologies for energy efficiency improvements and low-carbon steelmaking are being developed to address this challenge towards the transition to a climate-neutral economy. As steel is a versatile and indispensable material for key sectors of the economy, it is a significant material for enabling low-carbon technologies in the broad areas of construction, energy, transport, and other industries. Contributions by the steel industry to a climate-neutral economy include products in all areas of renewable energy, e.g. wind turbines, and low-carbon energy production, as well as improved energy- and resource-efficiency in the construction and transport sectors.

Global resources are estimated to be greater than 800,000 million tonnes of crude iron ore containing more than 230,000 million tonnes of iron. World iron ore reserves are estimated at 173 billion tonnes of ore containing 84,000 million tonnes of iron. Australia (29%), Brazil (20%) and Russia (17%) hold the most significant iron ore reserves (USGS, 2019d). In the EU, the most abundant iron ore resources and reserves are situated in Sweden, in particular at the deposits of the Kiruna district where the combined iron ore resources and reserves are about 3,100 million tonnes of ore, and iron ore reserves 1,200 million tonnes of ore.

The global crude steel output between 2012 and 2016 averaged to 1,621,000 ktonnes per year. The major steel-producing countries were China (49%), Japan (7%), India (5%), the United States (5%), Russia (4%), and the Republic of Korea (4%). The annual average EU crude steel production in the same period was 156,400 ktonnes, with Germany (27%), Italy (15%), France (10%) and Spain (9%) the most important producing countries in the EU (BGS 2019). Recycling from end-of-life products contributes 31% of the total steel supply in the EU.

Imbalances in the international trade of steel products are caused by the global steelmaking overcapacity. Notably in China, coupled with restrictive trade measures and unfair trade practices distorting the global level playing field.

13.2Market analysis, trade and prices

13.2.1Global market

According to data published by the World Steel Association (WorldSteel 2019d), the global iron ore production in 2017 reached 2,167,000 ktonnes on a saleable ore basis[87]. The global iron ore production has doubled from 2000 to 2017, increasing strongly with a compound annual growth rate (CAGR) of 4.1% (Worldsteel 2018)(WorldSteel 2001). In the past ten years (2008 to 2017) the CAGR of iron ore production is 2.3%.

Australia is the leading world producer of iron ore with a share of about 41% in 2017 (883,000 kt), followed by Brazil (435,000 kt, 20%), India (202,000 kt, 9%), and China (115,000 kt, 5%). The combined output from these four countries accounted for three-quarters of world

[87] Adjusted so that the Fe content of the Chinese ore is similar to world average

production. In 2017, the EU production totalled 27,200 ktonnes representing the 1.4% of the world output. The production value of iron ore was estimated at USD 134,400 million in 2017 (S&P Global 2019d).

The iron ore industry has undergone a corporate consolidation over the past 15 years (reference year 2016) through mergers and acquisitions (Comtois and Slack 2016). The largest iron ore mining companies are Vale, Rio Tinto, BHP Billiton, and Fortescue Metals; according to background data by S&P Global, in 2017 they controlled together 51% of the world production (S&P Global 2019d).

In 2016, world trade of iron ore rose to about 1,500,000 ktonnes. On the demand side, China dominates the market for iron ore accounting for 68% of world iron ore imports by value and 70% by volume. Japan, South Korea, Germany and France are following in the list of the top-5 iron ore importing countries, with a combined share of 17% of total imports value. Australia is by far the most significant exporter of iron ore worldwide (57% of total value), followed by Brazil (19% of total value) (Figure 122). In terms of volume, Australia and Brazil accounted for 82% of the global cross border trade. The iron ore exports of other countries are relatively low in comparison. The global trade patterns reflect transportation costs, as steel makers tend to buy iron ore from relatively nearby producers. Australia is the leader for iron ore imports in China, Japan, Taiwan and South Korea, while Brazil is the producer leader for iron ore imported into Europe (Comtois and Slack 2016).

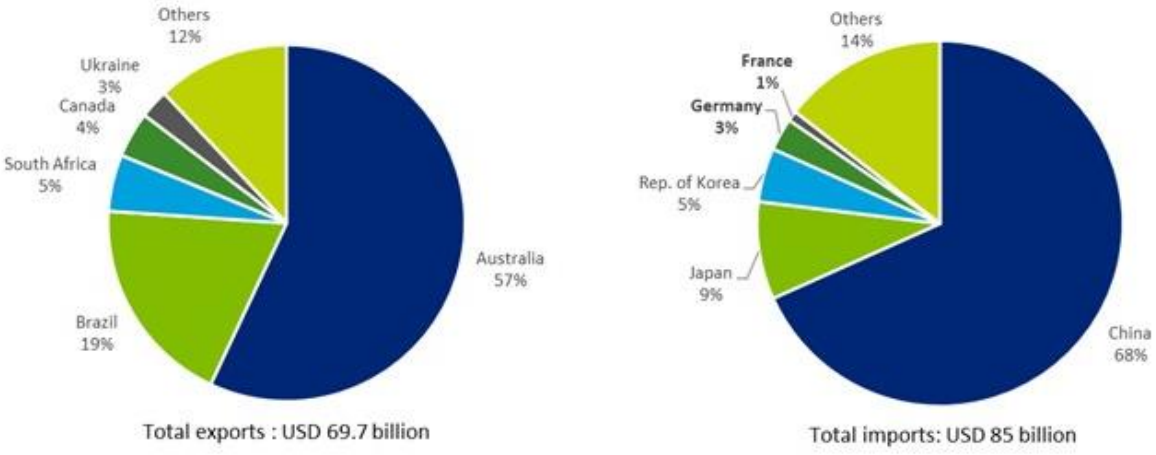


Figure 122: Top-5 iron ore exporting (left) and importing (right) countries, in 2016 by value. (UN Comtrade 2019)

Apart from iron ore, significant trade is taking place for steelmaking materials such as ferrous waste and scrap, pig iron and direct reduced iron, and ferroalloys for steelmaking. Figure 123 below illustrates the most significant players in the world markets of steelmaking materials.

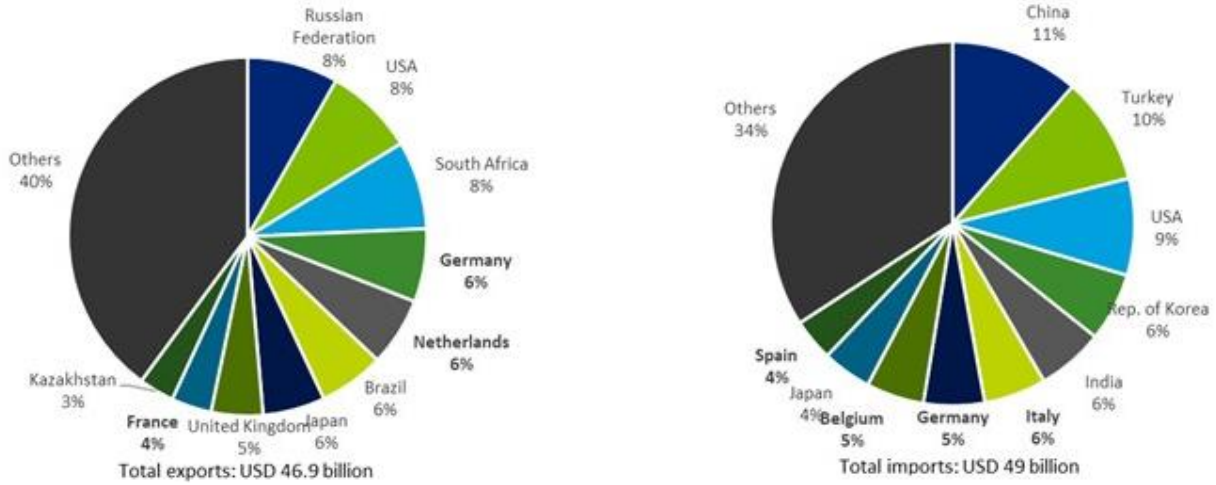


Figure 123: Top-10 exporting (left) and importing (right) countries of steelmaking materials for crude steel production (including pig iron, direct reduced iron, ferroalloys, and ferrous waste and scrap) by aggregated value, in 2016. (UN Comtrade 2019)

The worldwide steel production has increased by an impressive compound annual growth rate (CAGR) of 4.1% from 2000 to 2018, and the most robust growth is observed in years 2000-2005. In 2000, the world production of crude steel amounted to 850,000 ktonnes, whereas in 2018 it reached 1,808,000 ktonnes (WorldSteel 2019d). China was the frontrunner in the growth of global steel output with an increase of crude steel production from 127,000 ktonnes in 2000 (BGS 2019) to 928,000 ktonnes in 2018 with an overwhelming CAGR of 11%, while the CAGR in the rest of the world has been as low as 1%. By 2015, China's steelmaking capacity exceeded that of the European Union, Japan, Russia, and the United States combined.

In 2015, the global overcapacity was estimated at 700,000 ktonnes, of which 336,000 ktonnes in China, with an average utilisation rate of less than 70%, well below the 80% necessary for long-term industry viability (USGS 2018a). The excess production capacity in certain third countries, notably in China where overcapacity is the double of the EU's annual production, has increased dramatically in the last few years. As a result, exports have risen sharply destabilising global steel markets worldwide and depressing steel prices due to increasing volumes available. Many countries have reacted by restrictive trade measures. In addition, the overcapacity gave rise to an unprecedented wave of unfair trading practices distorting the global level playing field, such as distortive subsidies and government support measures (European Commission 2016)(European Commission 2019).

The EU has taken trade defence measures to face the challenges and defend the EU's internal market from surges of steel imports (European Commission 2016). The EU imposed provisional safeguard measures on imports of steel in July 2018 to prevent damage to the EU steel industry against sharply increasing imports for 23 finished steel product categories in the wake of tariffs on steel products imposed by the United States in March 2018 ('Section 232' tariffs) (European Commission 2018a). A regulation imposing definitive safeguard measures on imports of steel products took effect on February 2019 (European Commission 2019).

According to the World Steel Association (WorldSteel 2019d), China was the leading crude steel producer in the world during 2018 (928,300 kt) producing more than half of world total crude steel (51%), followed by India (106,500 kt) which overtook Japan (104,300 kt) as the world's second-ranked steel producer. The top world producers also include the United States (86,600 kt), Russia (71,700 kt), and the Republic of Korea (72,500 kt). In 2018, China and

these countries accounted for 76% of world production. The combined output of the EU Member States accounted for 9% of the global total, making the EU the second world producing region of crude steel after China.

Russia, Brazil and Ukraine are the most significant suppliers of crude steel globally in terms of cross border trade. In 2016, their combined market shares accounted for 62% of the total crude steel exports by volume (99,000 ktonnes), and for 54% of the total crude steel exports by value (see Figure 124). The destinations of these exports are widely distributed, with the US being the largest crude steel importer worldwide. The EU as a region, is the major destination for exports of crude steel with a share of 27% of total imports by volume in 2016.

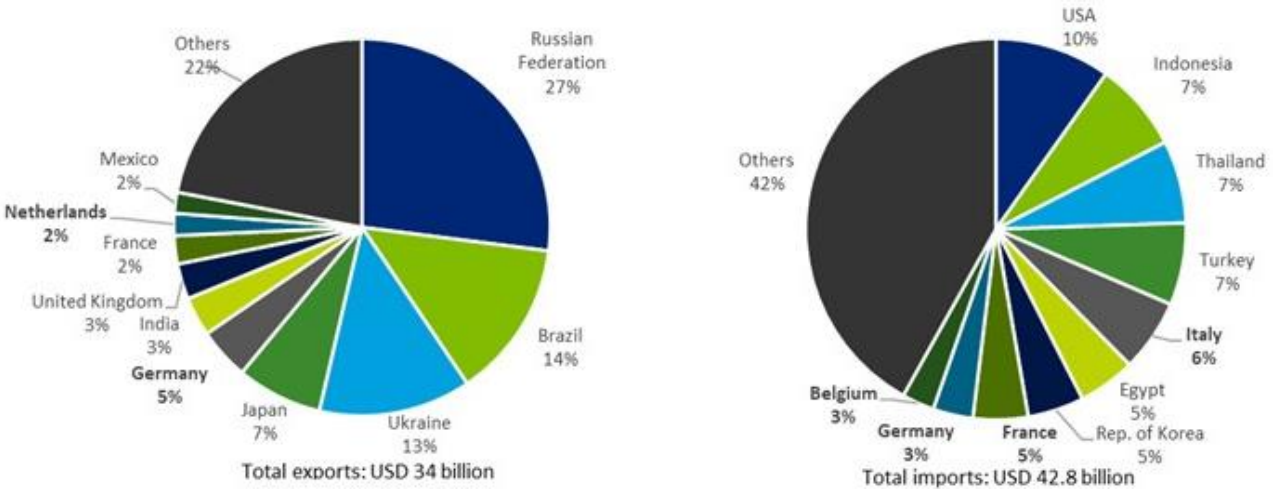


Figure 124: Top-10 crude steel (carbon steel, stainless steel and alloy steel) importing (left) and exporting (right) countries in 2016 by value. (UN Comtrade 2019)

As regards exports restrictions in place in 2017, China imposed a 10% tax to all types of iron ore. India, one of the top-5 producers of iron ore globally, removed an ad valorem export tax of 30% in March 2016 for all types of iron ore except pellets, whereas a 5% tax for pellets was removed in January 2016 (OECD 2019a)(Government of India 2016). For pig iron products (HS 7201), China had in place in 2017 an export tax of 25% for HS 720120 and 20% for HS 720150, whereas a tax of 25% for HS 720110 was removed in 2016. For direct reduced iron and other spongy ferrous products (HS 7203), China applied an export tax of 15% in 2017, decreased from 25% in 2016. For products of granules and powders (HS 7205), China again applied an export tax of 25% in 2017. For crude steel products of carbon steel corresponding to HS 7206 (ingots) and HS 7207 (semi-finished products such as blooms, billets, and slabs), China imposed an export tax of 15% in 2017, decreased from 25% in 2015. For crude steel products of stainless steel (HS 7218), China once more had in place an export tax of 10% in 2017 reduced from 15% in 2016, and Ukraine an export tax of 15%. For crude steel products of alloy steel (HS 7224), China yet again imposed an export tax of 10% in 2017 decreased from 15% in 2016.

13.2.2Outlook for supply and demand

Iron and steel production is the largest metals sector in volume as steel is an omnipresent and indispensable material across the economy. In a generic approach, as economic growth projections remain positive and the world's population is projected to grow from 7,700 million people in 2019 to 8,500 million people in 2030, and to increase further to 9,700 million in 2050 (United Nations 2019), it is straightforward to anticipate that global demand for iron ore

and steel will continue to rise for many years. A recent report by the OECD (OECD 2019b) provides a quantitative outlook to 2060 for steel demand. In the baseline scenario, assuming a four-fold increase of the world GDP, the global steel production is projected to roughly increase by 1.8 times up to 2060 in comparison to 2017. Steel demand growth will be partially decoupled from GDP growth due to a decrease of material intensity in the global economy. In case of improved efficiency of the steel-intensive industrial sectors in China and India, the report projects a 17% overall lower demand for steel in comparison with the baseline scenario, and the majority of the reduction will be met through decreased primary steel production. In general, secondary production is projected to grow faster than production from iron ore. In 2060, the share of world steel production from secondary sources will range between 39% and 43%, whereas in 2017 was 28% (OECD 2019b).

Table 61: Qualitative forecast of supply and demand for iron ore

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Iron ore		x	+	+	+	+	+	+

13.2.3EU trade

The annual average EU imports of iron ore in the period 2012-2016 amounted to approximately 102,100 ktonnes per year, consisting of about 75,200 ktonnes (74%) of non-agglomerated iron ore (HS 260111), and 26,900 ktonnes (26%) of agglomerated iron ore (HS 260112). Europe is a net importer of iron ore with an average annual net import figure in the period 2012-2016 of about 92,000 ktonnes. As it is apparent in Figure 125 below, the fluctuations in trade flows of iron ore in the 2012-2016 period are not significant. (Eurostat Comext, 2019)

EU imports iron ore from several countries, but the majority originates from Brazil (45% of the total iron ore imports), followed by Ukraine and Canada, with 15% and 14% share respectively of the total iron ore imports to the EU (Figure 127).

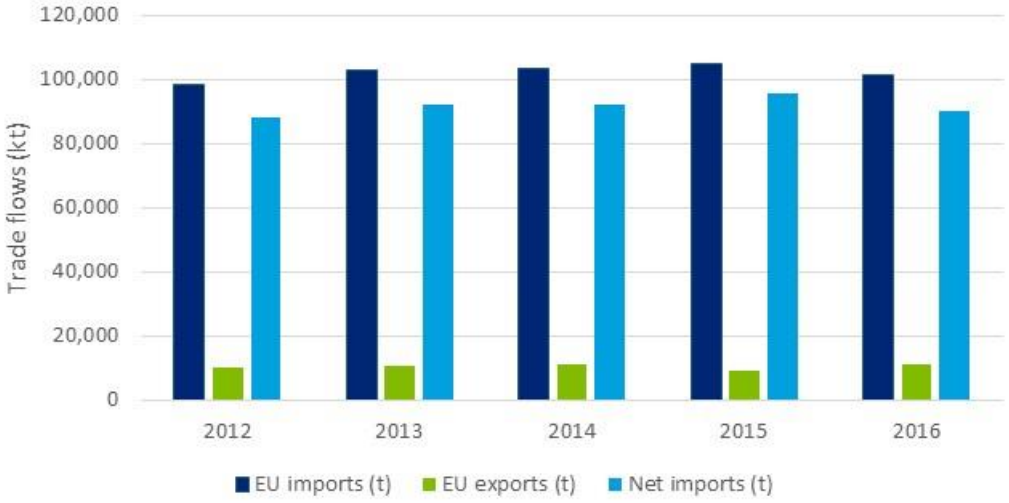


Figure 125: EU trade flows for iron ore (EUROSTAT Comext, 2019)

The EU is also a net importer of crude steel. Total imports of ingots and semi-finished products (blooms, billets, and slabs) increased in absolute terms by 26% from 2012 to 2016 to more than 9,500 ktonnes (Figure 126). In the same period, total EU exports fell by 61% to around 1,000 ktonnes. As a result, the net imports rose by 70% during the period 2012-2016, from 5,100 ktonnes in 2012 to 8,700 ktonnes in 2016. The rise in net imports is coupled with the declining EU crude steel output in the same period, i.e. the crude steel production was 4,300 ktonnes lower in 2016 (154,900 ktonnes) compared to 2012 (159,200 ktonnes), and can be associated to the general trend of–accelerating rise in imports for all steel products fuelled by global overcapacity (European Commission 2016) (European Commission 2018a).

Russia and Ukraine were the major exporting countries to the EU of crude steel between 2012 and 2016 accounting for 36% of the total EU imports each (see Figure 127).

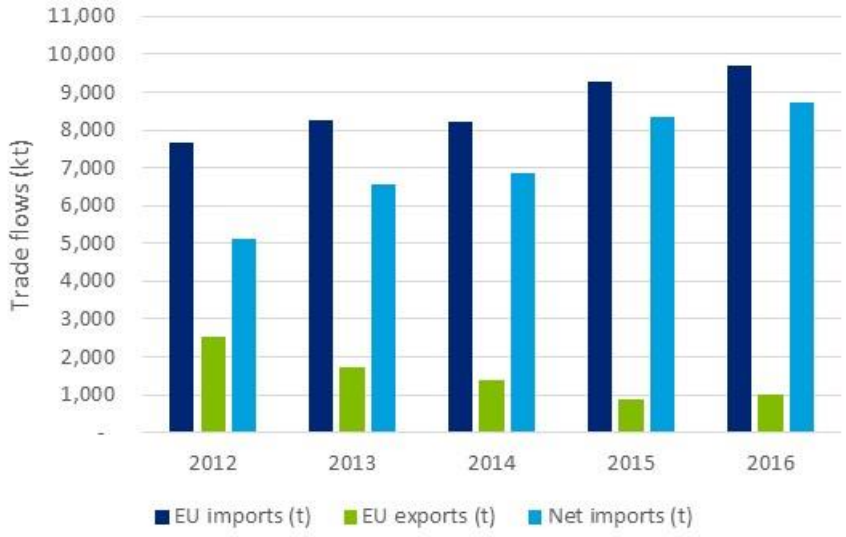


Figure 126: EU trade flows for crude steel (EUROSTAT Comext, 2019)

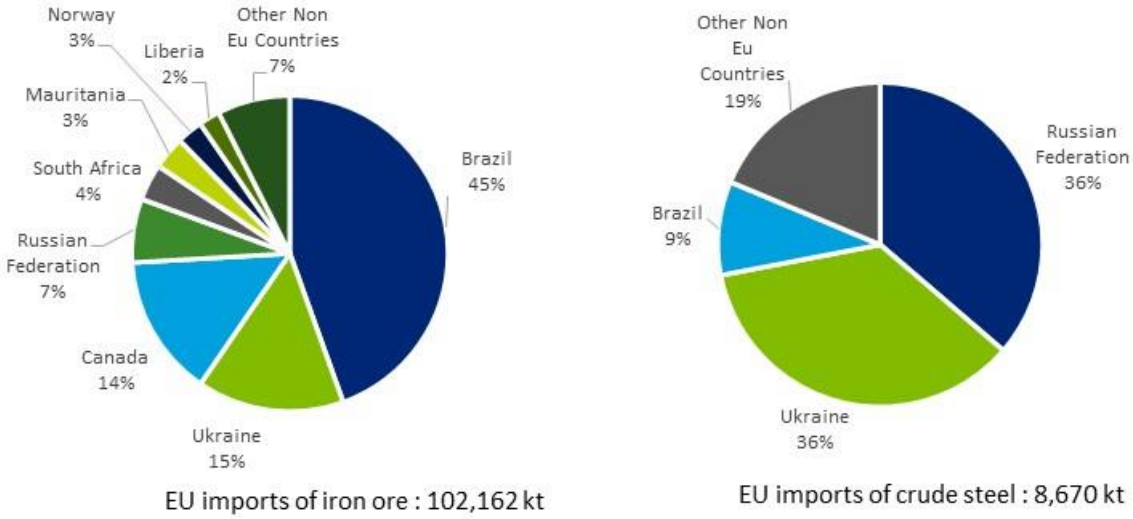


Figure 127: EU imports of iron ore (left) and crude steel (right). Average 2012-2016 (EUROSTAT Comext, 2019)

13.2.4Prices and price volatility

Until the early 2000s, the price of iron ore was exclusively fixed by annual over-the-counter (OTC) negotiations between producers and steel producers (Japanese, Korean, European and North American). The explosion of the Chinese steel demand and the resulting tightening of the iron ore supply disturbed the prevailing pricing system, and spot market emerged in the early 2000s. Chinese steel producers, in view of the steady growth of steel production in China, faced supply difficulties in the conventional market dominated by non-Chinese companies, and they turned to iron ore from India marking the beginning of a more flexible and transparent parallel spot market. The annual price-fixing system eventually collapsed in 2010, and BHP, Vale and Rio Tinto put in place a system of quarterly price-fixing closer to the prices recorded on spot markets, which were much higher than the annual reference prices fixed in 2008. Iron ore prices have since experienced significant volatility, and most of the iron ore trade continues to use long-term contracts (Le Gleuher 2019).

Nowadays, international price reporting agencies such as "The Steel Index and Metal Bulletin" are compiling spot prices from physical iron ore trading, and after applying a variety of methodologies, come up with various volume-weighted average reference prices (indexes) within a specified data collection window (e.g. daily, weekly or monthly) (Financial Times 2016) (Fastmarkets MB 2018). The benchmark prices assessed by agencies are used globally for short-term and spot contracts, as well as a basis for discussing longer-term contractual agreements (in any case less than one year). Iron ore's derivatives market has also developed in the recent years, e.g. the Singapore Mercantile Exchange (SMX) was one of the first exchanges to offer futures contract in 2011 (Fastmarkets MB 2018).

Sinter fines and lumps make up the bulk of the seaborne iron ore market and are the products most frequently traded on a spot basis. By contrast, the beneficiated iron ore comprising pellet and concentrate is smaller in terms of both volume and liquidity, and weekly assessed indices are therefore more appropriate (Fastmarkets MB 2018).

Multiple factors are of importance for iron ore prices. Iron ore is a variable commodity having specific physical and metallurgical properties affecting its price (e.g. Fe content, physical form) and premiums and discounts are applied to account for quality differences. For example, higher iron grade achieves a higher price, while lump ores and pellets that can be charged directly into the blast furnace attract a premium in comparison to fines requiring sintering prior to use. The profit margin that steelmakers are achieving drives the relative preference for different ore types, i.e. when profit margins are high, steelmakers prefer to use high-purity ores to maximise their blast furnace yield. It also depends on market availability and circumstances (e.g. ore used in the direct-reduction process to make direct-reduced iron (DRI) needs to be of much higher grade than that fed into a blast furnace), constraints derived from the end-use applications of steel (e.g. higher-grade flat steel products require higher-quality raw material inputs with lower impurities), and environmental considerations (e.g. lower-grade ores with higher fractions of impurities such as silica and alumina require increased consumption of coke, which can raise emissions) (Fastmarkets MB 2018).

Figure 128 presents the prices for iron ore between the years 1990 and 2019. The massive demand growth driven by the industrialisation of China has had a distinct effect on the iron ore price evolution. The peaks in price evolution are associated with supply deficits incurred in the seaborne market, and the troughs with periods when supply growth eventually exceeded demand growth (Wilson 2015) (S&P Global 2019c).

The price of iron ore (fines, 62% Fe, CFR China) varied from USD 26 per tonne to USD 38 per tonne between 1990 and 2004, averaging USD 31 per tonne. From 2005 to 2018, the price of

iron ore averaged USD 101 per tonne (World Bank 2019). A strong upward trend is observed since 2005 to mid-2008 (see Figure 128), when prices surged close to USD 200 per tonne, before collapsing rapidly to around USD 60 per tonne within one year during the global financial crisis (Löf and Ericsson 2016). Iron ore prices recovered almost to their pre-crisis levels by mid-2011 induced by increased demand from China due to an economic recovery plan to counter the effects of the global financial crisis, mainly based on infrastructure investments, which boosted demand for steel (Le Gleuher 2019). Since the end of 2013, iron ore prices declined significantly reaching USD 40 per tonne in December 2015 due to the fast capacity expansion, particularly from the three largest producers, i.e. Vale, Rio Tinto and BHP Billiton (Löf and Ericsson 2016).

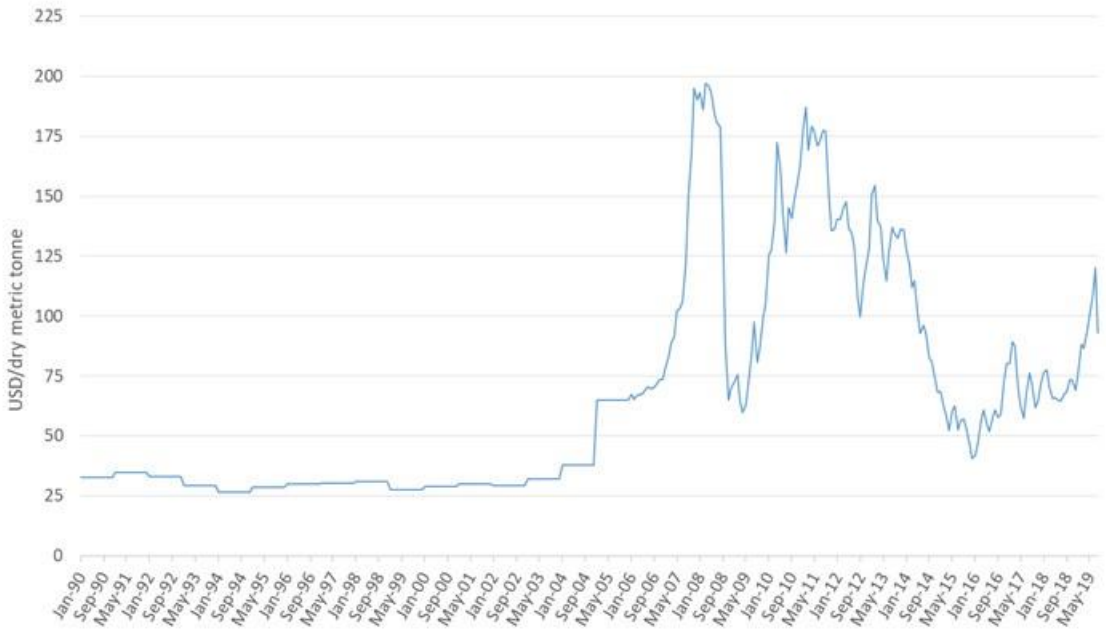


Figure 128: Iron ore monthly prices (in USD/dry metric tonne)[88] (World Bank 2019)

In 2019, the price of agglomerated iron ore qualities (e.g. pellets) rose sharply due to a supply deficit in the seaborne market after supply disruptions coupled with strong steel demand in China. In particular, the major disaster (Brumadinho tailings dam collapse) in January 2019 at top-producer Vale's mine in Corrego do Feijao in Brazil, triggered concerns about shortage of supply. The mine's operation was suspended, and several others were put under surveillance. The production of the Brazilian miner declined by one-third on a yearly basis in the second quarter, mainly from the southern system of iron ore mines in Brazil, which has led to a sharp drop in Brazilian iron ore exports of 30% yearly. In addition, at the Pilbara region of West Australia, the most important mining region of Australia for iron ore, mining and transport of iron ore from the operations of BHP, Rio Tinto and Fortescue Metals were disrupted by cyclone in March 2019, adding to tightness in global seaborne supply (DERA 2019) (S&P Global 2019a) (S&P Global 2019b)(Department of Industry and Science 2019). On the demand side, China, the world's largest steelmaker, recorded new steel production record in the first months of 2019, which drove a strong demand for iron ore, as China imports over 70% of the iron ore globally traded (DERA 2019)(Department of Industry and Science 2019).

[88] Nominal values, not adjusted for inflation. From December 2008 to present, the prices refer to spot (any origin), fines, 62% Fe, CFR China. From 2006 to November 2008, prices refer to spot, 63.5% Fe. Earlier data (from 1990) refer to annual contract prices (Brazil for Europe,) VALE Carajas mines sinter feed, FOB Ponta da Madeira.

As a result, iron ore prices recorded a five-year high (from 2009 to 2014) with remarkable gains of over 73% from December 2018 to July 2019. Spot prices advanced to the level of USD 100 per tonne for the first time in five years, and finally reached the level of USD 120 per tonne (S&P Global 2019d). For example, the NYMEX futures of iron ore (62% Fe content) reached EUR 106 per tonne in July 2019 (USD 120/t) from EUR 61 per tonne (USD 69/t) in December 2018 (see Figure 129). It is projected that as Brazilian production recovers and consumption growth from China will be moderated, the seaborne market will return soon to surplus and prices will decline (Department of Industry and Science 2019)(S&P Global 2019a). Such a trend is already observed in August 2019, iron ore prices (fines, 62% Fe, CFR China) have declined to USD 93 per tonne (World Bank 2019).



Figure 129: Iron ore (62% Fe) monthly price[89] in the New York Mercantile Exchange (NYMEX), in EUR/tonne (S&P Global 2019d)

13.3EU demand

13.3.1EU consumption

The apparent consumption of iron ore in the EU is estimated at 125,000 ktonnes per year (2012-2016 average), of which 22,900 ktonnes are provided by domestic production (calculated as EU production – exports to non-EU countries) and 102,100 ktonnes through imports to the EU, resulting in a net import reliance of 72%. The iron ore produced and imported to Europe is utilised in the production of crude steel (BGS 2019, Eurostat Comext 2019).

The EU apparent consumption for crude steel is calculated at 163,600 ktonnes per year, of which 154,900 ktonnes came from within the EU (again calculated as EU production – exports to non-EU countries). The remainder of about 8,700 ktonnes were imported from outside the

[89] Prices are not deflated

EU. On a net-imports basis, the EU imported approximately 4% of the crude steel it consumed in the period 2012-2016 (BGS 2019, Eurostat Comext 2019).

13.3.2Uses and end-uses in the EU

Iron ore is a critical component of steel manufacturing. Approximately 98% of the iron ore shipped worldwide is consumed in iron and steel manufacturing . The remaining 2% of the total iron ore consumption is used in a range of non-steel applications such as ballast, cement clinker production, coal washing, crushed road base material, fertilizer, dense media separation, iron oxide pigments, ferrite magnets, oil and gas well drilling, radiation shielding, water treatment, and other specialty applications (USGS 2018b).

Steel is the most important industrial material. It forms part of a number of industrial value chains and is closely linked to many downstream industrial sectors. Figure 130 and Figure 131 present the main steel markets worldwide and in the EU, respectively. In the EU, the principal end-use sectors, which account for about two-thirds of steel demand, are construction, automotive, and mechanical engineering.

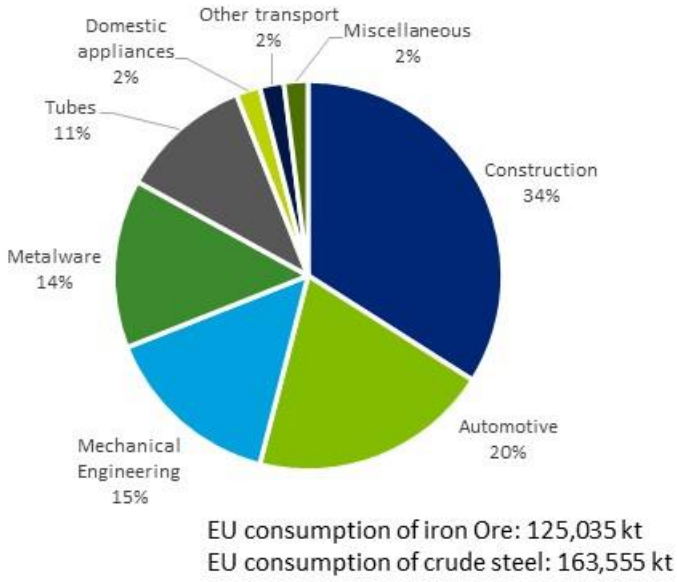


Figure 130: Steel consumption in the EU per steel-using sector in 2018 (EUROFER 2019c), and EU consumption of iron ore and crude steel

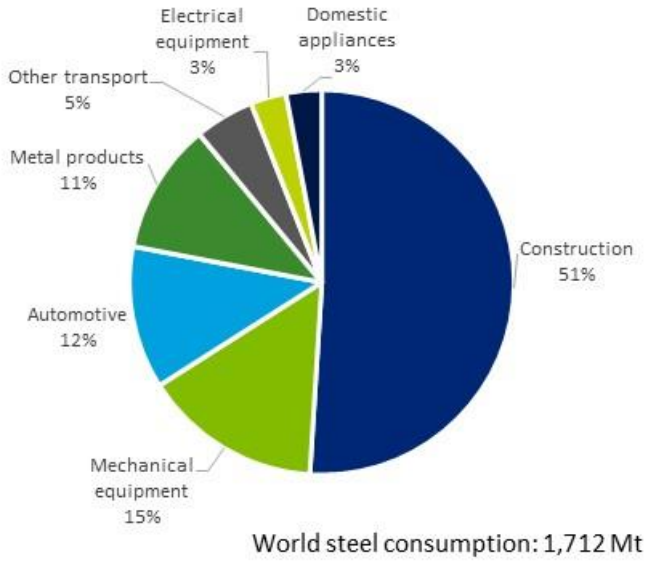


Figure 131: World steel consumption per steel-using sector in 2018 (WorldSteel 2019b)

Steel is ubiquitous in everyday life and it is impossible to make an exhaustive list of steel applications. A selection of the main end-uses of steel is presented below (WorldSteel 2019b) (EUROFER 2019d) :

• *Construction*. More than half of the steel produced worldwide goes into steel buildings and infrastructure. The possibilities for using steel in buildings are manifold: in structural sections of the building frame, in reinforcing bars in concrete, in sheet products in roofs and claddings for exterior walls. Likewise, steel is found in many non-structural applications such as heating and cooling equipment and interior ducting. Internal fixtures and fittings such as rails and stairs are also made of steel as well as a variety of other construction materials, such as bolts, nails, and screws. Besides, steel is used widely in the construction of major infrastructures including roads, bridges, tunnels, railways, ports and airports in the form of rebar sections, plates and rail track;

• *Automotive and other transport*. Steel is used in all motor vehicles. It is found in the body structure, panels, doors, engine, gears, wheels, tyres and many more. Advanced high-strength steels are used in all new vehicles, which enables them to be lighter by 25% to 39% compared to conventional steel. Other typical applications in the transport sector include ships and shipping containers, trains and rail cars and aircraft. Steel is also crucial to the related infrastructure: roads, bridges, ports, stations, and airports. Including automotive, 17% of the steel produced worldwide in 2018 was used in the transport sector;

• *Tools and machinery*. An immense range of equipment ranging from heavy equipment (cranes, bulldozers, drills and scaffolding used in construction) and tools used by the manufacturing sector, to small household tools. Even if a product is not made of steel, steel is required for the mechanical equipment and machines used to produce other materials;

• *Domestic appliances*. A variety of applications ranging from fridges to washing machines and other smaller equipment;

• *Metal products*. Numerous products of everyday use such as cutlery, cookware, office furniture, radiators, packaging and others are made of steel;

• *Energy and utilities*. Steel is indispensable in the production, distribution and storage of energy such as in high voltage pylons, in wind turbines, in nuclear, thermal and hydroelectric plants. Pipes and tubes made of steel are used in the energy sector for the transport of oil and natural gas, some of them made of special high-purity grades that withstand corrosion. Ships carrying liquefied natural gas cooled to below 160 C^{o} use low-temperature special steels, designed to withstand extreme cold without getting brittle or fragile. In the utilities sector (fuel, water, power), over 50% of the steel used is in underground pipelines to distribute water to and from housing, and to distribute gas;

• *Electrical*. Electrical steel with special magnetic properties is the core material for every electrical motor today. It is also essential for the engines of electric or hybrid vehicles.

Besides steel, pig iron has many applications in the manufacture of ferrous castings. In particular, foundry pig iron is suitable for grey iron castings made in cupola furnaces used in general engineering, machine tools and parts for the automotive industry. High purity pig iron constitutes the principal ferrous feedstock material for foundries producing ductile iron castings for high quality automotive, engineering and energy casting components.

Relevant industry sectors are described using the NACE sector codes in Table 62.

Table 62: Steel applications, 2-digit and examples of associated 4-digit NACE sectors (Eurostat 2019a)

Applications	2-digit NACE sector	Value-added of sector (million €)	Examples of 4-digit NACE sector(s)
Steel in Construction	C25 - Manufacture of fabricated metal products, except machinery and equipment	148,351	C2511 - Manufacture of metal structures and parts of structures
Steel in Automotive	C29 - Manufacture of motor vehicles, trailers and semi-trailers	160,603	C2920 - Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semi-trailers
Steel in Mechanical Engineering	C28 - Manufacture of machinery and equipment n.e.c.	182,589	C2811 - Manufacture of engines and turbines, except aircraft, vehicle and cycle engines
Steel in metalware	C25 - Manufacture of fabricated metal products, except machinery and equipment	148,351	C2571 - Manufacture of cutlery
Steel in tubes	C24 - Manufacture of basic metal	55,426	C2420 - Manufacture of tubes, pipes, hollow profiles and related fittings, of steel
Steel in domestic appliances	C28 - Manufacture of machinery and equipment n.e.c.	182,589	C2821 - Manufacture of ovens, furnaces and furnace burners
Steel in other transport	C30 - Manufacture of other transport equipment	44,304	C3011 - Building of ships and floating structures

13.3.3Substitution

Substitutes have been identified for the applications of steel in construction, automotive, mechanical engineering and metals products. There are no substitutes for iron ore itself. Substitutes are assigned a 'sub-share' within a specified application and considerations of the

cost and performance of the substitute, as well as the level of production, whether the substitute has a 'critical' status and produced as a co-product/by-product.

Substitutes for steel used in construction include reinforced concrete, timber, masonry and other construction products that are often used for construction purposes. These alternative materials have similar performance to steel or used for the same purposes (AISC 2018) (The Construction Index 2012), with the exception of wood for which the substitution performance is assessed in literature from reduced (DG ENV 2010) to adequate (Graedel et al. 2015a). Cost is considered equal or lower for all alternative materials. Steel finds use in a diverse range of applications including cladding, reinforced steel in buildings, infrastructure and as a structural construction material. Sub-shares for the identified substitutes are not available and for this assessment information corresponding to the UK construction industry and the use of steel in structural construction has been used as a proxy (The Construction Index 2012).

Potential substitutes for the use of steel in automotive include aluminium, magnesium and carbon fibre composites. Aluminium is considered the principal substitute (Graedel et al. 2015a). All of the identified alternatives have the same performance as steel, but the cost is higher, especially for magnesium and composites (McKinsey 2014)(General Motors 2012)(Liao 2017). The sub-shares applied in the assessment for the substitute materials are based on an average car composition and the current percentages of these materials used.

Substitutes for steel used in mechanical engineering include composites, aluminium, magnesium and titanium. The performance is assessed as similar, but the cost of the potential substitutes is higher, especially for titanium, carbon fibre composites and magnesium (Rao et al. 2018) (Mouritz 2012). Sub-shares for these substitutes are not known and have been estimated for the criticality assessment. Titanium could be an effective substitute for stainless steel in products such as medical devices, in marine applications and aircraft applications (see Titanium factsheet). Fibre-reinforced polymers are considered the primary substitutes in machinery (Graedel et al. 2015a).

Steel in metalware could be substituted by a variety of materials including plastics, silver, bronze, copper and aluminium. The different substitutes have different characteristics and performance to steel (European Commission 2017). Exact sub-shares for the substitute materials are unknown and have been estimated. Aluminium is again considered as the chief substitute in metal goods (Graedel et al. 2015a).

Substitutes for the other applications of steel have not been identified as their market shares are low.

13.4Supply

13.4.1EU supply chain

The iron flows through the EU economy are shown in Figure 132.

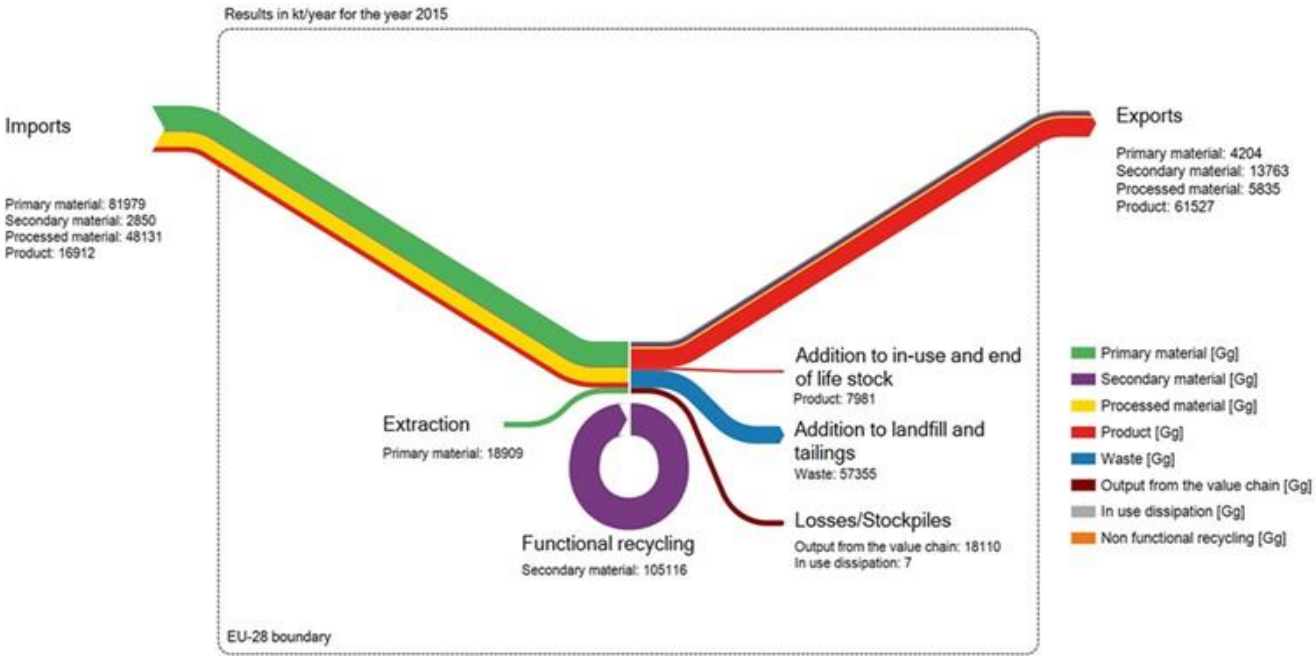


Figure 132: Simplified MSA of iron flows in the EU in 2015 (Passarini et al. 2018).

13.4.1.1 EU sourcing of iron ore

Iron ore is mined in Sweden, Austria and Germany. The 5-year average EU production of iron ore between 2012 and 2016 was about 36,500 ktonnes by volume (BGS 2019), or 18,000 ktonnes in iron content (WMD 2019), which accounts for just over 1% of the world's production of iron ore.

Sweden is by far the leading EU iron ore producer, with a yearly output of nearly 33,500 ktonnes of iron ore (or about 17,000 kt in Fe content). In the Kiruna district of northern Sweden, underground iron ore mines are operated by Luossavaara-Kiirunavaara AB (LKAB) at Kiruna (magnetite) and Malmberget (magnetite and hematite), operating at a depth of more than 1 km (LKAB 2018). In 2015, the Kiruna Mine was the largest underground iron ore mine in the world in terms of the value of production (USGS 2019b). Ore is extracted using the sub-level caving technique which, after drilling and blasting, utilises gravity to get the ore to fall into underlying production tunnels. Apart from underground mines, iron ore is also extracted in the open-cast mines at Leveäniemi and Gruvberget in the same district (LKAB 2018).

In Austria, iron ore is mined from the Erzberg open-pit mine operated by VA Erzberg GmbH and located in Eisenerz (Styria), which contains the largest siderite deposit in the world. Annual production is about 2,500 ktonnes of iron ore or 800 ktonnes in iron content. The output of the Erzberg mine supplies Voestalpine Stahl GmbH's steel plants in Donawitz and Linz (USGS 2019c) (VA Erzberg 2019).

Annual production in Germany is around 460 ktonnes of iron ore (65 kt in Fe content). Barbara Erzbergbau GmbH mines iron ore at the Wohlverwahrt-Nammen mine in Porta Westfalica, North Rhine-Westphalia, where only low-grade iron ore is produced (around 15% Fe content) which finds use as construction additive (USGS 2019a) (Barbara Erzbergbau 2019).

The above figures refer to the average 2012–2016 data. In addition to domestic production, about 102,000 ktonnes per year of iron ore are imported to the EU. The net import reliance for iron ore in the EU is estimated at 72%. Figure 133 presents the EU sourcing (domestic production + imports) for iron ore.

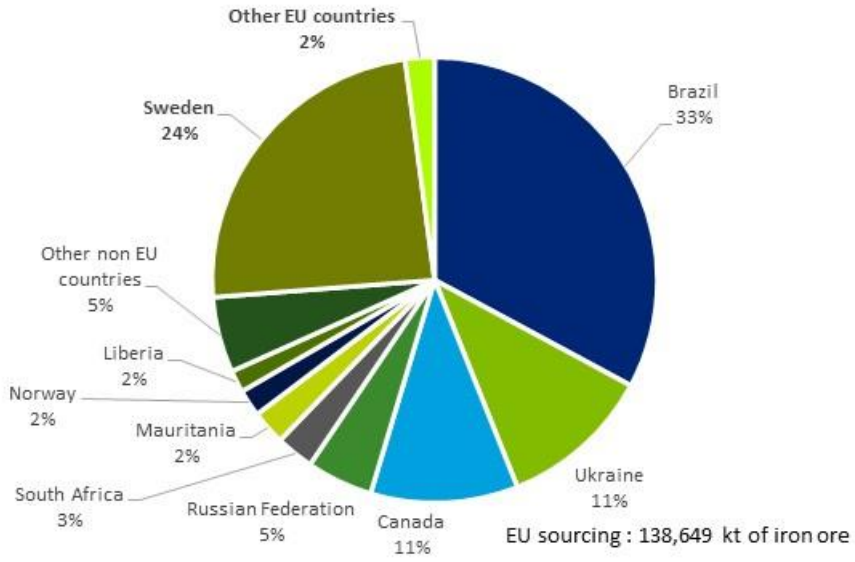


Figure 133: EU sourcing (domestic production + imports) of iron ore. Average 2012-2016 (BGS 2019) (Eurostat Comext 2019)

13.4.1.2 EU sourcing of crude steel

The steel industry is an essential contributor to the EU economy. It directly employs 314,000 people and supports more than 2 million indirect jobs jobs in the associated value chains (EUROFER 2019a). In 2018, the EU industry generated around EUR 148,000 million of Gross Value Added. Steel is produced in about 500 sites including primary steelmaking in Blast Furnace/Basic Oxygen Furnace integrated steelmaking, secondary steelmaking in Electric Arc Furnaces, and fabrication of steel mill products.

According to the latest available data of the European Steel Association (EUROFER 2019c), in 2018 the EU produced 160,100 ktonnes of crude steel across 22 Member States, accounting for 9% of the worldwide production. The share of the BF/BOF route stood at 58.3% of the total crude steel output in 2018, and the remainder (41.7%) was produced through the EAF route. In 2018, carbon steel accounted for 78.6% of the total EU27[90] crude steel production, alloy steel for 17%, and stainless steel for 4.4%. The net import reliance for crude steel is 4% as a percentage of apparent consumption.

[90] Including UK

Figure 134 shows the EU sourcing (domestic production + imports) of crude steel.

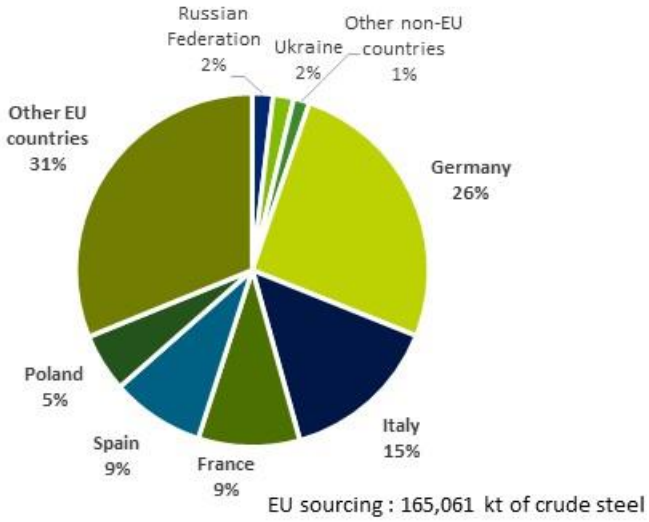


Figure 134: EU sourcing of crude steel. Average 2012-2016 (BGS 2019)(Eurostat Comext 2019)

13.4.2Supply from primary materials

13.4.2.1 Geology, resources and reserves of iron ore

Geological occurrence: Iron is the second most abundant metal in the Earth's crust (after aluminium). The average concentration in the continental crust is 6.71% FeO_T[91], and in the upper crust is 5.04% FeO_T (R. L. Rudnick and Gao 2014). Iron forms several common minerals including hematite (Fe_2O_3), magnetite (Fe_3O_4), goethite ($FeO(OH)nH_2O$), limonite ($2Fe_2O_3.3H_2O$), siderite ($FeCO_3$) and pyrite (FeS_2). It is also present in many rock-forming minerals, including mica, garnet, amphibole, pyroxene and olivine (FOREGS 2006). The principal iron ores for iron making are hematite (70% Fe content) and magnetite (72% Fe content).

Despite its abundance in the Earth's crust, only a small part of iron is concentrated in rich deposits. The grade of iron ore deposits varies from 20% to 30% for poorer sources to as much as 60% to 70% for the higher-grade deposits (Comtois and Slack 2016).

Iron ore deposits occur mainly in iron-rich sedimentary rocks known as banded iron formations (BIF). The BIF-hosted iron ore deposits represent the most extensive iron ore resources worldwide and most of the high-grade concentrations of iron ore currently mined. Major BIF-hosted deposits with average ore grade above 60% iron occur in Australia (Hamersley province), Brazil (Quadrilatero Ferrifero and Carajas deposits) and India (Noamundi deposit). Iron ore deposit types also include the volcanic-associated massive sulphide deposits which predominantly consist of iron sulphide in the form of pyrite. With increasing magnetite content, these ores become massive oxide ores of magnetite and/or hematite. Typical examples of such deposits include the Savage River in Tasmania, Fosladen in Norway and Kiruna in Sweden.

[91] Total iron expressed as the calculated ferrous or ferric amount

Iron ores vary considerably in iron content. On average the iron content of Chinese iron ores is 30-40%, whereas the Fe content of iron ores originating from Australia and Brazilia is above 60%. The iron content of iron ores extracted in Sweden ranges from 45% to 53%.

Concerning iron ore deposits in the EU, the apatite-iron oxide Kiruna-type deposit at the Kiruna district in northern Sweden is mainly composed of apatite-bearing magnetite and accounts for about 90% of EU iron ore production. According to data published by the Fennoscandian Mineral Deposits database (FODD 2017), at the end of the year 2017 the iron ore resources and reserves (including active and closed mines, as well as not exploited deposits and all reporting codes of mineral resources and reserves) of the Kiruna-type deposit amounted to 3,100 million tonnes of ore, of which the iron ore reserves are 1,200 million tonnes of ore.

Global resources and reserves[92]*:* The United States Geological Survey (USGS, 2019d) estimate that world resources are greater than 800,000 million tonnes of crude iron ore containing more than 230,000 million tonnes of iron. The world iron ore reserves are estimated by USGS at about 173,000 million tonnes, containing 84,000 million tonnes of iron. The world's largest iron reserves are located in Australia (29%), Brazil (20%) and Russia (17%). The breakdown per counties is given in the following table

Table 63: Global reserves of iron ore in 2018 (USGS 2019d)

Country	Iron ore Reserves (million tonnes)	Iron content (million tonnes)	Percentage of the total (%)
Australia	50,000	24,000	29
Brazil	32,000	17,000	20
Russia	25,000	14,000	17
China	20,000	6,900	8
India	5,400	3,200	4
Ukraine	6,500	2,300	3
Canada	6,000	2,300	3
Iran	2,700	1,500	2
Kazakhstan	2,500	900	1
South Africa	1,200	770	1
United States	2,900	760	1
Sweden	1,300	600	1
Other countries (unspecified)	18,000	9,500	11
World total (rounded)	**173,000**	**84,000**	100

[92] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of iron ore in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template, which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

EU resources and reserves[93]*:* The most abundant iron ore resources and reserves in the EU are located in Sweden. At the end of 2018, the mineral resources of the operating mines of LKAB are reported in accordance to the FRB standard to 1,440 million tonnes at an average iron grade of 41.8%, whereas the mineral reserves (not included in resources) to 1,151 million tonnes at an average iron grade of 43.7% (LKAB 2019). Minerals4EU (2019) compiled resources and reserve data for other countries in Europe (see Table 64 and Table 65). Collected data they cannot be summed as they are partial and they do not use the same reporting code.

Table 64: Iron ore resources data in the EU

Country	Reporting code	Quantity (Mt of iron ore)	Grade (% Fe)	Classification	Reporting date	Source
Finland	None	327.7	27.85	Historic Estimate	12/2017	(FODD 2017)
	NI 43-101	190	30	Measured	12/2017	(FODD 2017), (Minerals4EU)
		12	26	Indicated		
		62	32	Inferred		
Greece	USGS	7	45 (Fe_2O_3)	Measured	11/2014	(Minerals4EU)
		5	NA	Inferred		
	None	10	40-45 (Fe_2O_3)	Historic Estimate		
Hungary	Russian classification	0	NA	A	11/2014	(Minerals4EU)
		1.75	24.4	B		
		23.84	24.4	C1		
		11.92	24.1	C2		
Lithuania	State reporting code	61.69 (million m^3)	NA	Indicated (preliminary explored)	01/2015	(Minerals4EU)
	None	58.73	NA	Inferred (prognostic)		
Portugal	None	790.65	38.25	Historic Estimates	11/2014	(Minerals4EU)
Slovakia	None	4.02	33.81	Verified (Z1)	11/2014	(Minerals4EU)
		12.9	33.94	Probably (Z2)		
		3.62	34.97	Anticipated (Z3)		

[93] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for iron ore. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for iron ore, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for iron ore the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019). Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However a very solid estimation can be done by experts.

Country	Reporting code	Quantity (Mt of iron ore)	Grade (% Fe)	Classification	Reporting date	Source
		51.75	30.19	Sub-economic		
Spain	None	282	NA	Identified	12/2014	(Minerals4EU)
		155.4	NA	Indicated		
		480	NA	Inferred		
Sweden	FRB	181	42.1	Measured	12/2018	(LKAB 2019)
		436	41.4	Indicated		
		823	41.9	Inferred		
	JORC	942	37.11	Total Resources	12/2017	(FODD 2017)
	NI 43-101	770.43	35.72	Total Resources		
	None	795.16	34.89	Historic Estimate		

Table 65: Iron Ore reserves data in the EU

Country	Reporting code	Quantity (Mt of iron ore)	Grade (% Fe)	Classification	Reporting date	Source
Italy	None	3.5	NA	Estimated	03/2015	(Minerals4EU)
Romania	UNFC	57	NA	Probable (121)	11/2014	(Minerals4EU)
Slovakia	None	4.02	34	Verified (Z1)	11/2014	(Minerals4EU)
	None	12.9	34	Probable (Z2)		
Sweden	JORC	29.1	34.46	Total Reserves	12/2017	(FODD 2017)
Sweden	NI 43-101	70.4	42.33	Total Reserves	12/2017	(FODD 2017)
Sweden	NI 43-101	94.5	25.72	Total Reserves	12/2017	(FODD 2017)
Sweden	FRB	1,057	43.94	Proven	12/2018	(LKAB 2019)
		94	40.53	Probable		

13.4.2.2 Exploration and new mine development projects in the EU

Exploration and new mine development projects having iron ore as the main commodity are located in Sweden, Finland and Spain with varying degrees of development and undertaken studies (S&P Global 2019d). The more advanced ones are the Kiruna project in Sweden with JORC-compliant total resource estimate at 395,000 ktonnes (40.1% Fe) (Hannans Reward Ltd 2019), the Kallak project in Sweden with total resources estimated at 152,000 ktonnes (27.2% Fe) (Beowulf Mining plc 2019), and the Hannukainen iron-(copper-gold) project in Finland with 221,000 ktonnes of total resources at 32.2% Fe (GTK 2019)(Hannukainen Mining 2019).

13.4.2.3 Mining of iron ore

Extraction of iron ore is undertaken mostly through surface mining as many deposits are situated near the surface. The extracted iron ore is hauled to the beneficiation plant, where the direct-shipping ores, i.e. those with sufficiently high Fe content (at least 55-58% Fe) undergoes only crushing and screening to produce iron ore lump and sinter feed fines. For lower-grade ores, additional beneficiation is required to remove impurities and achieve sufficient iron content before use in ironmaking. Iron oxide minerals are separated from the gangue through grinding and gravity separation, magnetic separation (for magnetite) or flotation. According to background data by S&P Global (2019d), it is estimated in 2017 the iron ore production consisted of 55% fines, 25% concentrates, and 21% lump ore.

Following separation, agglomeration is required for fine and very fine iron ore concentrates into pellets capable of being transported over long distances and fed directly into the blast furnace. Alternatively, the fine iron ore concentrates can be mixed with residues and additives to produce iron-rich sinters (i.e. semi-fused and solidified lumps of iron oxide) prior to being charged to the blast furnace; the sintering plant is often located adjacent to the blast furnace.

13.4.2.4 World and EU mine production of iron ore

World and EU mine production of iron ore is summarised in Figure 135. The world's production of iron ore amounted to 2,308,000 ktonnes of saleable ore. The global supply of iron ore is dominated by Australia with about 35% of the total mine production, equivalent to 707,000 ktonnes of iron ore. Brazil is the second-ranked producer accounting for 18% (375,000 ktonnes of ore) of the global iron ore production. China (197,000 ktonnes), India (154,000 ktonnes), and Russia (102,000 ktonnes) complete the list of the top-5 iron ore producers. The above figures are annual averages for 2012-2016.

In the EU, Sweden was the leading producer of iron ore with a five-year annual average (2012-2016) of 33,500 ktonnes representing a share of 92% of the total EU production. Austria produced in the same period approximately 2,500 ktonnes and Germany 461 ktonnes.

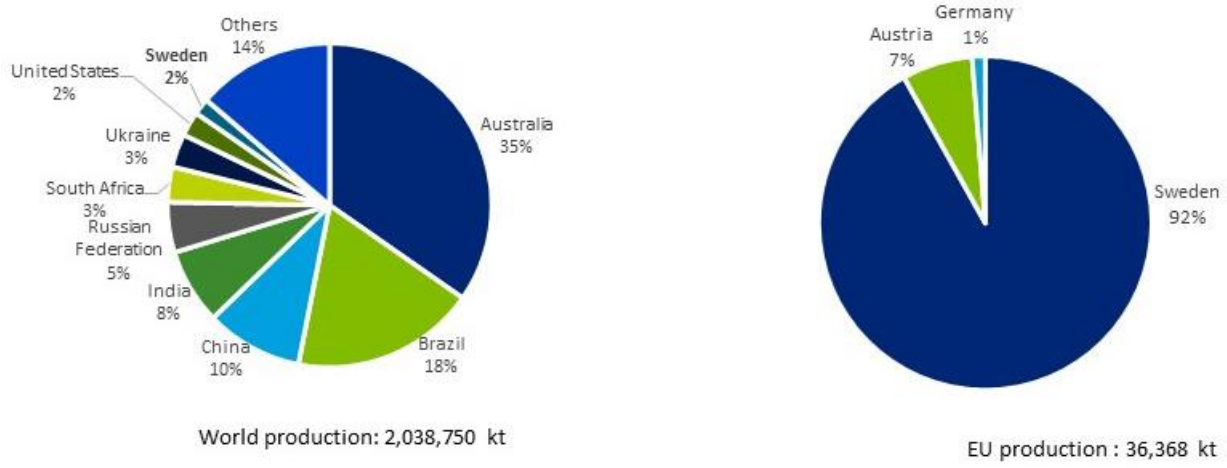


Figure 135: Global and EU mine production of iron ore. Average for the years 2012-2016. (BGS 2019) (Worldsteel 2018)[94]

[94] Data for iron ore production in China were sourced from the World Steel Association to correspond with world average Fe content, as the total production reported by the British Geological Survey includes ore with low Fe content

13.4.3Steelmaking

Steel is produced via two routes:

- The integrated steelmaking process (BF/BOF), in which iron ores are first converted to iron metal utilising the blast furnace (BF) and then iron is converted to steel in the basic oxygen furnace (BOF);
- The electric arc furnace (EAF) process.

The key difference is the type of raw materials they consume. The BF/BOF route uses as raw materials iron ore, coal (mainly in the form of metallurgical coke), limestone and iron and steel scrap while the EAF route uses mainly iron and steel scrap and electric power to melt the scrap. Electric arc furnaces can be charged by up to 100% ferrous scrap feedstock. The BF/BOF route is the most utilised steelmaking technology worldwide. According to data published by the World Steel Association (WorldSteel 2019c), in 2017 71.4% of global crude steel output was produced in oxygen-blown converters which transform pig iron into steel, and 27.9% in electric arc furnaces. In the EU, the share of the EAF production is higher. In 2018, 40.3% of steel output came from electric arc furnaces and 59.3% from the BF/BOF route. Another steelmaking technology, the open-hearth furnace (OHF), contributes to less than 1% of global steel output and is no longer utilised in Europe. The OHF process is very energy-intensive and is in decline, on account of its environmental and economic disadvantages.

13.4.3.1 Blast furnace-basic oxygen furnace integrated steelmaking (BF/BOF)

The blast furnace is the central operational unit in ironmaking in which iron-bearing oxide ores are reduced to elemental iron, also called 'hot metal' or 'pig iron'. The main reducing agent in a blast furnace is coal in the form of metallurgical coke; coke also partly acts as an energy carrier for sustaining the processes within the metallurgical reactor. The blast furnace is a counter-current gas/solids reactor in which the descending column of feed materials (coke, iron ore and fluxes/additives) reacts with the ascending hot gases (IIMA 2019).

Modern high-performance blast furnaces require physical and metallurgical preparation of the charge. Pelletizing and sintering are the two types of iron ore preparation generally applied. The load of the blast furnace is charged from the top consisting of alternate layers of coke and a mixture of sinter and/or pellets, lump ore and fluxes such as limestone to collect impurities. Air which is heated to about 1200°C, is blown into the furnace through nozzles in the lower section (World Coal Association 2019). The hot blast provides the necessary oxygen to burn the coke and form carbon monoxide, which is the basic reductant for the iron oxides, as well as generates heat to melt the iron. In the furnace, the iron ore is progressively reduced, and molten iron is collected at the bottom of the furnace. The majority of impurities present in the ore and fuel are removed from the melt as a separate liquid by-product called slag, also collected at the bottom of the furnace, floating on top of the molten iron. The process is continuous with raw materials being regularly charged to the top of the furnace and molten iron and slag being tapped from the bottom of the furnace at regular intervals (IIMA 2019).

Part of pig iron can be cast into ingots or rapidly solidify to form granules (granulated pig iron). However, the vast majority of pig iron produced from the blast furnace is consumed within integrated steelmaking complexes where molten iron (hot metal) from the blast furnace is transferred directly to the basic oxygen furnace.

The process converts iron into steel using pure oxygen to oxidise carbon and the unwanted impurities in molten iron. Typically, the carbon content is lowered from around 4% to less than 1%. The necessary energy is obtained from the exothermal oxidation reactions; ferrous scrap

is added to the converter in order to cool the process, which can be as much as 30% of the furnace charge (Worldsteel 2018). Upstream ladle desulphurisation of the hot metal and downstream ladle metallurgy of the molten steel are applied in order to refine molten steel and achieve the required quality; in particular, the former is applied when needed (depending on the ore grade) and the latter is a necessary step for targeting the desired steel composition. Ferrous slag is also generated from the added fluxes and the energy of the process, at an average rate of 400 kg per tonne of crude steel (WorldSteel 2019c). Molten steel is then cast either into ingots or by means of continuous casting into billets, blooms and slabs (semi-finished products). Nowadays, ingots are not common anymore and are used only for some specific/niche applications. In 2017, continuously cast semis (billets, blooms, and slabs) accounted for 96.3% of the world steel output, ingots for 3.5%, whereas the remainder (0.2%) was delivered in liquid form for castings (WorldSteel 2019c).

On average, the integrated steelmaking route uses 1,370 kilogram of iron ore, 780 kilogram of coal, 270 kilogram of limestone, and 125 kilogram of ferrous scrap to produce 1,000 kilogram of crude steel (WorldSteel 2019c).

13.4.3.2 Electric Arc Furnace (EAF) steelmaking

The principal material input for the EAF is iron and steel scrap, which may be comprised of scrap from inside the steelworks, cut-offs from iron and steel product manufacturers and post-consumer scrap. The electric arc furnace can be charged with 100% steel scrap. Depending on the plant configuration and on the availability and quality of ferrous scrap, other sources of metallic iron such as direct reduced iron (DRI), pig iron or hot metal can be used in the EAF route too. As in the BF/BOF, a slag is formed by the addition of fluxing agents (limestone and/or dolomite) to refine and condition the steel composition and also to form a protective layer separating the liquid steel from the external atmosphere. In the EAF, around 170 kilogram of slag is produced per tonne of crude steel (BGS 2019). The downstream casting process is the same for all the steel production routes.

On average, the EAF route uses approximately 710 kilogram of ferrous scrap, varying amounts of iron sources (i.e. metallics, DRI, hot metal, and granulated iron) corresponding to 586 kilogram of iron ore, 150 kilogram of coal, 88 kilogram of limestone and 2.3 gigajoule of electricity to produce 1,000 kilogram of crude steel (BGS 2019).

13.4.3.3 Other ironmaking processes

An alternative process of ironmaking is the direct reduction of iron ore oxides in solid-state, i.e. without melting as in blast furnace, with natural gas, hydrogen or coal as reducing agents. Direct reduced iron (DRI), also called sponge iron, is mainly used as feedstock in electric arc furnaces. Hot Briquetted Iron (HBI) is a form of DRI which is briquetted at elevated temperature to form dense briquettes which can be transported and handled efficiently and safely. Because there is no separation of iron from gangue in the reduction facility, high-grade ores must be used (>67% iron and a low gangue content; commonly DRI-pellets grades are commercialised, but the supply is limited). Global DRI output accounts for about 0.7% of total iron production (average 2012-2016).

Another process is the production of nodular pig iron which contains much less manganese, sulphur and phosphorus content and is almost exclusively used in foundries and castings.

13.4.3.4 World and EU production of crude steel

The average annual global crude steel production between 2012 and 2016 is estimated at 1,622,000 ktonnes. The major producers are presented in Figure 136. China has been the leading producer of crude steel with an outstanding share of 49% of global production and a notable difference from the other producers. Other major producing countries globally are Japan (7%), India (5%), the United States (5%) Russia (4%) and South Korea (4%) (BGS 2019).

The EU as a region is the second steel producer worldwide after China, producing about 9% of the world output, which reveals the important status of European steel production globally. The average EU crude steel production between 2012 and 2016 was 156,400 ktonnes per year. Within the EU, Germany is the leading producer (27% of the EU production), followed by Italy (15%), France (10%), and Spain (9%) representing the major producing countries in the EU (WorldSteel 2019c). Most of the EU countries are steel producers.

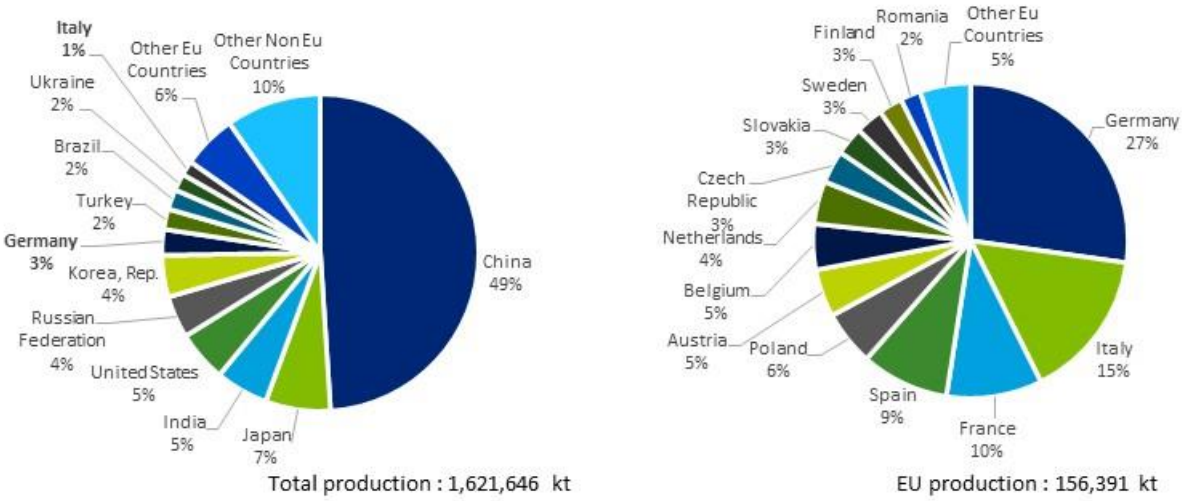


Figure 136: Global and EU production of crude steel. Average for the years 2012-2016. (BGS 2019).

13.4.4Supply from secondary materials/recycling

Steel is 100% recyclable and has a potentially infinite life cycle without loss of properties. The World Steel Association reports that about 630,000 ktonnes of ferrous scrap is recycled every year, making steel the most recycled material in the world by volume (WorldSteel 2019a).
The recycling process of steel is well established globally, and it is an integral part of steel manufacturing. Steel recycling reduces the demand for primary ore, and at the same time offers substantial environmental benefits and savings in raw material inputs. In particular, steel production from scrap requires a lower amount of energy in comparison to production from iron ore decreasing by about half the generation of CO_2 emissions. At the same time, every tonne of steel scrap used in steelmaking offsets the consumption of around 1,400 kilogram of iron ore, 740 kilogram of coal and 120 kilogram of limestone required by the integrated steelmaking route (WorldSteel 2017) (WorldSteel 2016).

The average lifetime of steel in different applications and products is another factor to be taken into consideration when examining secondary supply sources. The average life expectancy of steel goods ranges from 35 to 40 years. In construction, the largest consumer of steel, steel

will not be available for recovery for several decades, as the average lifetime of steel is above 60 years (Allwood 2016). As most steel products remain in use for decades before they can be recycled, there is not enough ferrous scrap available to meet current levels of demand for steel products by using the EAF steelmaking route only. The projections of increasing demand imply that primary steel production will continue to play an essential role in the future and, therefore, demand will be met through a complementary and interdependent use of the BF/BOF and EAF production routes (EUROFER 2015)(EUROFER 2019c)(Worldsteel 2018).

In the EU, ferrous scrap plays a vital role in steel making. Approximately 42% of the crude steel output in 2018 was produced by the EAF route that uses up to 100% ferrous scrap, while globally the share of electric arc furnaces in steel production is about 28% (UNEP 2013) (Worldsteel 2019d).

13.4.4.1 Post-consumer recycling (old scrap)

Recycling of post-consumer products is enhanced as steel is used in large amounts in easily recoverable applications (e.g. vehicles). Also, due to its magnetic properties (except some stainless steel types), it is easy to separate and recover steel from waste streams. According to (UNEP 2011), the end-of-life functional recycling rate (EOL-RR) for iron and steel is high, estimated to range from 70% to 90%.

Recycling rates from simple products, such as packaging, construction and vehicles is high (above 85%) but for more complex products (for instance electronics) is lower at around 50% (WorldSteel 2019c). Ferrous scrap originates from different alloys, which changed their composition and increased in number over time to accommodate the latest requirements from technology innovation. This, in turn, influences the recycling process, especially from complex products such as electronics which currently include over 50 different elements in their composition. Apart from the complex product composition, inefficient collection rates are also responsible for the lower recycling rate of electronic EOL products. Moreover, the recovery of steel and other metals from waste electrical and electronic equipment often poses significant challenges to metallurgy if the products are not designed for recyclability and disassembling. In case steel is recycled together with other metals, it is substantially downgraded and in some cases might not be functionally recycled at all (UNEP 2011). By sector, global steel recovery rates are estimated at 85% for construction, 90% for automotive, 90% for machinery, and 50% for electrical and domestic appliances (Allwood 2016).

A notable end-of-life recycling performance for iron and steel is shown for the EU. According to the datasets developed by the MSA study of iron (see Table 66), of the total amount of old scrap generated at end-of-life in the EU in 2015 (108,000 kt), about 81,000 ktonnes were collected for recycling, resulting in EOL-RR (i.e. the fraction that is recycled at the end of the material's life cycle) of 75%. If exports are accounted for (EU is a net-exporter of ferrous scrap and waste), the EOL-RR[95] decreases to 62%. As regards the end-of-life recycling input rate (EOL-RIR), which measures the quantity of end-of-life scrap (i.e. 'old scrap') contained within the total amount of metal available to manufacturers (which would also include primary metal and 'new scrap'), the input from secondary materials accounted for 31% of the EU metal supply in 2015.

[95] EOL-RR= (G.1.1 + G.1.2)/(E.1.6 + F.1.2)

Table 66: Material flows relevant to the EOL-RIR[96] of steel in 2015. (Wyns, Khandekar, and Robson 2018)

MSA Flow	Value (kt)
B.1.1 Production of primary material as the main product in EU sent to processing in EU	12,625
B.1.2 Production of primary material as a by-product in EU sent to processing in EU	0
C.1.3 Imports to the EU of primary material	81,979
C.1.4 Imports to the EU of secondary material	2,850
D.1.3 Imports to the EU of processed material	48,131
E.1.6 Products at end-of-life in EU collected for treatment	108,075
F.1.1 Exports from the EU of manufactured products at end-of-life	0
F.1.2 Imports to the EU of manufactured products at end-of-life	0
G.1.1 Production of secondary material from post-consumer functional recycling in the EU sent to processing in the EU	66,894
G.1.2 Production of secondary material from post-consumer functional recycling in the EU sent for manufacturing in the EU	0

13.4.4.2 Industrial recycling (new scrap)

A quarter of the finished steel made each year (including half of all sheet steel) is never fabricated into a product but is cut off in manufacturing. This represents a significant amount of new scrap available for recycling. In 2008, more than half of the ferrous scrap recycled came from the manufacturing process rather than end-of-life products (European Commission 2018c).

13.5Other considerations

13.5.1Environmental and health and safety issues

The iron and steel industry apply processes requiring a significant amount of energy and emitting, directly or indirectly, a high amount of greenhouse gas (GHG) emissions. The EU iron and steel sector has achieved significant improvements by reducing its GHG emissions by 26% between 1990 and 2015, along with reducing the energy to produce one tonne of steel by 33% between 1990 and 2016 due to the higher share of steel production in electric arc furnaces, as it has increased from 30% of total EU steel production in 1990 to 40% in 2016 (WorldSteel 2019c). However, steel production is an energy-intensive industry and in 2016 accounted for about 7% of the verified emissions of all stationary installations of the European Union and around 22% of industrial emissions excluding combustion (European Commission 2018b).

In 2017, on average, 1.83 tonnes of CO_2 were emitted for every tonne of steel produced globally (European Commission 2018d). The biggest share of CO_2 emissions in steel production comes from the reduction of iron ore in the Blast Furnace/Basic Oxygen Furnace (BF/BOF) steelmaking route. The efforts so far to reduce the emissions from the BF route have mainly focused on resource efficiency (energy and material), as well as improved process control, and the blast furnaces have approached the technically feasible maximum of process efficiency, close to the thermodynamic limits; therefore, any substantial further improvement of energy efficiency and reduction of CO_2 emissions requires breakthrough technologies (European Commission 2018d) (Wyns, Khandekar, and Robson 2018). Many research and innovation projects for low-carbon steel production are underway by the EU steel industry, and some of

[96] EOL-RIR=(G.1.1+G.1.2)/(B.1.1+B.1.2+C.1.3+D.1.3+C.1.4+G.1.1+G.1.2)

them are already being tested at technologies at pilot plant scale (Technology Readiness Level (TRL) varying greatly between 3 and 9), whereas the emissions abatement potential ranges from 20% to 90% (European Commission 2018c) (European Commission 2018d). According to the European Steel Association, market roll-outs are planned up to 2036 for seven ongoing carbon-neutral projects across the EU, if costs are competitive at the demonstration phase, and regulatory framework conditions and infrastructures beyond site borders are in place (Eggert 2018).

The fundamental principles of the low-carbon technological paths in the EU comprise the following (Wyns, Khandekar, and Robson 2018) (European Commission 2018d) (WorldSteel 2012):

- *Enhanced steel recycling*. The emission reduction potential of shifting from the BF to the EAF steelmaking route (using scrap metal) is high, especially if the electrification of steel production is combined with a decarbonised power sector;
- *Use of low-carbon hydrogen,* as a reducing agent in DRI or smelting processes. Hydrogen-based direct reduction process aims using hydrogen to altogether bypass the use of coal for the production of primary steel (e.g. projects Hybrit, Salcos and H2Steel);
- *Direct use of low-carbon electricity* for iron ore reduction, i.e. CO_2-free steelmaking through electrolysis of iron oxide (e.g. Siderwin project);
- *Direct reduction based on natural gas*. In the case of replacement of the BF route by EAF using DRI production by using natural gas as a reduction agent, the carbon intensity can be reduced (EUROFER 2016);
- *New smelting technologies,* with reduced use of carbon (e.g. HIsarna project);
- *Carbon valorisation combined with Carbon Capture and Utilisation (CCU) and/or Carbon Capture and Storage (CCS),* using steelmaking waste gases (CO/CO_2) as raw materials to produce basic chemicals and fuels for other sectors (e.g. Steelanol, Carbon2Chem projects), or to produce heat and reform gases enabling less coke consumption (e.g. IGAR project).

13.5.2Contribution to low-carbon technologies

Steel is a versatile industrial material, forming the basis of many industrial value chains. In this context, steel is a key enabler for other industries to reduce their environmental footprint towards the transition to a green economy (WorldSteel 2016).

New grades of advanced high-strength steel have reduced the weight of many steel applications by 25% to 40% over the past three decades, and as a result, less steel is required to provide the same strength and functionality. According to the World Steel Association, substituting high-strength steels for conventional structural steels in construction can achieve a CO_2 reduction of around 30% in steel columns and about 20% in steel beams (EUROFER 2016). Its high-strength to volume ratio allows buildings to maximise their thermal performance and save valuable resources by reducing the mass of the building. Furthermore, the modular design that steel construction methods employ provides high adaptability for the reuse or refurbishing of old buildings with CO_2 savings (WorldSteel 2017) (WorldSteel 2019b)(EUROFER 2016).

In the energy sector, steel is essential in the broad areas of renewable energy generation and delivery (tower structures and associated infrastructure, use of electrical steels in transformers and generators). Steel is also essential in the manufacture of onshore and off-shore wind turbines (for specific magnetic properties, and crucial structural elements), as several hundred tonnes of steel are contained in a single windmill. Steel is also used in solar systems (used in thermal panels, pumps, tanks and heat exchangers), tidal energy systems (a steel pile is the main component of tidal turbines), hydroelectric dams (used in reinforced concrete) (Euromines 2019) (EUROFER 2016) (WorldSteel 2017).

In the transport sector, special high-strength steel grades can achieve up to 40% mass reduction of car components, therefore making vehicles more fuel-efficient and reducing overall vehicle lifecycle GHG emissions, while still meeting all the functional and safety requirements (WorldSteel 2017). Moreover, electrical steels are essential for building high-speed motors for electric vehicles (Sonter et al. 2014).

Finally, significant reductions of CO_2 emissions can be achieved in cement production with the substitution of clinker with granulated blast furnace slag (Wasylycia-Leis, Fitzpatrick, and Fonseca 2014).

13.5.3Socio-economic issues

The governance indicators for Brazil, most important supplier of iron ore to the EU and the second-ranked world producer, range from 0 to 1, thus are not particularly critical for the EU supply. Other countries supplying to EU have a good governance level (Australia and Canada), and only a minor part of the iron imported to the EU comes from countries with low governance levels (Ukraine, Russian Federation and Mauritania). Iron ore mining is particularly important in the Brazilian economy and has fostered economic growth and employment. Sustainability challenges concern land-use change and deforestation due to mining, as well as relations with indigenous communities (Sonter et al. 2014).

13.6Comparison with previous EU assessments

The assessment has been performed using the revised methodology introduced in the 2017 assessment. The supply risk (SR) has been analysed at both mine and processing stages of the value chain, whereas the assessment for the 2017 list of CRM considered only the extraction stage. In the processing stage, the material under study is crude steel. No assessment has been carried out for the intermediate stage between iron ore extraction and crude steel, namely the production of pig iron and other forms of iron. The results of this and earlier assessments are presented in Table 67.

Table 67: Economic importance and supply risk results for iron ore in the assessments of 2011, 2014, 2017, 2020 (European Commission 2011, 2014, 2017)

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Iron Ore	8.1	0.4	7.4	0.5	6.2	0.8	6.8	0.5

The revised methodology introduced in the 2017 assessment of critical raw materials affects both the economic importance (EI) and supply risk (SR) calculations; hence, the calculated indicators of EI and SR are not directly comparable with results of the 2011 and 2014 assessments. For instance, the fact that the economic importance of iron has been reduced between 2014 and 2017 is due to a change in methodology, as the value-added used in the 2017 and 2020 assessments correspond to a 2-digit NACE sector rather than a 'megasector' used in the previous evaluations.

The supply risk was assessed using both the global HHI and the EU-28 HHI as prescribed in the revised methodology. The higher supply risk is identified for the mine stage (SR=0.46) than the processing stage (SR=0.19) due to higher EU import reliance of EU for iron ore than crude steel. The overall supply risk for iron ore is considered for the stage with the highest value, i.e. SR=0.46 (rounded to SR=0.5). The supply risk is lower compared to 2017 exercise

(SR=0.78), mainly due to a lower Global supply risk as mine production of China was adjusted to correspond with world average Fe content. Other factors contributing to the lower supply risk are a slightly decreased import reliance for the extraction stage in the 2012-2016 period (IR=72%) in comparison to years 2010-2014 (IR=74%), the higher EOL-RIR used in the calculations (31% in the current assessment instead of 24% in the 2017 assessment), and a slightly reduced HHI for EU supply.

The calculation of the economic importance of iron ore is not straightforward due to the complicated value chain of steel products. The calculation of economic importance is based on the use of the NACE 2-digit codes and the value added at factor cost for the identified sectors (see Table 62). The same NACE 2-digit codes were used for steel applications in the current and the previous (2017) assessment. The Economic Importance indicator (EI) appears higher in the current evaluation compared to the 2017 exercise, but this is due to the results scaling step[97], i.e. the value-added of the largest manufacturing sector in the 2020 assessment is lower as it is considered for 27 Member States (i.e. excluding the UK), whereas in the 2017 assessment it corresponded to 28 Member States.

13.7Data sources

Production data for iron ore and crude steel were sourced from the British Geological Survey's World Mineral Statistics. Trade data were extracted from the Eurostat Comext database. Data for iron ore production in China were taken from the World Steel Association. The dataset developed by the EU MSA study of iron was the source for the EOL-RIR. For the end-uses of steel, data published by the European Steel Association (EUROFER) were used. Data on trade agreements were taken from the DG Trade webpage, and information on export restrictions was derived from the OECD inventory on export restrictions on Industrial Raw Materials.

13.7.1Data sources used in the factsheet

AISC (2018) Structural steel: An industry overview. Available at: https://www.aisc.org/globalassets/aisc/publications/white-papers/structural_steel_industry_overview_2018.pdf.

Allwood, J. M. (2016) 'A bright future for UK steel: A strategy for innovation and leadership through up-cycling and integration', University of Cambridge, pp. 1–16.

Barbara Erzbergbau (2019) Bergbau, Barbara Erzbergbau GmbH website. Available at: https://barbara-erzbergbau.de/bergbau-eisenerzgewinnung (Accessed: 16 September 2019).

Beowulf Mining plc (2019) Kallak - Iron ore. Available at: https://beowulfmining.com/projects/sweden/kallak/#overview (Accessed: 12 November 2019).

BGS (2019) World mineral statistics data, British Geological Survey. Available at: https://www.bgs.ac.uk/mineralsuk/statistics/wms.cfc?method=searchWMS.

Comtois, C. and Slack, B. (2016) Dynamic Determinants in Global Iron Ore Supply Chain. Available at: https://www.cirrelt.ca/DocumentsTravail/CIRRELT-2016-06.pdf.

[97] The results are scaled by dividing the calculated EI score by the value of the largest manufacturing sector NACE Rev. 2 at the 2-digit level and multiplied by 10, in order to reach the value in the scale between 0-10.

Department of Industry and Science, I. and (2019) Resources and Energy Quarterly. June 2019, Australian Government. Available at: https://publications.industry.gov.au/publications/resourcesandenergyquarterlyjune2019/index.html.

DERA (2019) 'Chart des Monats, Juli 2019. Brasilianische Lieferrückgänge und chinesischer Stahlboom'. Available at: https://www.deutsche-rohstoffagentur.de/DERA/DE/Publikationen/Chart_des_Monats/cdm_node.html.

DG ENV (2010) Green Public Procurement: Windows Technical Background Report, Report for the European Commission – DG Environment by AEA, Harwell.

Eggert, A. (2018) 'EU Steel Industry. EUROFER. Conference presentation: Coal to Steel – Responsible Mining & Sustainable Steel Brussels, 27 June 2018'. Brussels. Available at: https://www.coaltosteel.eu/.

ESTAT Comext (2019) Easy Comext database. Available at: http://epp.eurostat.ec.europa.eu/newxtweb/.

EUROFER (2015) Steel and the Circular Economy. Available at: http://www.eurofer.eu/News&Events/Press releases/Steel and the Circular Economy.fhtml.

EUROFER (2016) Steel, the Backbone of Sustainability in Europe. Available at: http://www.eurofer.eu/News&Events/Press releases/Steel and the Circular Economy.fhtml.

EUROFER (2019a) European Steel in Figures. Available at: http://www.eurofer.org/News%26Events/News/20190703 European Steel in Figures 2019.fhtml.

EUROFER (2019b) European Steel in Figures (2009-2018). Available at: http://www.eurofer.org/News%26Events/Publications.itpl.

EUROFER (2019c) Facts & Figures. Crude steel production. Available at: http://www.eurofer.org/Facts%26Figures/Crude Steel Production (Accessed: 11 November 2019).

EUROFER (2019d) Made of Steel. Available at: http://www.eurofer.org/About us/About Steel/Made of Steel.fhtml (Accessed: 12 November 2019).

Euromines (2019) 'The raw materials contribution to the implementation of the EU Sustainable Finance Action Plan'. Available at: http://www.euromines.org/news/euromines-position-on-the-eu-sustainable-finance-action-plan.

European Commission (2011) Critical raw materials. Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en (Accessed: 8 July 2019).

European Commission (2014) Report on critical raw materials for the EU. Non-Critical Raw Materials Profiles.

European Commission (2016) 'COM(2016)155. Steel: Preserving sustainable jobs and growth in Europe'. Brussels,.

European Commission (2017) Study on the review of the list of critical raw materials. Non-Critical Raw Materials Factsheets. European Commission. doi: 10.2873/876644.

European Commission (2018a) 'Commission Implementing Regulation (EU) 2018/1013 of 17 July 2018 imposing provisional safeguard measures with regard to imports of certain steel products', 2018(669). Available at: https://eur-lex.europa.eu/eli/reg_impl/2018/1013/oj.

European Commission (2018b) European Steel - The Wind of Change -Energy in Future Steelmaking -Steel in the Energy Market Applications -Greening European Steel, EU Publications. doi: 10.2777/236603.

European Commission (2018c) European Steel - The Wind of Change -Energy in Future Steelmaking -Steel in the Energy Market Applications -Greening European Steel, EU Publications. doi: 10.2777/236603.

European Commission (2018d) In-depth analysis in support of the Commission Communication COM(2018)/773. 'A Clean Planet for all. A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy'. Available at: https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf.

European Commission (2019) 'Commission Implementing Regulation (EU) 2019/159 of 31 January 2019 imposing definitive safeguard measures against imports of certain steel products', 2019(January), pp. 1–48. Available at: https://ec.europa.eu/commission/presscorner/detail/en/IP_19_821.

Eurostat (2019) Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). Available at: https://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2 (Accessed: 7 July 2019).

Fastmarkets MB (2018) Iron ore pricing explained. Available at: https://www.metalbulletin.com/Article/3811904/Iron-ore-pricing-explained.html (Accessed: 16 September 2019).

Financial Times (2016) How is iron ore priced? Available at: https://www.ft.com/content/aeaaddf4-e5de-11e5-a09b-1f8b0d268c39 (Accessed: 16 September 2019).

FODD (2017) Fennoscandian Mineral Deposits, Fennoscandian Ore Deposit database. V.2017.

FOREGS (2006) Fe-Iron. Geochemical Atlas of Europe (FOREGS). Electronic version. EuroGeoSurveys. Available at: http://weppi.gtk.fi/publ/foregsatlas/text/Fe.pdf.

General Motors (2012) 'Future Material Opportunities and Direction for Lightweighting Automotive Body Structures.', Advanced High-Strength Steels for Automotive Lightweighting. Southfield, Michigan. doi: 10.2202/1555-5879.1266.

Le Gleuher, M. (2019) La chute du prix du minerai de fer : surproduction et affaiblissement de la demande chinoise en acier, BRGM Minéralinfo. Available at: http://www.mineralinfo.fr/ecomine/chute-prix-minerai-fer-surproduction-affaiblissement-demande-chinoise-en-acier (Accessed: 10 November 2019).

Government of India (2016) 'Notification No. 1/2016-Customs, Dated: January 4, 2016', pp. 1–2. Available at: https://taxguru.in/custom-duty/notification-12016customs-dated-january-4-2016.html.

Graedel, T. et al. (2015a) 'On the materials basis of modern society. Supporting information file', Proceedings of the National Academy of Sciences of the United States of America. National Academy of Sciences, pp. 6295–300. doi: 10.1073/pnas.1312752110.

Graedel, T. et al. (2015b) 'On the materials basis of modern society', Proceedings of the National Academy of Sciences, 112(20). doi: 10.1073/pnas.1312752110.

GTK (2019) 'Hannukainen Mineral Deposit Report', pp. 1–26.

Hannans Reward Ltd (2019) Kiruna Project. Available at: https://hannans.com/mobile/sweden-iron-m.php#rakDep (Accessed: 12 November 2019).

Hannukainen Mining (2019) Mining history of Kolari - Tapojärvi Oy. Available at: https://www.hannukainenmining.fi/en/hannukainen-mining/mining-history-of-kolari.html (Accessed: 12 November 2019).

IIMA (2019) Home. International Iron Metallics Association. Available at: https://www.metallics.org/ (Accessed: 23 November 2019).

Liao, G. (2017) 'Lightweight Materials for Automotive Applications'. Available at: https://atecentral.net/downloads/1585/Lightweight_Materials_for_Automotive.pdf.

LKAB (2018) 2017 Annual and Sustainability Report. Available at: https://www.lkab.com/en/investors/financial-reports/annual-and-sustainability-reports/.

LKAB (2019) '2018 Annual and Sustainability Report'. Available at: https://www.lkab.com/en/about-lkab/financial-information/financial-reports/annual-and-sustainability-reports/.

Löf, A. and Ericsson, M. (2016) Iron Ore Market Report—2016 |, Engineering and Mining Journal. Available at: https://www.e-mj.com/features/iron-ore-market-report-2016/ (Accessed: 17 September 2019).

McKinsey (2014) Lightweight, heavy impact. How carbon fiber and other lightweight materials will develop across industries and specifically in automotive. Available at: https://www.mckinsey.com/~/media/mckinsey/dotcom/client_service/automotive and assembly/pdfs/lightweight_heavy_impact.ashx.

Minerals4EU (2019) European Minerals Yearbook. Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html.

Mouritz, A. P. (2012) 'Introduction to aerospace materials'.

OECD (2019a) Export Restrictions on Industrial Raw Materials. Available at: https://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials (Accessed: 5 July 2019).

OECD (2019b) Global Material Resources Outlook to 2060, Global Material Resources Outlook to 2060. doi: 10.1787/9789264307452-en.

Passarini, F. et al. (2018) Material flow analysis of aluminium, copper, and iron in the EU-28. Joint Research Centre. European Commission. doi: 10.2760/1079.

Rao, S. et al. (2018) Infosys, Carbon composites are becoming competitive and cost effective. Available at: https://www.infosys.com/engineering-services/white-papers/Documents/carbon-composites-cost-effective.pdf (Accessed: 3 July 2019).

Rudnick, R. L. and Gao, S. (2014) Composition of the Continental Crust, Treatise on Geochemistry: Second Edition. Elsevier Ltd. doi: 10.1016/B978-0-08-095975-7.00301-6.

S&P Global (2019a) Analyst views on iron ore majors mixed amid price rally.

S&P Global (2019b) Commodity briefing Service. Iron Ore. May 2019.

S&P Global (2019c) Iron ore CBS April 2019. Back to scarcity price profile of 2012.

S&P Global (2019d) S&P Global Market Intelligence. Commodity profile. Iron Ore, Market Intelligence Platform.

Sonter, L. J. et al. (2014) 'Global demand for steel drives extensive land-use change in Brazil's Iron Quadrangle', Global Environmental Change. doi: 10.1016/j.gloenvcha.2014.03.014.

The Construction Index (2012) Steel grows market share in key sectors. Available at: https://www.theconstructionindex.co.uk/news/view/steel-grows-market-share-in-key-sectors (Accessed: 16 September 2019).

UN Comtrade (2019) International Trade Statistics Database. Available at: https://comtrade.un.org/ (Accessed: 8 July 2019).

UNEP (2011) Recycling Rates of Metals – A Status Report, A Report of the Working Group on the Global Metal Flows to the International Resource Panel., Group. doi: ISBN 978-92-807-3161-3.

UNEP (2013) Metal Recycling: Opportunities, Limits, Infrastructure, A Report of the Working Group on the Global Metal Flows to the Inter- national Resource Panel.

United Nations (2019) 2019 Revision of World Population Prospects. Available at: https://population.un.org/wpp/ (Accessed: 12 November 2019).

USGS (2018a) 2015 Minerals Yearbook. Iron and Steel, The United States Geological Survey. doi: 10.1016/j.ijporl.2012.07.018.

USGS (2018b) 2015 Minerals Yearbook. Iron Ore, The United States Geological Survey. doi: 10.1016/j.ijporl.2012.07.018.

USGS (2019a) 2015 Minerals Yearbook. Germany. Available at: https://www.usgs.gov/centers/nmic/europe-and-central-eurasia#au.

USGS (2019b) 2015 Minerals Yearbook. Sweden. Available at: https://www.usgs.gov/centers/nmic/europe-and-central-eurasia#au.

USGS (2019c) 2016 Minerals Yearbook. Austria. Available at: https://www.usgs.gov/centers/nmic/europe-and-central-eurasia#au.

USGS (2019d) Mineral Commodity Summaries 2019. U.S Geological Survey. doi: 10.1007/978-3-540-47108-0-4.

VA Erzberg (2019) Tagbau, VA Erzberg GmbH' website. Available at: http://www.vaerzberg.at/erzproduktion.html (Accessed: 16 September 2019).

Wasylycia-Leis, J., Fitzpatrick, P. and Fonseca, A. (2014) 'Mining communities from a resilience perspective: Managing disturbance and vulnerability in Itabira, Brazil', Environmental Management. Springer New York LLC, 53(3), pp. 481–495. doi: 10.1007/s00267-014-0230-1.

Wilson, J. (2015) Iron ore fundamentals, BHP website. Available at: https://www.bhp.com/media-and-insights/reports-and-presentations/2015/06/iron-ore-fundamentals (Accessed: 17 September 2019).

World Bank (2019) Commodity Price Data (The Pink Sheet), Commodity Markets. Available at: https://www.worldbank.org/en/research/commodity-markets (Accessed: 2 July 2019).

World Coal Association (2019) How is Steel Produced? Available at: https://www.worldcoal.org/coal/uses-coal/how-steel-produced (Accessed: 23 November 2019).

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

WorldSteel (2001) 'World Steel Association. Steel Statistical Yearbook 2001', pp. 1–7. Available at: https://www.worldsteel.org/steel-by-topic/statistics/steel-statistical-yearbook.html.

WorldSteel (2012) 'Sustainable steel. At the core of a green economy'. World Steel Association, p. 40. doi: 10.1016/0022-3913(63)90259-2.

WorldSteel (2016) 'Steel. The Permanent Material in the Circular Economy'. World Steel Association, pp. 1–24. Available at: https://www.worldsteel.org/media-centre/press-releases/2016/steel-permanent-material-circular-economy.html.

WorldSteel (2017) 'Sustainable Steel – Indicators 2017 and the future'. World Steel Association, pp. 1–12. Available at: https://www.worldsteel.org/media-centre/press-releases/2017/sustainable-steel---indicators-2017-and-the-future.html.

WorldSteel (2018) World Steel Association. Steel Statistical Yearbook 2018, WorldSteel Association. Available at: https://www.worldsteel.org/steel-by-topic/statistics/steel-statistical-yearbook.html.

WorldSteel (2019a) 'Factsheet. Steel and Raw materials'. World Steel Association. Available at: https://www.worldsteel.org/steel-by-topic/raw-materials.html.

WorldSteel (2019b) Steel Markets. Available at: https://www.worldsteel.org/steel-by-topic/steel-markets.html (Accessed: 12 November 2019).

WorldSteel (2019c) World Steel Association. About Steel and Steel facts. Available at: https://www.worldsteel.org/about-steel.html (Accessed: 10 November 2019).

WorldSteel (2019d) 'World Steel in figures 2019'. Available at: https://www.worldsteel.org/media-centre/press-releases/2019/world-steel-in-figures-2019.html.

Wyns, T., Khandekar, G. and Robson, I. (2018) Industrial Value Chain: a Bridge Towards a Carbon Neutral Europe. Available at: http://www.euroalliages.com/web/low carbon economy/1011306087/list1187970084/f1.html.

13.7.2Data sources used in the criticality assessment

BGS (2019) World mineral statistics data, British Geological Survey. Available at: https://www.bgs.ac.uk/mineralsuk/statistics/wms.cfc?method=searchWMS.

WorldSteel (2018) World Steel Association. Steel Statistical Yearbook 2018, WorldSteel Association. Available at: https://www.worldsteel.org/steel-by-topic/statistics/steel-statistical-yearbook.html.

ESTAT Comext (2019) Easy Comext database. Available at: http://epp.eurostat.ec.europa.eu/newxtweb/.

Passarini, F. et al. (2018) Material flow analysis of aluminium, copper, and iron in the EU-28. Joint Research Centre. European Commission. doi: 10.2760/1079.

EUROFER (2019b) European Steel in Figures (2009-2018). Available at: http://www.eurofer.org/News%26Events/Publications.itpl.

OECD (2019a) Export Restrictions on Industrial Raw Materials. Available at: https://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials (Accessed: 5 July 2019).

European Commission (2019b) Negotiations and agreements. Available at: http://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/ (Accessed: 7 July 2019).

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

13.8Acknowledgments

This factsheet was prepared by the JRC. The authors would like to thank the Ad Hoc Working Group on Critical Raw Materials, in particular Mr Aurelio Braconi (Eurofer) and Mr Johannes Drielsma (Euromines), as well as experts participating in SCRREEN workshops for their contribution and feedback.

14. KAOLIN

14.1 Overview

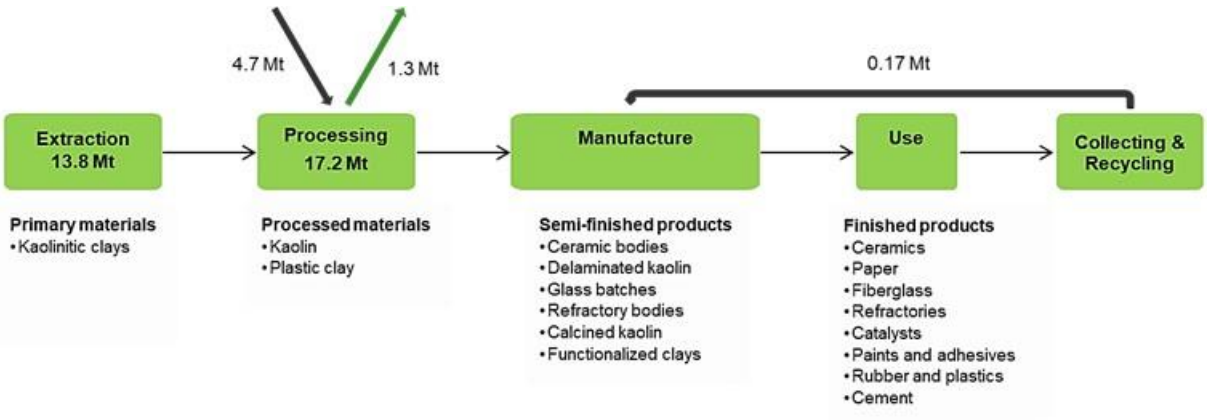


Figure 137: Simplified value chain for kaolinitic clays in the EU98 (2012-16)

Kaolin is a general term encompassing clay materials rich in kaolinite group minerals (>50%wt) derived primarily from the alteration of feldspars and micas. The name kaolin is derived from the Chinese word "kaoling" meaning *high ridge*, the name of a hill in China, where it was mined since centuries. It is a white, soft, plastic clay mainly composed of fine-grained, plate-like particles, pertai ning mainly to kaolinite group minerals: kaolinite, dickite, nacrite, and halloysite (Murray, 2006,Pruett, 2006; McCuistion, 2006).

In previous assessments, it was named alternatively "kaolin" or "kaolinitic clays". For sake of clarity, here "kaolinitic clays" will be used as a general term, including two different raw materials: "kaolin" and "plastic clay" that come from diverse geological sources and have distinct properties and uses. Kaolinitic clays were not on the list of CRMs in 2011, 2014, and 2017.

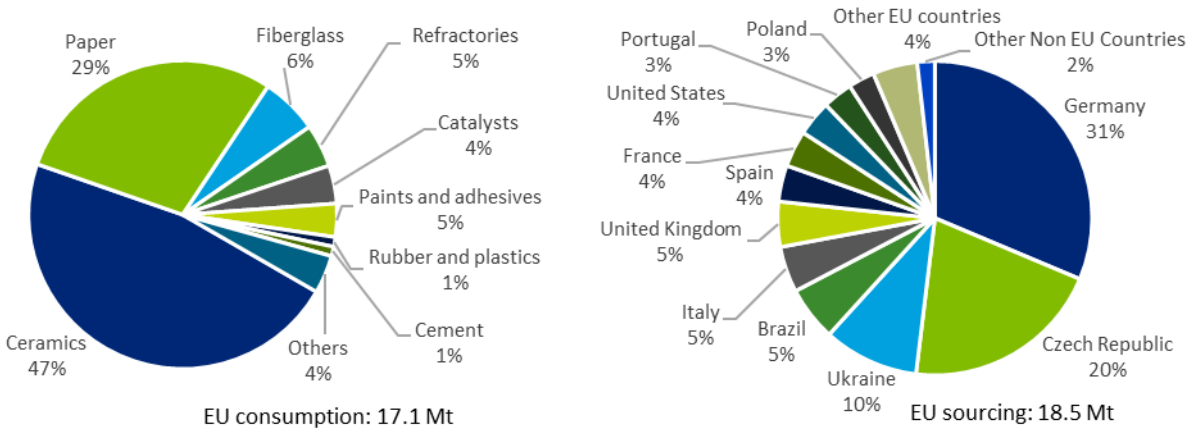


Figure 138: End-uses[99] (IMA-Europe, 2018; Dondi, 2014)and EU sourcing (WMD, 2019, Eurostat, 2019) of kaolinitic clays (2012-16).

[98] JRC elaboration on multiple soruces (see next sections)

Such raw materials go on the market with a plethora of names: kaolin (raw and calcined), ball clay, China clay, kaolinitic clay, plastic clay, kaolinitic earth, refractory clay, fireclay, halloysite, and so on. Every name should correspond to specific features, but there are no generally accepted definitions (Pruett, 2006; McCuistion, 2006). Thus, commercial terms reflect more the customs in a given sector than actual requirements about composition or technological properties.

Commercial kaolinitic clays often do not entirely fulfil the above definition: the color can vary from white to light brown; both 'soft' and 'hard' (i.e. lithified) kaolins are well-known; plasticity and particle size distribution can vary widely; along with kaolinite, other phases are usually present: quartz, feldspars, and other phyllosilicates (illite, smectite, and mixed-layers) are the most common.

In the EU, kaolin is industrially used, based on its physical and chemical characteristics, as plasticity provider in ceramic bodies; as filler and coating in paper; as filler and extender in paints, adhesives, rubber and plastics; as alumina source in fiberglass and as support for catalysts. Kaolin is marketed under various CN8 codes (Eurostat, 2019): 25070020 (KAOLIN), 25070080 (KAOLINITIC CLAY), 25083000 (FIRECLAY) and 25084000 (CLAY) .

The world market of kaolinitic clays was 57.3 Mt (average 2012-2016) growing close to 59 Mt in 2018. The value is approximately 6,500 million €, expected to keep steady to 2020. It is distinct in kaolin (about 38.7 Mt for a turnover around 5,000 million EUR and plastic clays (about 18.5 Mt for a turnover around 1,500 million EUR). The majority of kaolin is sold on the open market and only in part traded on annual contracts. The prices fluctuated in the period 2012-2018 between EUR 150 to EUR 200 per tonne for kaolin and in the range EUR 50-100 per tonne for plastic clays. According to trade values (Eurostat, 2019) the average price of kaolin imported to the EU increased by ~7% from EUR 145 per tonne (2011) to EUR 160 per tonne (2018). A similar price growth occurred, in the same period, for plastic clays: the average value of imports to the EU grew by ~7% from EUR 64 to EUR 68 per tonne.

The EU consumption of kaolinitic clays is around 18.5 Mt (61% kaolin and 39% plastic clays), which are sourced (Eurostat, 2019; WMD, 2019; BGS, 2019) through domestic production, mainly in Germany and Czechia, and importing primarily from Ukraine, Brazil and the United Kingdom. Import reliance is 24%. EU is a net importer of kaolinitic clays: ~1.4 Mt of kaolin (~21% of internal demand) and ~3.0 Mt of plastic clays (~44% of internal demand).

Kaolinitic clays are irreplaceable in the ceramic sector. There are no viable substitutes, especially for plastic clays in vitrified ceramic bodies (porcelain stoneware tiles and vitreous china sanitaryware). A limited replacement of kaolin is conceivable in the refractories, fiberglass, rubber, plastics, paints, adhesives, and cement sectors. The use of kaolin is less crucial in the catalyst and paper industries, which have apparently more alternatives.

Kaolinitic clays are currently exploited in at least 64 countries, even if 75% of the global production comes from the United States, Ukraine, China, Germany, India, Czechia, Turkey, Brazil and the United Kingdom. The EU has a share of 25% (kaolin) and 19% (plastic clays) of the world output. Resources of kaolinitic clays are considered globally large. Data on the reserves of kaolin and plastic clays are to a large extent missing or not accessible.

The world annual production of kaolinitic clays is about 57.3 Mt with 15% of production in China and 12% each in Ukraine and the United States. The EU production of around 13.7 Mt, mainly ensured by Germany and Czechia, which together account for 52% of the EU demand

[99] Average of "kaolin" and "kaolinitic clays".

(WMD, 2019; BGS, 2019). In addition, significant contributions (each accounting for 3-4% of the EU output) come from France, Spain, Portugal, Poland, and Italy. Kaolinite group minerals break down during thermal treatment above 400°C; this fact implies that in all applications where a firing occurs (ceramics, glass, refractories, cement) kaolin is destroyed and no recycling is possible (58.5% on total). In the applications where it is englobed in paints, glues, rubber and plastics, no kaolin recycling is viable. In paper recycling, different fillers and coatings are mixed, so no pure kaolin can be recovered. Some recycling is feasible among catalysts.

There are no major issues with health, regulatory or trade restrictions about kaolinitic clays.

14.2Market analysis, trade and prices

14.2.1Global market analysis and outlook

The global production of kaolinitic clays was around 57.3 Mt, as average 2012-2016 (growing up to about 59 Mt in 2018) summing 38.7 Mt of kaolin and 18.6 Mt of plastic clays (BGS, 2019; WMD, 2019; USGS, 2018). These data are conservative and probably do not account for a significant share of kaolinitic raw materials exploited directly by end-users (especially in the ceramic sector) which are out of trade statistics. However, available production data are not always clearly identifiable, whether referred to processed kaolin (washed) or to raw kaolin. The raw-to-washed ratio is 3:1 to 5:1 in most kaolin deposits. The major kaolin producers in 2018 are: United States (7.3 Mt), Germany (4.3 Mt), India (4.1 Mt), Czechia (3.5 Mt), China (3.2 Mt), Brazil (2.0 Mt), Turkey (1.9 Mt), Ukraine (1.8 Mt), Kyrgyzstan (1.3 Mt), and United Kingdom (1.0 Mt). The major producers of plastic clays are: Ukraine (5.5 Mt), China (4.0 Mt), Turkey (1.6 Mt), Germany (1.5 Mt), United States (1.0 Mt), United Kingdom (0.8 Mt), Malaysia and India (both 0.6 Mt).

The world production has been trending upward in the last decade: kaolin output increased on average 500 kt per year since 2009 to 2016, but it boomed in 2017 with +5 Mt, mostly due to a boost in the United States, India, Germany and Czechia. It is not sure whether this abrupt increment is real or effect of any change in statistical data collection. Although complete annual series of data are not available for plastic clays, the tendency over time seems to be parallel to kaolin and a net increment is registered by the major suppliers in the last decade, particularly Ukraine.

The global demand is expected to keep growing, even though the market should reflect the evolution in the different end-use sectors: steady for paper, refractories, catalysts; moderate growth for ceramics, paints, rubber and adhesives; significant increase for cement and fiberglass; contraction for plastics. In the incoming years, the overall rate growth in the demand of kaolinitic clays could be reasonably set around 500 kt per year.

Table 68: Qualitative forecast of supply and demand of kaolin

Material	Criticality of the material in 2017		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Kaolin		X	+	+	+	+	+	=
Plastic clay		X	+	+	+	=	-	?

There are critical factors that can drastically alter the present picture, in a different way for kaolin (basically obtained though mineralurgical processing of primary deposits) and plastic

clays (mainly recovered by selective mining of sedimentary deposits). At a global level, all the mining districts producing kaolinitic plastic clays suffer from increasing extraction cost (thick coverage) and decreasing quality (reserves are richer in iron oxide and more refractory). The risk of exhaustion is tangible in many clay deposits, unless the end-users relax their technical expectations. Kaolin supply chain is less prone to short-time changes.

14.2.2EU trade

EU trade is analysed using product group codes (Eurostat, 2019). Kaolinitic clays are marketed under various CN8 codes: 25070020 (KAOLIN), 25070080 (KAOLINITIC CLAY), 25083000 (FIRECLAY) and 25084000 (CLAY). It is possible that materials are part of product groups also containing other materials and/or being subject to re-export, the "Rotterdam-effect".

The trend in recent years shows that the EU is increasingly dependent on kaolinitic clays from outside the EU (Eurostat, 2019). The situation is rather steady for kaolin, but denotes a clear upward demand for plastic clays that apparently relaxed in 2018.

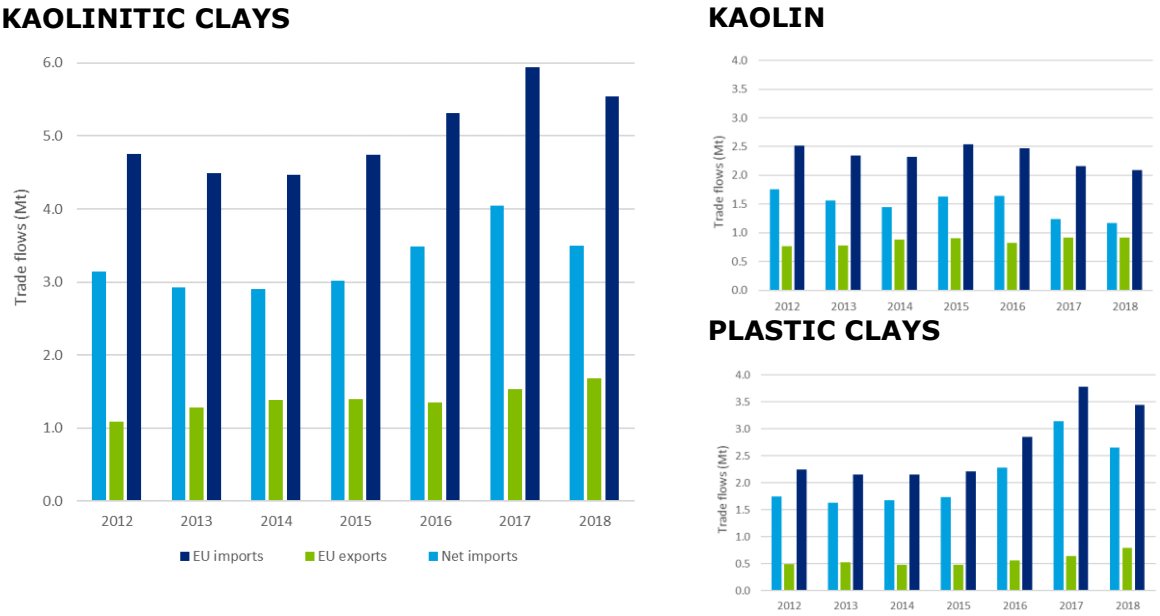


Figure 139: EU trade flows[100] for kaolinitic clays (average 2012-2016) and separately for kaolin and plastic clays (Eurostat, 2019)

The EU is a net importer of kaolinitic clays: about 4.7 Mt per year in the period 2012-2016, for an average annual value of EUR 450 million, versus an export averaging 1.3 Mt per year and 220 EUR million. The trend is increasing from 3.6 Mt in 2014 (Eurostat, 2019).

Kaolinitic clays are mainly imported from Ukraine, Brazil, the United Kingdom and the United States. High-quality raw materials are imported, because they are not produced in the EU in sufficient quantity or the quality does not meet industry standards (Pruett, 2006; McCuistion, 2006; Dondi, 2014). This is the case of kaolin for the paper industry (imported from Brazil, UK and US) as well as plastic clays for ceramic tiles (from Ukraine) or tableware and sanitaryware (from UK). Kaolin accounts for 38% of import in quantity, but 61% in value (Eurostat, 2019).

[100] 2017 and 2018 data not used in criticality calculations

There are EU free trade agreements in place with Turkey (Customs Union) as well as Ukraine, Serbia and Morocco (European Commission, 2019). There are no exports quotas or prohibition in place between the EU and its suppliers (OECD, 2019).

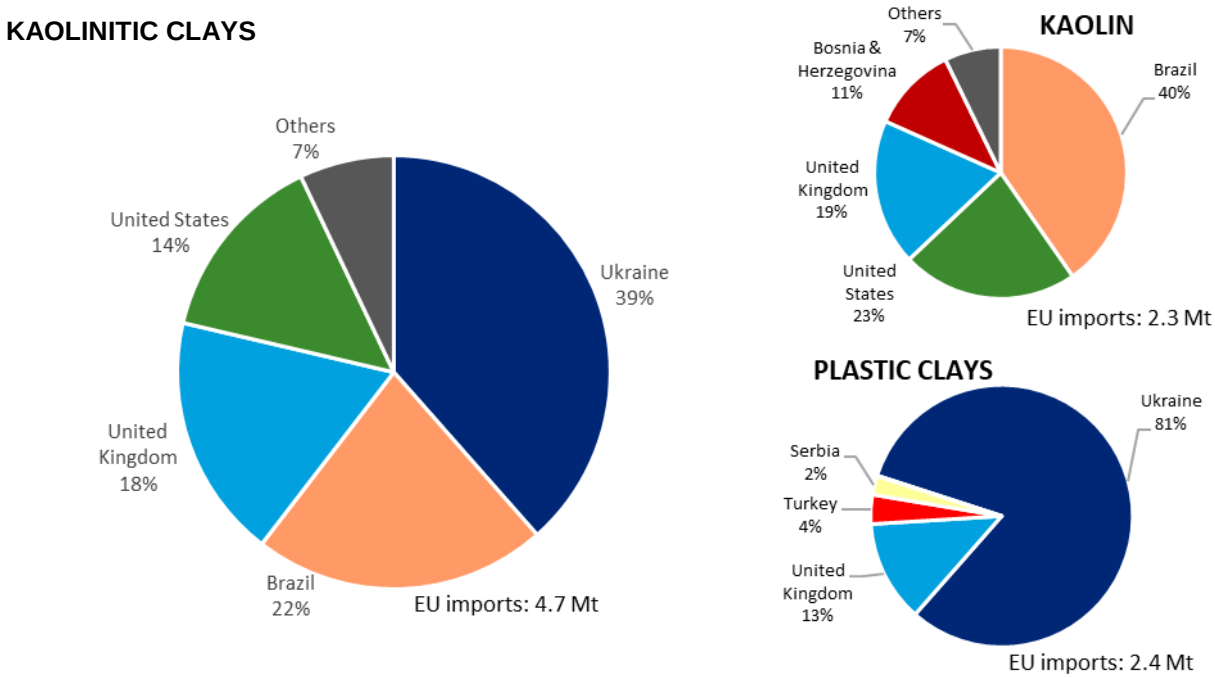


Figure 140: EU imports of kaolinitic clays (average 2012-2016) and separately for kaolin and plastic clays (McCuistion, 2006; Eurostat, 2019)

14.2.3 Prices and price volatility

Prices are around EUR 150-200 per tonne for kaolin and EUR 50-100 per tonne for plastic clays. According to trade values (Eurostat, 2019) the average price of kaolinitc clays imported to the EU increased moderately in the period 2011-2014, then peaked in 2015 to +15% (kaolin) and +22% (plastic clays). The values went down in the latest years and the overall price increment is close to 7%: from EUR145 per tonne (2011) to EUR 160 per tonne (2018) for kaolin, and from EUR 64 per tonne (2011) to EUR ~68 per tonne (2018) for plastic clays.

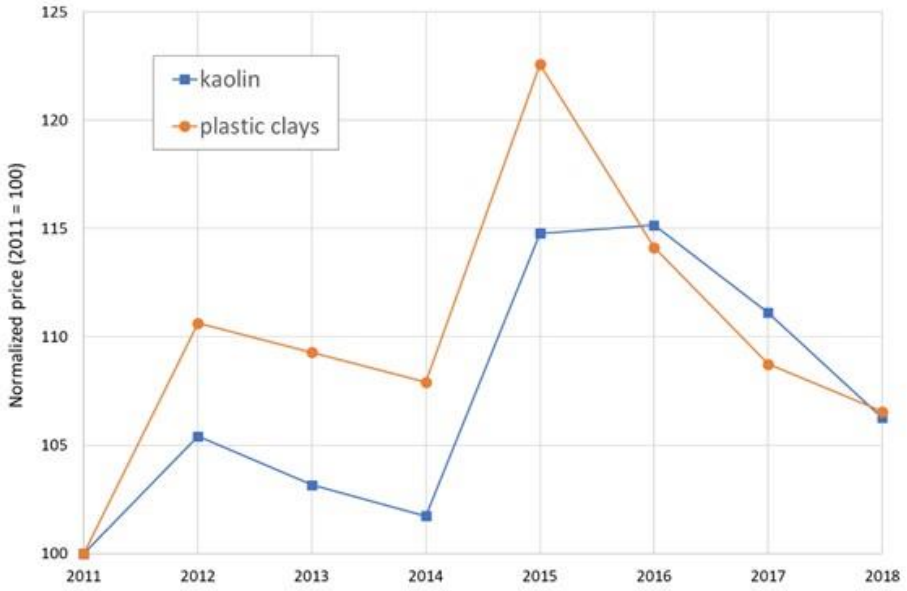


Figure 141: Price of kaolinitic clays imported in the EU, normalized to the average 2011 price, elaborated after (Eurostat, 2019)

14.3EU demand

14.3.1EU demand and consumption

The EU consumption of kaolinitic clays was about 17.1 Mt per year (61% kaolin and 39% plastic clays) by averaging the 2012-2016 period. There is a growing trend since 2014. The EU is a net importer of kaolinitic clays: 1.4 Mt of kaolin (21% of the internal demand) and 3.0 Mt of plastic clays (44% of the internal demand).

14.3.2Uses and end-uses of kaolin in the EU

Kaolinitic clays have a vast spectrum of applications that depend on the mineralogical composition and physical properties of raw materials (Murray, 2006; Pruett, 2006; McCuistion, 2006, Dondi, 2014; European Commission, 2017b). Specifications vary widely upon the end-use and distinguish commercial grades (e.g., paper coating-grade, ceramic-grade, filler-grade, glass-grade, refractory-grade). The amount of kaolinite group minerals and their particle size and degree of crystallinity are of particular commercial interest, since they influence brightness, whiteness, opacity, gloss, film strength, and viscosity. In any application, very important is the amount and type of minerals associated with kaolinite (usually quartz, feldspars, illite, interstratified clay minerals) because they affect the kaolin performance, for instance abrasiveness, plasticity, refractoriness, and rheological behavior.

The main industrial applications of kaolinitic clays are in the manufacture of ceramics, paper, fiberglass, refractories, catalysts, and paints. Minor volumes are used in the rubber, plastics, adhesives, and cement industries, along with a number of further end-users (insecticides, cosmetics, sealants, pharmaceuticals, fertilizers, etc.). Plastic clays mainly find application in ceramics and refractories, even if they can replace kaolin in most uses (USGS, 2018).

KAOLINITIC CLAYS **KAOLIN**

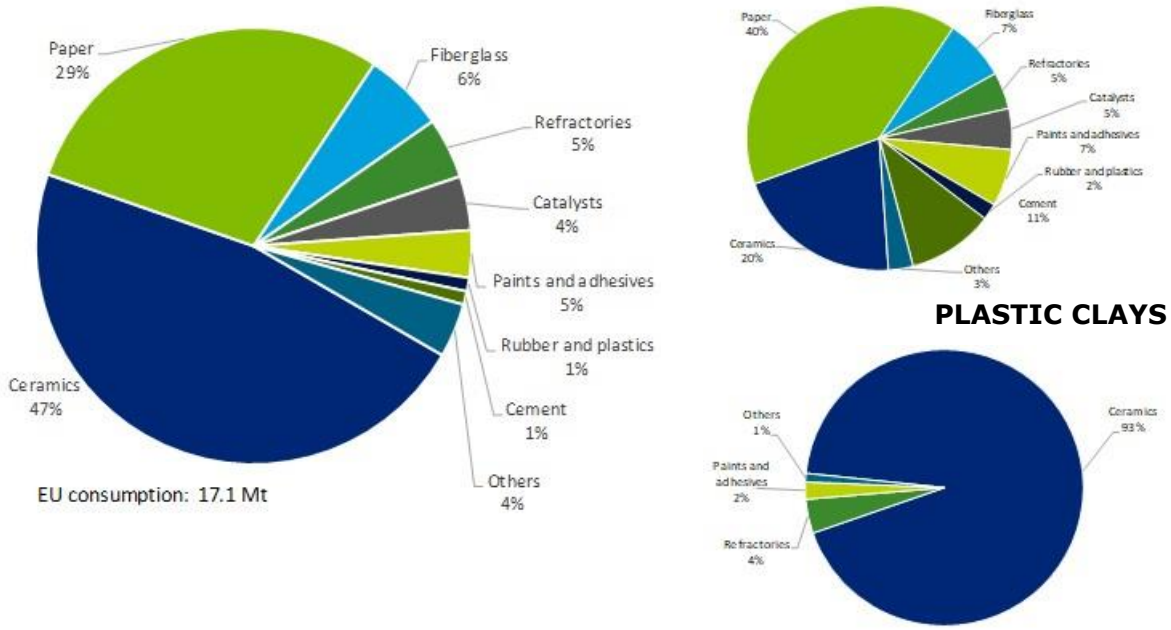


Figure 142: End uses of kaolinitic clays, average 2012-2016, and separately for kaolin and plastic clays (Dondi, 2014; IMA-Europe, 2018a).

In Europe, the most important uses of kaolin and plastic clays are summarized as follows (Dondi, 2014; IMA-Europe, 2018a):

- Ceramics and refractories: about 52% of total consumption of kaolinitic clays is destined to feed this value chain, principally floor tiles and sanitaryware, which make a large use of plastic clays, as well as refractories, tableware and glazes which utilize kaolin. Some kaolinitic clays are employed also for wall tiles and stoneware pipes. These clays provide strength and plasticity in the shaping of these products, and improve refractoriness by reducing the pyroplastic deformation in the process of firing.
- Paper: industry uses only kaolin, both as filler in the bulk paper and to coat its surface. Consumption accounts for another 29%.
- Fibreglass and cement: kaolin is commonly used as alumina supplier in the glass and cement batches, requiring 7% of total consumption.
- Catalysis, with kaolin as support for catalyzers, justifies about 4% of the total demand.
- Others: kaolin plays as filler and extender in paints, rubber, plastics, cosmetics, and pharmaceuticals, for a total share around 8%.

Table 69: Kaolin applications (IMA-Europe, 2018a), 2-digit NACE sectors and value added per sector (Eurostat, 2019)

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (M€)
Ceramics	C23 - Manufacture of other non-metallic mineral products	23.31, 23.42, 23.41, 23.4	57,255
Paper	C17 - Manufacture of paper and paper products	17.1	38,910
Fiberglass	C23 - Manufacture of other non-metallic mineral products	23.14	57,255
Refractories	C23 - Manufacture of other non-metallic mineral products	23.2	57,255
Catalysts	C19 - Manufacture of coke and refined petroleum products	19.2	17,289

Paints and adhesives	C20 - Manufacture of chemicals and chemical products	20.30, 20.52	105,514
Rubber and plastics	C22 - Manufacture of rubber and plastic products	22.10, 22.20	75,980
Cement	C23 - Manufacture of other non-metallic mineral products	23.51	57,255

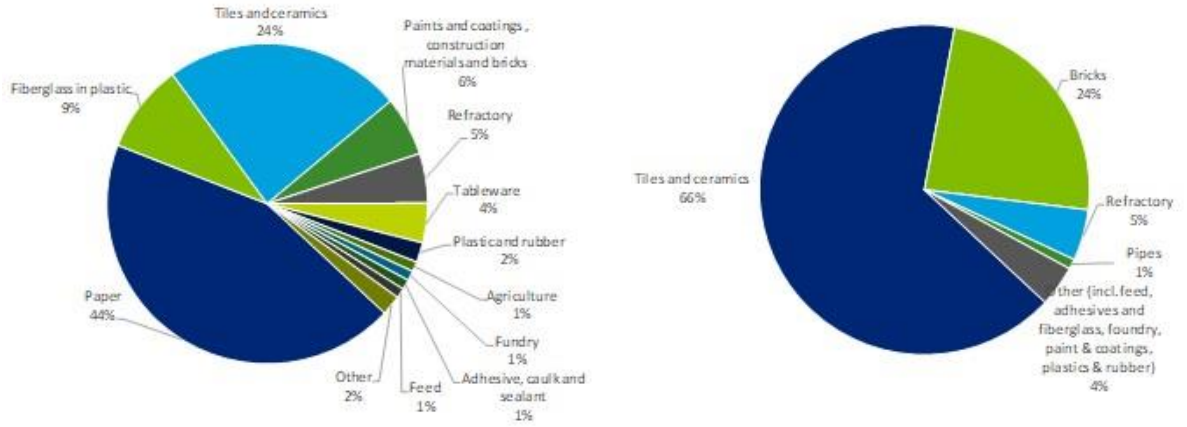


Figure 143: Market shares of kaolin (L) & clays (R) according to IMA-Europe (2018a).

14.3.3Substitution

Kaolinitic clays have a wide spectrum of applications, each having its own alternatives for kaolin or plastic clay (European Commission, 2017b; Kogel, 2006; USGS, 2018). In the field of ceramics, a typical surrogate is pyrophyllite (Dondi, 2014). In the production of paper, the main substitutes of kaolin are: talc, calcium carbonate (ground or precipitated), zeolites, diatomite, or gypsum. Feldspar could replace kaolin in the manufacture of fiberglass. In the refractories industry, kaolinitic clays can be replaced by fireclay or pyrophyllite. For catalysts, alternatives to kaolin can be found in zeolites, rare earth oxides, silica, alumina, or bauxite. Used as extender in paints and adhesives, kaolin can be substituted by calcium carbonate, talc, wollastonite, feldspar, mica, pyrophyllite, silica, diatomite, or bentonite. As a filler in rubber and plastics, kaolin can be replaced by calcium carbonate, talc, wollastonite, feldspar, mica, pyrophyllite, silica, diatomite, bentonite. In cement, substitutes are alumina or bauxite.

14.4Supply

14.4.1EU supply chain

The EU demand for kaolinitic clays is fed through domestic production and importing primarily from Ukraine, Brazil and the United Kingdom (Eurostat, 2019). Import reliance is 20%. The European producers of kaolinitic clays are: Germany (5.8 Mt), Czechia (4.0 Mt), France (0.72 Mt), Spain (0.58 Mt), Portugal (0.56 Mt), Poland (0.52 Mt), (Italy 0.51 Mt), Bulgaria (0.32 Mt), Belgium (0.30 Mt), plus 0.26 Mt from others (Romania, Hungary, Austria and Slovakia).

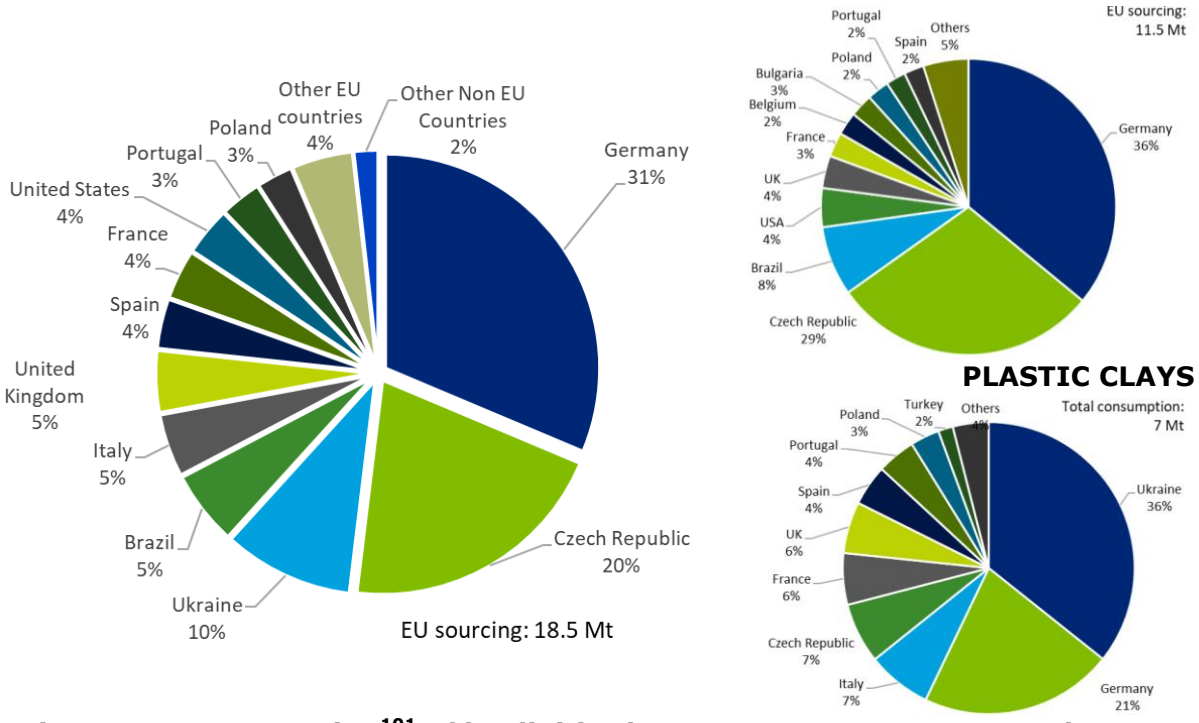


Figure 144: EU sourcing[101] of kaolinitic clays, average 2012-2016, and separately of kaolin and plastic clays (Eurostat, 2019; BGS, 2019; WMD, 2019; USGS, 2018)

14.4.2Supply from primary materials

14.4.2.1 Geology, resources and reserves of kaolinitic clays

Geological occurrence: Deposits of kaolinitic clays, in all sizes, can be found all over the world (Murray, 2006,Pruett, 2006; McCuistion, 2006). Kaolinitic clays may occur as primary or secondary ore, where the primary type is quintessentially kaolin, originated by alteration of igneous or metamorphic rocks for action of hydrothermal fluids or weathering. The secondary type, typically plastic clays, is sedimentary and formed through erosion, transportation and deposition of mineral particles. Kaolin is formed by alteration of feldspar-rich rocks, like granite or rhyolite, through weathering or hydrothermal processes. The process which converted the parent rock into the soft matrix found in kaolin pits is known as "kaolinisation" (Murray, 2006; Pruett, 2006). Some primary minerals (e.g., quartz, anatase) remain substantially unaffected, whilst feldspars are transformed into kaolinite group minerals (the most common being kaolinite and halloysite) and sometimes other phyllosilicates (illite, smectite, mixed layers).

Global resources and reserves: Kaolinisation is a common process by which a wide range of feldspathic rocks can be transformed, through weathering or hydrothermal action, into a product with a variable degree of alteration (hence different kaolinite content). On this basis, resources of kaolinitic clays are considered extremely large and widespread. In reality, there are many technological constraints in the various industrial applications that significantly restrict the resources actually useful for end-users (Pruett, 2006; McCuistion, 2006; Dondi, 2014). This is crucial for plastic clays, which reserves appear to be not so extended as previously thought, at variance of kaolin, which can be beneficiated by mineralurgical treatments. Major kaolin reserves are located in the United States (Georgia), Australia, Brazil

[101] IMA-Europe estimates are 13 Mt

(Jari, Capim), Germany (Bavaria, Saxony), the UK (Cornwall, Devon), Czechia (Karlovy Vary, Pilsen), France (Bretagne), Ukraine, Poland, China and India.

There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of kaolin and plastic clays in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not make accessible data on reserves. Individual companies may publish mineral resource and reserve reports, but by a variety of systems of reporting, often depending on the location of their operation, their corporate identity and stock market requirements. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

Table 70: Global reserves of kaolininitic clays (Minerals4EU, 2019)

Country	Reporting code	Quantity	Unit	Grade	Code Resource Type
Czechia	National reporting code	225.1 506.0	Mt	kaolin	Economic explored Economic prospected
Slovakia	None None	22.2 5.9	Mt	kaolin	Verified Z1 Probable Z2
Spain	none	93.8	Mt	kaolin	Proven reserves
Ukraine	Russian classification	1.6 137.9	Mt	kaolin kaolin	A B
United Kingdom	National reporting code	>50.0 52.0	Mt	kaolin ball clay	Permitted reserves Permitted reserves

EU resources and reserves*:* For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for kaolin and plastic clays. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for kaolin, but this information does not provide a complete picture for Europe (Minerals4EU, 2019). It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). Many documented resources in Europe are based on historic estimates and are of little current economic interest.

Known resources of kaolinitic clays exist in most EU countries, but limited quantitative data are available. The Minerals4EU database has filed 534 kaolin deposits and 82 occurrences, but this information is limited to some countries (mainly Spain, Portugal, France, and Czechia). Kaolin deposits are well known in Belgium, Bulgaria, Czechia, France, Germany, Italy, Poland, Portugal, Romania, and Spain (where mines are in operation). Limited or discontinued production is recorded also in Austria, Denmark, Finland, Greece, Hungary, Slovakia, and Sweden.

Plastic clays are currently exploited in Austria, Czechia, France, Germany, Italy, Poland, Portugal, Romania, Slovakia, and Spain. In addition, limited or discontinued production is recorded also in Bulgaria, Croatia, and Hungary.

Table 71: Resource data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2019)

Country	Reporting code	Q.ty	Unit	Grade	Code Resource Type

Poland	National report. code	139.1 73.6	Mt	—	A+B+C1 C2+D
Czechia	National report. code	460.0 25.1	Mt	—	Potentially economic P1
Hungary	Russian classification	1.7	Mt	1.6 t/m^3	A+B
Slovakia	None None None	22.2 5.9 3.6	Mt	—	verified Z1 probable Z2 subeconomic

14.4.2.2 World production

The World production of kaolinitic clays was about 57 Mt (average 2012-2016) growing up to 59 Mt in 2018, with a clear upward trend from about 49 Mt in 2010 (BGS, 2019; WMD, 2019; USGS, 2018). Summing the figures for kaolin and plastic clays, the main producers at a global level are: China (8.8 Mt), Ukraine (7.1 Mt[102]), United States (6.9 Mt), Germany (5.8 Mt), India (4.9 Mt), the Czechia (3.8 Mt), and Turkey (3.1 Mt). Looking separately at kaolin and plastic clays, this picture changes appreciably. The global output of kaolin grew from 31.5 Mt (2010) to 38.5 Mt (2018) with the United States as the largest producer (7.3 Mt) followed by Germany (4.3 Mt), India (4.1 Mt), the Czechia (3.5 Mt), China (3.2 Mt), Brazil (2.0 Mt), Turkey (1.9 Mt) and Ukraine (1.8 Mt). The global production of plastic clays passed from 17.5 Mt (2010) to 20.5 Mt (2018). Leading suppliers are: Ukraine (5.5 Mt) and China (4.0 Mt) followed by Turkey (1.6 Mt), Germany (1.5 Mt) and the United States (1.0 Mt).

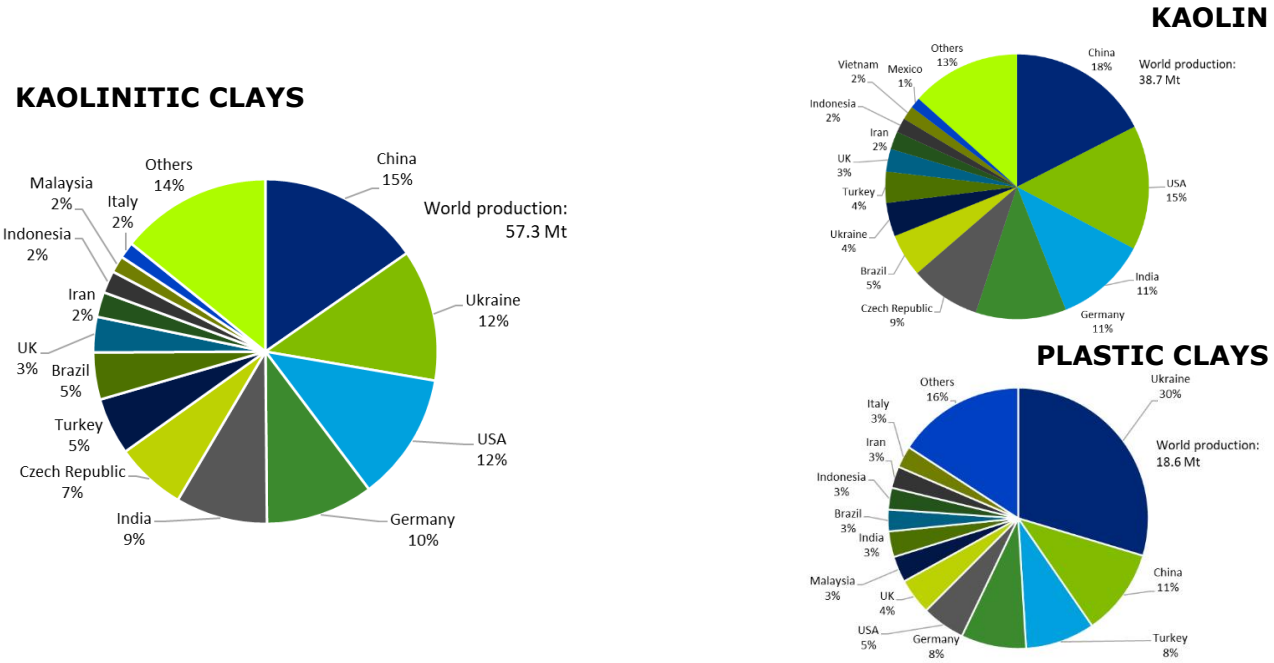


Figure 145: Global mine production[103] of kaolinitic clays, average 2012-2016.

[102] WMD reports circa 2 Mt

[103] Ukraine includes 1.8 Mt kaolin + 5.5 Mt plastic clays

14.4.3Supply from secondary materials

End of life recycling input rate for kaolin is estimated to be approximately 1%. This is due to the fact that many applications (ceramics, glass, refractories, cement, etc.; on the whole about 60% of total consumption) entail a thermal treatment above 400°C, during which any kaolinite group mineral is destroyed and no direct recycling is possible. In the applications where kaolin is englobed in paints, glues, rubber, plastics (and so on) no recycling is viable, because kaolinite crystals are firmly retained in the matrix. In paper recycling, different types are mixed, each having its own mineral filler and/or coating, so kaolinite occurs admixed with calcium carbonate, talc, etc and no "pure" kaolin can be recovered. Some recycling is feasible among catalysts (SCRREEN workshops, 2019).

14.4.4Processing of kaolinitic clays

A clear distinction exists in the processing of kaolin and plastic clays (Pruett, 2006; McCuistion, 2006). Kaolin mining and processing always entail an enrichment of kaolinite group minerals through separation of other components of the raw deposit. Plastic clays are extracted by selective mining and their mineralurgical treatment is aimed at obtaining the physical status required by different end-users and it usually does not involve any separation. Therefore, plastic clays are usually processed into various forms (McCuistion, 2006): shredded (in lumps with natural humidity), mechanically dried (in lumps with a lower humidity), air-floated (in dry powder), and slurry (as water suspension ready for slip casting). In contrast, kaolin processing is technically complicated and constitutes a costly barrier for entry into many markets, where specific properties are valued, such as purity, appearance, consistency and handling characteristics (Pruett, 2006). Once raw kaolin is obtained by washing, settling and dewatering, further processing can be performed either in the wet state or in the dry state. Most kaolin employed as pigment or filler is processed by the wet route to feed the paper, rubber, plastics, paints industries, among other applications. Kaolin is typically processed in the dry state for the refractory and ceramic industries. Low grade kaolin can be sold unprocessed to cement or some ceramic manufacturers. Different kaolin categories are present on the market: airfloat, calcined, delaminated, unprocessed, and water washed. As for plastic clays, kaolin can be delivered in lumps, powder or slurry.

14.5Other considerations

14.5.1Environmental and health and safety issues

There are no major issues about health, regulatory or trade restrictions about kaolinitic clays. Since clays may contain some quartz, there might be some concern about Respirable Crystalline Silica (RCS) in the framework of the EU Directive 2017/2398 on "Protection of workers from exposure to carcinogens or mutagens at work" that implements a set of legal limits on exposure to certain substances in industrial workplaces. RCS is known to cause lung diseases in workers who are exposed high levels of it regularly for many years. However, Directive 2017/2398 has no impact upon product classification and labelling, which is ruled by other separate legislation (the CLP Regulation 1278/2008). Directive 2017/2398 addresses respirable dust generated by work processes, not the substance itself. Kaolinitic clays placed on the market is subject to the classification obligation under Regulation (EC) 1272/2008, while crystalline silica dust generated by a work process is not placed on the market and therefore is not classified in accordance with that Regulation (IMA-Europe, 2018b).

14.5.2Socio-economic issues

EU imports of plastic clays rely more than 80% on supply from Ukraine, where clays are mined in an area of approximately 30 km^2 in the Donbas (Donetzk Basin). Such a mining district is comprised in the conflict zone between Ukraine and Russia. This uncertain situation introduced additional supply chain risks, in particular in terms of access to the Ukrainian ports on the Black Sea.

14.6Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. In the current edition, supply risk has been analysed for kaolinitic clays (kaolin + plastic clays), also with the objective of improving the granularity of previous assessments, where a more generic term kaolin was used. The results of this and earlier assessments are shown in Table 72.

Table 72: Economic importance and supply risk results for kaolin in the assessments of 2011, 2014, 2017, 2020 (European Commission, 2011-2014-2017)

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Kaolinitic clays	4.44	0.33	4.77	0.30	2.3	0.5	2.44	0.40

Although it appears that the economic importance of kaolinitic clays has reduced between 2014 and 2017, this is a false impression created by the change in methodology. Since 2017, the value added criticality assessment corresponds to a 2-digit NACE sector rather than a 'megasector', which was used in the previous assessments. The supply risk since 2011 fluctuated between 0.3 and 0.5, and 2020 assessment scores 0.40. Nevertheless, recent trends are changing significantly the picture for kaolinitic plastic clays, with a strong increase of the EU import reliance and supply coming from a particular mining district situated in a conflict zone (Donbass, Ukraine).

14.7Data sources

Data for the production of kaolin are available in time series, while data for plastic clays are not present in official statistics, but for some countries, and were estimated from literature and industrial reports.

14.7.1Data sources used in the factsheet

BGS (2019). World Mineral Production 2013-2017. British Geological Survey, Available at: https://www.bgs.ac.uk/mineralsuk/statistics/worldStatistics.html

Dondi, M., Raimondo, M., Zanelli, C. (2014). Clays and bodies for ceramic tiles: Reappraisal and technological classification. Applied Clay Science, 96 (2014) 91-109.

European Commission (2011). Materials. Critical raw materials for the EU, Report of the Ad-hoc Working Group on defining critical raw materials.

European Commission (2014). Communication On the Review of the List of Critical Raw Materials for the EU and the Implementation of the Raw Materials Initiative, COM(2014)297final. Brussels.

European Commission (2017a). Communication on the List of Critical Raw Materials 2017, COM(2017) 490 Final. Brussels.

European Commission (2017b). Study on the review of the list of Critical Raw Materials – Non-critical raw materials factsheets. DG Internal Market, Industry, Entrepreneurship and SMEs (Deloitte Sust., BGS, BRGM, TNO), 476 p.

European Commission (2019). DG Trade. Agreements [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/

Eurostat (2019). "Easy Comext Database." http://epp.eurostat.ec.europa.eu/newxtweb/.

IMA-Europe (2018a). Recycling industrial minerals, 24 p., Brussels.

IMA-Europe (2018b). Using crystalline silica safely, White Paper, 22 p., Industrial Minerals Association, www.safesilica.eu

Kogel, J.E., Trivedi, N.C., Barker, J.M. & Krukowski, S.T. (eds.) (2006). Industrial Minerals and Rocks: Commodities, Markets and Uses, Littleton, Colorado, Society of Mining, Metallurgy and Exploration, 1565 p.

McCuistion, J., Wilson, I., (2006). Ball clays, in Industrial Minerals and Rocks: Commodities, Markets and Uses (Kogel, J.E., Trivedi, N.C., Barker, J.M. & Krukowski, S.T., eds.). Littleton, Colorado, Society of Mining, Metallurgy and Exploration, 343-356.

Minerals4EU (2019) European Minerals Knowledge Data Platform (EU-MKDP), www.minerals4eu.eu.

Murray, H. H. (2006). Kaolin applications. Developments in Clay Science, 2, 85-109, Elsevier.

OECD (2019). OECD Export restrictions on Industrial Raw Materials database. [online] Available at: http://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

Pruett, R.J., Pickering, S.M.Jr. (2006). Kaolin, in Industrial Minerals and Rocks: Commodities, Markets and Uses (Kogel, J.E., Trivedi, N.C., Barker, J.M. & Krukowski, S.T., eds.). Littleton, Colorado, Society of Mining, Metallurgy and Exploration, 383-399.

SCRREEN CRM validation workshop (2019). Expert's comment, Brussels, 11 Sep. 2019.

USGS (2018). Clay and shale, in 2015 Minerals Yearbook, Flanagan, D.M., 18 (27 pp)

USGS (2019). Clays, in Mineral Commodity Summaries, West, D.N., 48-49, U. S. Geological Survey.

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

14.7.2Data sources used in the criticality assessment

BGS (2019). World Mineral Production 2013-2017. British Geological Survey, Available at: https://www.bgs.ac.uk/mineralsuk/statistics/worldStatistics.html

Dondi, M., Raimondo, M., Zanelli, C. (2014). Clays and bodies for ceramic tiles: Reappraisal and technological classification. Applied Clay Science, 96 (2014) 91-109.

European Commission (2017b). Study on the review of the list of Critical Raw Materials – Non-critical raw materials factsheets. DG Internal Market, Industry, Entrepreneurship and SMEs (Deloitte Sust., BGS, BRGM, TNO), 476 p.

European Commission (2019). DG Trade. Agreements [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/

Eurostat (2019). "Easy Comext Database." http://epp.eurostat.ec.europa.eu/newxtweb/.

IMA-Europe (2018a). Recycling industrial minerals, 24 p., Brussels.

IMA-Europe (2018b). Using crystalline silica safely, White Paper, 22 p., Industrial Minerals Association, www.safesilica.eu

Kogel, J.E., Trivedi, N.C., Barker, J.M. & Krukowski, S.T. (eds.) (2006). Industrial Minerals and Rocks: Commodities, Markets and Uses, Littleton, Colorado, Society of Mining, Metallurgy and Exploration, 1565 p.

McCuistion, J., Wilson, I., (2006). Ball clays, in Industrial Minerals and Rocks: Commodities, Markets and Uses (Kogel, J.E., Trivedi, N.C., Barker, J.M. & Krukowski, S.T., eds.). Littleton, Colorado, Society of Mining, Metallurgy and Exploration, 343-356.

Pruett, R.J., Pickering, S.M.Jr. (2006). Kaolin, in Industrial Minerals and Rocks: Commodities, Markets and Uses (Kogel, J.E., Trivedi, N.C., Barker, J.M. & Krukowski, S.T., eds.). Littleton, Colorado, Society of Mining, Metallurgy and Exploration, 383-399.

USGS (2018). Clay and shale, in 2015 Minerals Yearbook, 2018 (advance release), 18 (27 pp) , U. S. Geological Survey.

USGS (2018). Clay and shale, in 2015 Minerals Yearbook, Flanagan, D.M., 18 (27 pp)

USGS (2019). Clays, in Mineral Commodity Summaries, West, D.N., 48-49, U. S. Geological Survey.

USGS (2019). Mineral Commodity Summaries, 2019, U. S. Geological Survey, 204 p.

WMD (2019). World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, Non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels.

14.8Acknowledgments

This factsheet was prepared by the JRC in collaboration with Mr. Michele Dondi (CNR-ISTEC, Faenza, Italy). The authors would like to thank the Ad Hoc Working Group on Critical Raw Materials, in particular Ms. Aurela Shtiza and Ms. Francesca Girardi of IMA-Europe, as well as experts participating in SCRREEN workshops for their valuable contribution and feedback.

15. LEAD

15.1 Overview

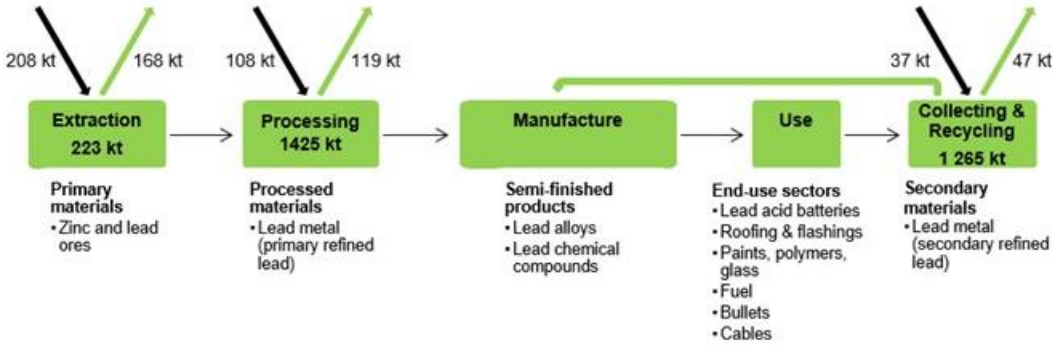
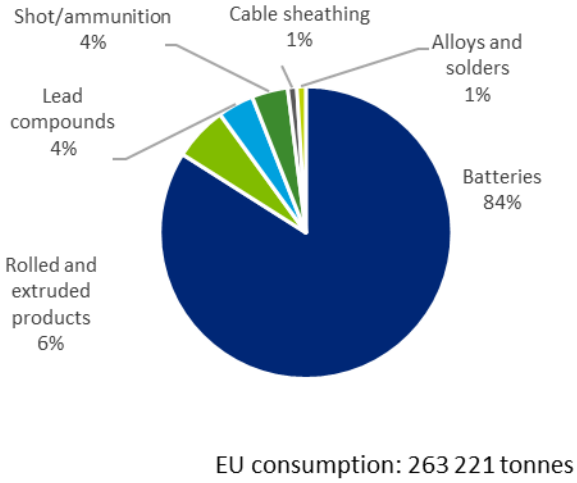


Figure 146: Simplified value chain for lead concentrates[104] for the EU, average 2012-2016

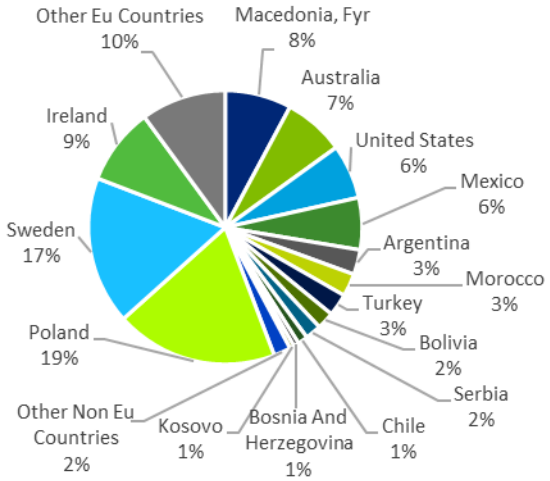
Lead (Pb) is a soft, malleable grey metal with a high density of 11.3 g/cm^3, a poor electrical conductivity and a good resistance to corrosion to most acids, including sulphuric and chromic acids. Lead is usually extracted together with zinc, silver and copper.

For the purpose of this assessment lead is analysed at both extraction and processing stages. Mine production is expressed in terms of metal content. Trade data is analysed using CN codes 26070000 which is labelled "Lead ores and concentrates" (60% lead) and 78011000 "Refined lead" containing by weight at least 99,9% of lead. Production and trade data are yearly averages over the period 2012-2016. .

Global usage of refined lead metal amounted to 11.7 million of tonnes in 2018 (International Lead and Zinc Study group, 2019). The London Metal Exchange trades a contract on ingots of lead that are 99.97% pure. Each contract represents 25 t of lead and is quoted in US dollars.



EU consumption: 263 221 tonnes



EU sourcing : 431 kt

[104] JRC elaboration on multiple sources (see next sections).

Figure 147: End uses and EU sourcing of lead concentrates(ILZSG, 2017; BGS, 2018; Eurostat, 2019)

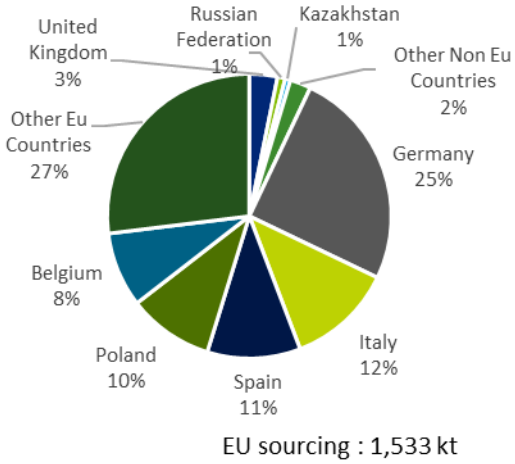


Figure 148: EU sourcing of lead concentrates(BGS, 2018; Eurostat, 2019)

The EU consumption of lead concentrates was 263 kt which were sourced through domestic production (223 kt; 52%), mainly in Poland (77 kt; 18%) and Sweden (70 kt; 16%) and imports, mostly from Peru (32 kt; 7%) and North Macedonia (31 kt; 7%).

The EU is self-sufficient in terms of lead metal supply with a domestic production of primary and secondary lead metal of 1.4 Mt. Germany is the main supplier with a production of 384 kt (27%).

Lead-acid batteries are the largest end-use sector accounting for about 85% of global lead demand. Lead is also used in a wide range of applications including roofing material, soldering alloys, plastics, paint additives. Some of these applications have been phased out in the EU over adverse health effects of lead. Lead-batteries are facing increasing competition from lithium-ion batteries in both automotive and industrial applications.
It is expected that advanced lead batteries will play an essential role as one of the leading energy storage battery technologies required to meet future needs as Europe transitions towards electrification and decarbonisation (European Association for Storage of Energy, 2019). Lead is also a key enabler in the retention of embedded energy in a circular economy, as recovery and recycling of several critical technology elements is based on metallurgical processes in which the lead acts as a carrier metal (Blanpain et al. (2019).
Identified world lead resources were approximately 2,000 Mt (metal content) (USGS, 2019). World known reserves of lead are estimated at around 83 Mt (USGS, 2019). Australia has the world's largest identified lead reserves, followed by China.

The world production of lead concentrates was 5.1 Mt per year on average between 2012 and 2016 with China accounting for 49% of the total production, followed by Australia (12%) and the United States (7%). The European production was 223 kt or 4% of the global production. Poland (77 kt), Sweden (69 kt) and Ireland (36 kt) together contributed 82% of the EU production.

World refined lead metal production amounted to 10.9 Mt (average 2012-2016) (BGS, 2018). China was the world leading supplier with 43% (4.7 Mt per year) of the global production. The EU produced on average 1.4 Mt per year of refined lead, i.e. 13% of the global production. Germany is the major EU producer, accounting for 27% (384 kt) of the EU production. Lead produced from secondary materials amounted to around 58% (6,3 kt) of the total production.

Lead and its compounds can be toxic to humans and animals and their use is regulated in the EU.

15.2Market analysis, trade and prices

15.2.1Global market analysis and outlook

The lead market recorded a deficit in 2017 and 2018 (ILZSG, 2019) which reflected the closure of major lead and zinc mines over the last few years prior to 2018 and environmental crackdown in China. However, new primary lead supplies should push the global lead market into balance or even a small surplus in the coming years.

On the demand side, the largest market is for automotive batteries with a turnover of around USD 25,000 million in 2015. The second market is for industrial batteries for standby and motive power with a turnover of USD 10,000 million USD(May, 2018).

Lead-acid battery production is expected to be the main driver as other applications will be progressively phased out - except for niche applications - with rising health and environmental awareness in developing countries. The lead battery sector is expected to grow with the demand for the automotive and stationary batteries.

Lead-acid batteries will still have the biggest market share in 2025 in terms of volume (European Commission, 2019). The market for battery energy storage is set to grow substantially in the coming ten years. However, there are longer-term competitors to lead-acid battery usage in both automotive and industrial applications, e.g., lithium-ion and other competing technologies. Longer term demand will depend on the speed and scale of the penetration of these technologies. The global lead acid battery market is anticipated to expand at a compound annual growth rate (CAGR) close to 5% from 2018 to 2026 (Transparency Market Research, 2018).

Glencore was the largest producer of lead in concentrates in 2018 with a production of 273 kt (Glencore, 2019), followed by Vedanta Resources and Doe Run Company. Stalprodukt SA, in Poland, was the main EU producer in 2018.

Table 73: Qualitative forecast of supply and demand of lead

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Lead		x	+	+	?	++	+	+

15.2.2EU trade

EU lead ores and concentrates imports amounted to 208 kt per year on average over the period 2012-2016. 21% of the concentrates imported to the EU came from European countries with North Macedonia (15%) being the main European supplier. Peru was the other major supplier (15 %), followed by Australia (14%), the United States (12%) and Mexico (12%) (Eurostat, 2019).

The EU exported 168 kt per year of lead concentrates. China was the main importer with 92% of all EU exports. The EU industry reliance on imports of lead concentrates was 15% during the period 2012-2016.

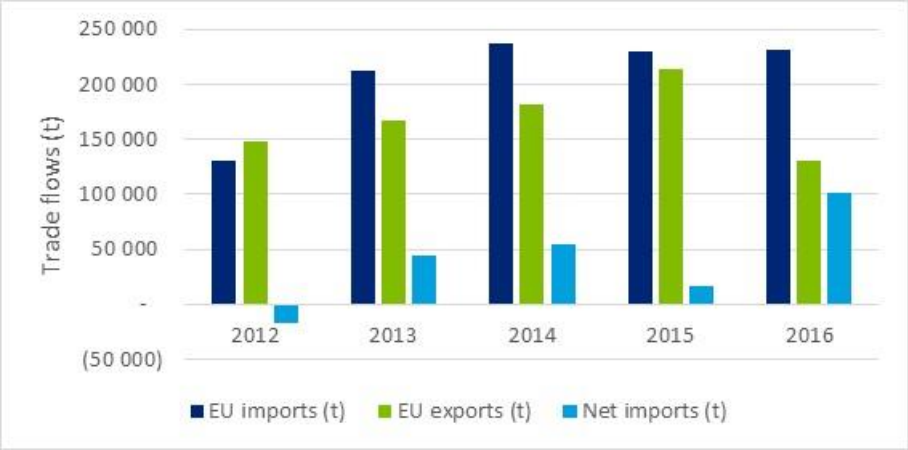


Figure 149: EU trade flows for lead concentrates (Eurostat, 2019)

The EU imports of refined lead amounted to 108 kt per year, mainly from the United Kingdom, Russia, Kazakhstan, and South Korea. The export quantity was on average 119 kt per year (average 2012-2016).

There are EU free trade agreements in place with Peru, North Macedonia, Mexico, Morocco, Turkey, Serbia, Chile, Bosnia and Herzegovina and Kosovo (European Commission, 2016).

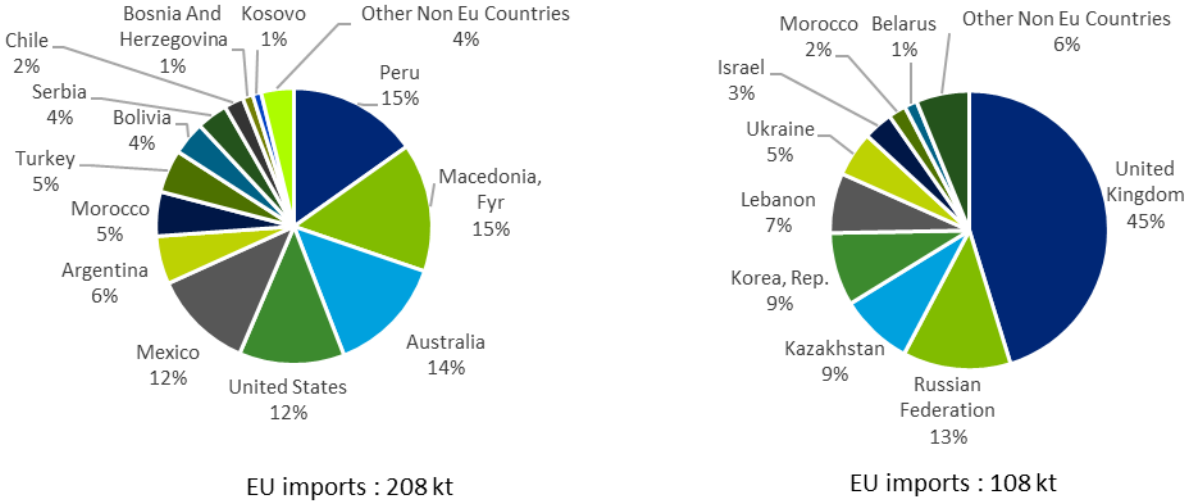


Figure 150: EU imports of lead concentrates (A) and refined lead (B), yearly average in 2012-2016 (Eurostat, 2019)

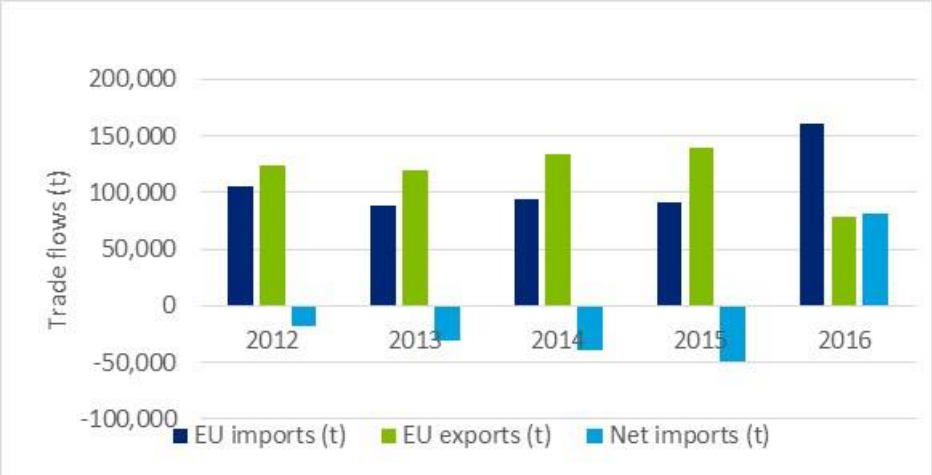


Figure 151: EU trade flows for refined lead (Eurostat, 2019)

15.2.3Prices and price volatility

Lead is traded on the major exchanges around the world, including the London Metals Exchange (LME) and the Shanghai Metal Exchange (SHME). The LME trades a contract on ingots of lead that are 99.97% pure. Each contract represents 25 tonnes of lead and is quoted in US dollars.

The price of lead is driven mostly by Chinese demand for automotive and traction batteries, power storage devices and global stocks. Average annual prices (from 2012 to 2014) which were slightly above the USD 2,000 per tonne mark declined in 2015 amid weak demand, before strongly recovering in 2016 as concerns on primary supply issues rose following the closure of the Century mine in Australia and Lisheen mine in Ireland (Figure 152). After reaching a high point in February 2018 at USD 2,682 per tonne, lead lost around 25% of its value through 2018 as market became better supplied. Despite the fact that the lead market is in a small deficit, prices are kept at a relatively low level owing mainly to the trade tensions between the US and China.

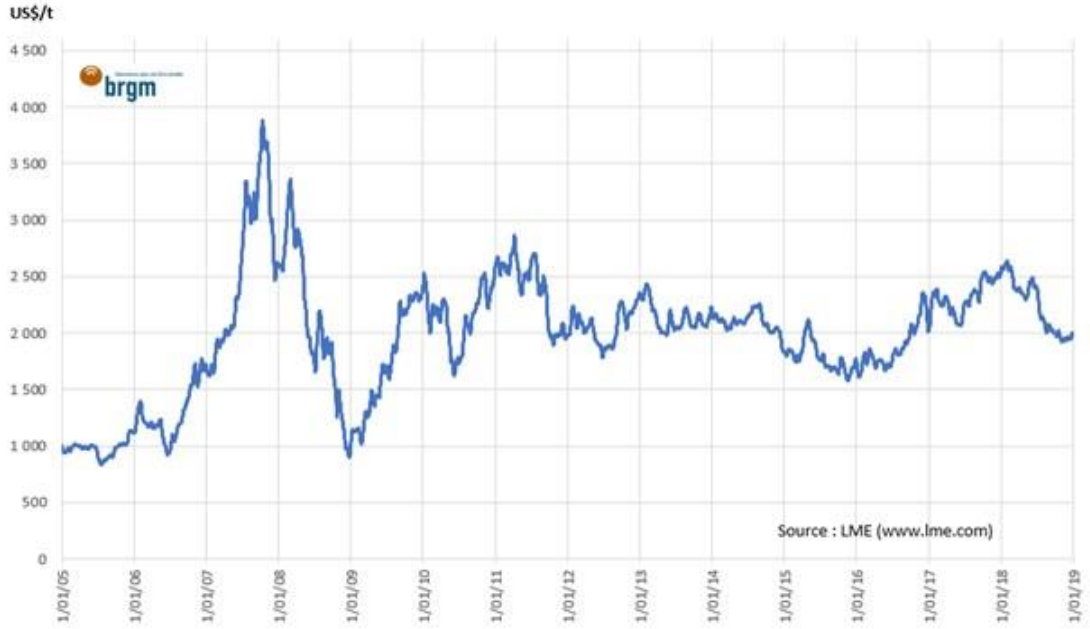


Figure 152: Refined lead prices (USD/t, 7–day moving average) from January 2008 to December 2018 (LME, 2019)

The long-term prices of lead are shown in Figure 153. The price curve shows real prices.



Figure 153: Lead prices in USD per tonne. Vertical dashed line indicate breaks in price specification.(Buchholz *et al.* 2019)

15.3EU demand

15.3.1EU demand and consumption

Over the year 2012-2016, the EU consumption of lead concentrates was 263 kt per year which were sourced through domestic production (223 kt; 52%), mainly from Poland (77 kt; 18%) and Sweden (70 kt; 16%) and imports, mostly from Peru (32 kt; 7%) and North Macedonia (31 kt; 7%).

The EU is self-sufficient in terms of lead metal supply with a domestic production of primary and secondary lead metal of 1.400 kt per year. Germany is the main supplier with a production of 384 kt per year averaged over 2012-2016 (27%).

15.3.2Uses of lead in the EU

Figure 154 presents the main uses of lead in the EU in 2015.

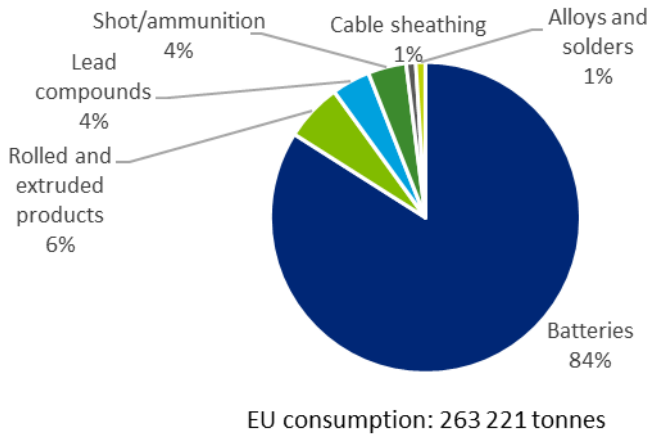


Figure 154: EU end uses of lead in 2015 (ILZSG, 2017).

Lead-acid batteries: The largest application for lead is by far the manufacture of lead acid batteries which accounted for about 84% of global lead consumption in the EU in 2015 (ILZSG, 2017). Lead-acid technology is used in numerous applications for starting, lighting and ignition (SLI) in conventional combustion engine vehicles (64%), traction in battery electric vehicles (25%) and back-up for uninterruptible power supplies and grid energy storage (11%) (ILZSG, 2017; Ecobat, 2019).

Rolled and extruded lead products: Lead is used in the manufacture of rolled and extruded products (lead sheets, wires etc.). Lead sheet is used in the building, construction and chemical industry due to its durability, malleability, high density and corrosion resistance. Sheet is used for flashings to prevent water penetration, for roofing and cladding and also, to a lesser degree, as a radiation shielding and sound insulation material. Lead sheet is used by the chemical industry for the lining of chemical treatment baths, acid plants and storage vessels. Lead pipes are used for carriage of corrosive chemicals at chemical plants and as "sleeves" to join lead sheathed cables.

Lead compounds: Lead compounds used as stabilisers in PVC have been voluntarily eliminated within the EU under the Vinyl 2010/VinylPlus voluntary commitments of the PVC industry, and their sales ceased in late 2015 (The European council of vinyl manufacturers, 2016; the European stabiliser producers association, 2016). Lead based paints and frits are also being phased out in Europe. However, lead-based paints are still widely sold in all developing regions of the world (IPEN, 2016), and their use is limited to a few specific applications (artist paints, some industrial paints) in the rest of the world.

Shot/ammunition: Shot lead is an alloy of lead, antimony, and tin.

Cable sheathing: Lead alloys are used as a sheathing material for power cables in the petrochemical industry or undersea and for underground high voltage cables.

Alloys and solders: Tin-lead alloys are the most widely used soldering alloys. Soft solders are largely lead-tin alloys with or without antimony, while fusible alloys are various combinations of lead, tin, bismuth, cadmium and other low melting point metals.

Relevant industry sectors are described using the NACE sector codes (Eurostat, 2019b).

Table 74: Lead applications, 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2019b)

Applications	2-digit NACE sector	Value added of NACE 2 sector (M€)	4-digit NACE sectors
Batteries	C27 - Manufacture of electrical equipment	80,745	C27.20 - Manufacture of batteries and accumulators
Rolled and extruded products	C24 - Manufacture of basic metals	55,426	C24.4.3 Lead, zinc and tin production
Lead compounds	C20 - Manufacture of chemicals and chemical products	105,514	C20.1.6 - Manufacture of plastics in primary forms.
Shot/ammunition	C25 - Manufacture of fabricated metal products, except machinery and equipment	148,351	C25.4.0 - Manufacture of weapons and ammunition
Cable sheathing	C27 - Manufacture of electrical equipment	80,745	C27.3.2 - Manufacture of other electronic and electric wires and cables
Alloys and solders	C24 - Manufacture of basic metals	55,426	C24.4.3 - Lead, zinc and tin production

15.3.3Substitution

Batteries: Lead-acid batteries are the predominant technology option, due to their low cost, reliability in a wide range of climates and well-established supply chain. They represented between 70 and 75% of the global battery market in 2018 (Avicenne, 2019). Lithium-ion (Li-ion) batteries are increasingly replacing lead-acid batteries for some applications and account now for 25% of the battery market. Other commercially available systems include nickel-metal hydride (NiMH) and nickel-cadmium (NiCd) batteries. However portable batteries and accumulators used in cordless power tools which contain more than 0.002% of cadmium by weight have been banned in the EU since 31 December 2016.

Rolled and extruded lead products: There are several alternatives to the use of lead in most sheet applications such as galvanized steel, aluminium, copper and non-metallic materials.

Lead compounds: Lead based PVC stabilisers can be replaced by calcium-based stabilisers (Ca-Zn and Ca-organic). Lead-based stabilisers have been phased out by the PVC industry and the replacement was completed by the end of 2015. Cost-effective non-leaded pigments, driers

and anti-corrosive agents have been available for decades (titanium dioxide, organic and inorganic pigments, zinc phosphate primers etc.).

Cable sheathing: Lead free cables have been developed by industry manufacturers. Some of the designs include an inner aluminium polyethylene (AluPE) tape, a high-density polyethylene (HDPE) sheath and a polyamide cover. The advantages of lead-free alternative designs – apart from their non-toxicity- are the lower cable weight and reduced diameters, which can be beneficial in the installation (Nexans, 2016).

Alloys: Within the EU, all soldering materials meet European standard's requirements and lead-free solders are compliant with European Directives RoHS and WEEE. Existing exemptions are periodically reviewed. There are several families of tin-based alloys commercially available as lead-free solders which are generally specific to a certain application such as SnAgCu (tin-silver-copper), SnAgCuBi (tin-silver-copper-bismuth), SnIn (tin-indium) alloys etc.

15.4Supply

15.4.1EU supply chain

Lead ore is extracted and processed in the EU. The EU produced 223 kt per year of lead in concentrates over the period 2012-2016. Poland (77 kt), Sweden (70 kt) and Ireland (36 kt) accounted for 82% of the EU production.

The domestic production of refined lead amounted to 1,400 kt per year (average 2012-2016), with Germany (384 kt) accounting for 27% of this production. Secondary refined lead production represented 80% (1,100 kt) of the total EU metal production. Most of this production results from the processing of waste generated in the Union and from a small amount of imported scraps.

The EU industry manufactured 15% of the global production of lead-acid batteries and was estimated to be worth EUR 5,141 million in 2016 (European Commission, 2019c)

15.4.2Supply from primary materials

15.4.2.1 Geology, resources and reserves of lead

Geological occurrence:

Lead concentration in the Earth continental upper crust is estimated to be 17 ppm (Rudnick & Gao, 2014), which is relatively low compared to the other base metals.

Lead is mainly extracted as a zinc co-product from two main types of deposits hosted in sedimentary rocks: sedimentary-exhalative (SEDEX) and Carbonate hosted deposits which include Mississippi-valley type (MVT) and Irish type carbonate lead zinc deposits. These Pb-Zn deposits which, put together, contain around half of the global resources of lead (Singer, 1995) and dominate world production of lead and zinc. Lead occurs in the form of galena, a sulphide (PbS), in association with sphalerite (ZnS). Silver and barite may also be economically recovered from these deposits. Carbonate replacement deposits (CRD), zinc-lead skarn deposits and volcanogenic massive sulphide deposits (VMS) are also important sources of lead.

SEDEX deposits are hosted in fine grained clastic sediments, mainly shales. Most are large, tabular or stratiform deposits which typically consist of lead and zinc sulphide-rich beds inter-layered with sulphide-poor clastic units. They form from warm brines (100-200C°) discharged on or just below the seafloor, in sedimentary basins in continental rift settings. They include

some of the largest lead-zinc deposits in the world, such as McArthur River in Australia and Red Dog in the USA.

MVT deposits are epigenetic stratabound deposits hosted mainly by dolomites and limestones. They form from warm brines with temperatures in the range of 75-200°C (the Irish style tend to have higher temperatures with some data indicating up to 240°C) in carbonate platforms adjacent to cratonic sedimentary basins (e.g. Viburnum trend, USA; Silesia, Poland). The mineralization occurs as replacement of the carbonate rocks and as open-space fill (Paradis et al, 2007; Leach et al., 2010).

Carbonate-replacement deposits (CRD) and zinc-lead skarn deposits (e.g. Groundhog, USA; Bismark, Mexico) are hosted by carbonate rocks (limestones, dolomites, calcareous clastic sediments). They form by reaction of high temperature hydrothermal fluids (>>250°C) with the carbonate rocks, in the vicinity of igneous intrusions. CRD deposits occur as massive lenses, pods, and pipes (mantos or chimneys) (Hammarstrom, 2002).

Volcanogenic Massive Sulphide Deposits (VMS) are hosted either in volcanic or in sedimentary rocks and occur as lenses of polymetallic massive sulphide. VMS deposits form on, and immediately below the seafloor, by the discharge of a high temperature, hydrothermal fluids in submarine volcanic environments. They also are significant sources for cobalt, tin, selenium, Manganese, cadmium, inium, bismuth, tellurium, gallium, and germanium.

Global resources and reserves [105] *:* USGS (2019) estimated the world identified lead resources at more than 2,000 Mt.

Global reserves of lead at the end of 2018 were estimated at around 83 Mt (USGS, 2019), with Australia and China accounting for half of the global total (Table 75).

Table 75: Global reserves of lead in year 2018 (USGS, 2019)

Country	Estimated Lead Reserves (Mt)
Australia	24,0
China	18,0
Russia	6,4
Turkey	6,1
Peru	6,0
Mexico	5,6
United States	5,0
India	2,5
Kazakhstan	2,0
Bolivia	1,6

[105] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of lead in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template.[105], which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

Country	Estimated Lead Reserves (Mt)
Sweden	1,1
Other countries	5,0
World Total (rounded)	83,0

Mudd et al. (2017) assessed the known world lead-zinc mineral resources. In this study it is indicated that at least 226 million of tonnes of lead were present at that time within 851 individual mineral deposits and mine waste projects from 67 countries, at an average grade of 0.44% lead.

EU resources and reserves[106]*:*

Resource data for some countries in Europe are available in Minerals4EU (2019)

Table 76: Reserve data for the EU compiled in the European Minerals Yearbook (Minerals4EU, 2019)

Country	Reporting code	Quantity	Unit	Grade	Code Resource Type
Czech Republic	Nat. rep. code	0.2	Mt	0.67%	Potentially economic
		0.8	Mt	-	P1
		5.3	Mt	-	P2
France	None	0.8	Mt	Metal content	Historic resource estimate
Greece	USGS	35.3	Mt	4.12%	Measured
Hungary	Russian Classification	0	Mt	-	A
		0.5	Mt	-	B
		4	Mt	-	C2
Ireland	JORC	57.4	Mt	1.28%	Measured, Indicated & Inferred
Italy	None	0.1	Mt	-	Sub-economic
Poland	Nat. rep. code	1.3	Mt	0.08	A+B+C1
		0	Mt	0.02	C2 + D

[106] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for lead. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for flead, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for lead the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019). Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However, a very solid estimation can be done by experts.

Country	Reporting code	Quantity	Unit	Grade	Code Resource Type
		1.3	Mt	0.07	Total
		0.6	Mt	1.84	A+B+C1
		0.7	Mt	1.78	C2 + D
		1.3	Mt	1.8	Total
Portugal	NI43-101	33.9	Mt	1.40%	Measured
		112.2	Mt	0.90%	Indicated
		47.2	Mt	0.64%	Inferred
Slovakia	None	0	Mt	1.17%	Probable (Z2)
		1.6	Mt	1.17%	Anticipated (Z3)
Spain	NI43-101	10.8	Mt	0.01%	Measured
Sweden	JORC	0.5	Mt	0.40%	Measured
		3	Mt	2.05%	Indicated
		1.5	Mt	1.60%	Inferred
	NI43-101	8.5	Mt	4.80%	Measured
		6.4	Mt	4.20%	Indicated
		5	Mt	3.20%	Inferred
	FRB-standard	5.2	Mt	0.91%	Measured
		26.2	Mt	1.23%	Indicated
		39.5	Mt	1.26%	Inferred
United Kingdom	JORC	2.1	Mt	2.18%	Indicated
		4.1	Mt	1.20%	Inferred

The Pallas Green Project in Ireland is one of the largest undeveloped zinc-lead deposits in the world. Glencore estimated inferred mineral resources (JORC) to be 45.1 Mt at a grade of 7% zinc and 1% lead, as at 31 December 2018.

15.4.2.2 World and EU mine production

During the period 2012-2016, 5,100 kt of lead (metal content in ore) were mined on average annually, in the world. The output decreased by 7% from 2012 to 2016 to reach 4,780 kt (metal content, BGS data) in 2016, due to mine closures or production cutbacks in Australia. China was the leading producer and accounted for 49% of the global mine production (average 2012-2016), followed by Australia (12%).

With an annual average production of 223 kt (2012-2016), the EU accounted for 4% of world production. The major EU production of lead took place in Poland (77 kt, or 35% of EU production), Sweden (70 kt, 31% of EU production) and Ireland (36 kt, 8% of EU production) . Lead was also mined in Bulgaria (17 kt) and Greece (16 kt), and very small quantities were extracted in Spain, Portugal, Slovakia and Romania (see Figure 155). The production from Slovakia and Romania stopped in 2014 and 2013, respectively (Figure 155).

In Poland, the Klucze I, Olkusz and Pomorzany deposits in the Silesia–Cracow mining district were reported as under exploitation in 2017 (Polish Geological Institute, 2017). The Garpenberg and Zinkgruvan mines produced most of the lead extracted in Sweden.

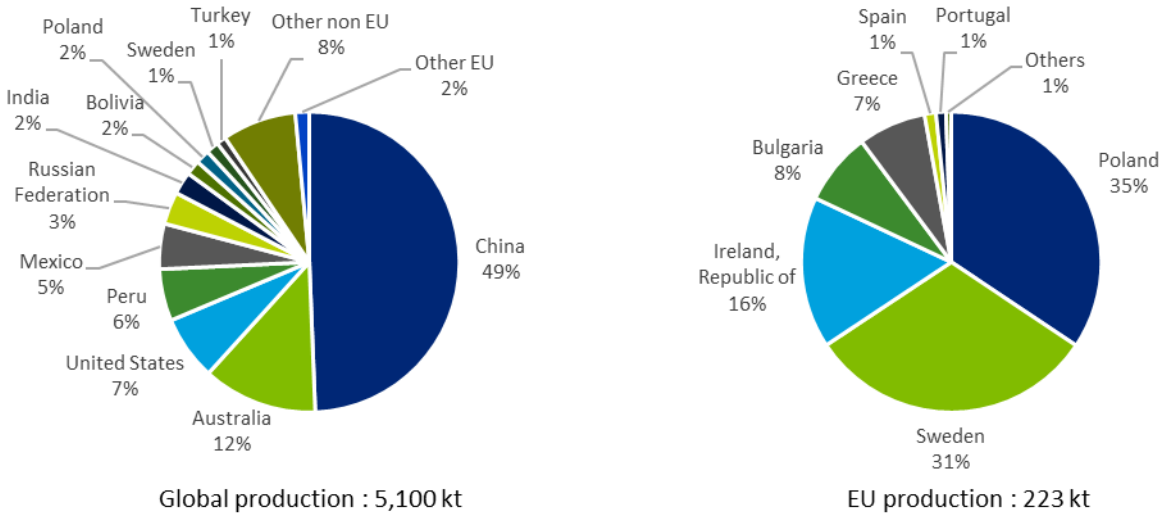


Figure 155: Global (left) and EU (right) mine production of lead in tonnes and percentage. Average for the years 2012-2016. (BGS, 2018)

15.4.3Supply from secondary materials/recycling

15.4.3.1 Post-consumer recycling (old scrap)

Lead has one of the highest recycling rates of all materials in common use to-date. More refined lead is produced by recycling than from mines. World annual secondary lead production amounted to 6,300 kt on average over the period 2012-2016, representing 57% of the total metal output (ILZSG, 2017).

Lead was recycled in 20 EU countries EU: Austria, Belgium, Bulgaria, Croatia, Czech Republic, Estonia, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden. The EU secondary refined lead production increased by 3% over the period 2012-2016 with an average output of about 1,146 ktper year, which was 80% of the EU total refined lead production. Germany was the largest producer with about 22% of the total production of the EU, followed by Spain, Italy and Belgium. Most of this production results from the processing of waste generated in the EU and from a small amount of imported scraps.

Most of the secondary lead comes from scrap lead-acid batteries, lead pipe, sheet and cable sheathing. Scrap lead from the building trade is usually fairly clean and is re-melted without the need for smelting, though some refining operations may be necessary (International Lead Association, 2016). Lead batteries are the only battery system that is almost completely recycled. In the EU, recycling efficiencies of lead-acid batteries for a vast majority of countries were above 75% in 2017 (Eurostat, 2019c); 99% of the automotive lead-based batteries which were collected have been recycled during the period 2010-2012 (IHS, 2014). More than 95% of the lead sheet used in the construction industry for roofing was collected and recycled (The European Lead Sheet Industry Association, 2016). Pipe scraps, sludge, dross and dusts were also recycled.

15.4.4 Processing of lead

The conventional process for smelting lead starts by removing the sulphur from the concentrates which is normally achieved by a roasting and sintering process which turns the lead sulphides into lead oxide and converts most sulphurs into sulphur dioxide (SO_2). The lead oxide (the sintered concentrate) is then fed to a blast furnace together with limestone and coke in order to reduce the oxide to metal. Alternatively, direct smelting systems perform roasting, sintering and smelting in a single furnace (e.g. Isasmelt furnace). The crude lead coming from the smelting furnace may still contain impurities (e.g., copper, Arsenic, antimony, tin, bismuth, zinc, silver, gold) and needs to be refined.

World refined lead metal production amounted to 10,900 kt per year on average during the period 2012-2016 (BGS, 2018). China was the world leading supplier with 43% (4,700 kt per year) of the global production, followed by the United States contributing 1,100 kt per year, and South Korea 600 kt per year (ILZSG, 2019).

There is a small and stable production of refined primary lead - from imported concentrates and from concentrates produced within the EU - that amounted to 389 kt per year, on average over the period (2012-2016). The EU was a net exporter of refined lead – primary or secondary– from 2012 to 2016, with average imports and exports amounting to 108 kt and 119 kt of metal, respectively.

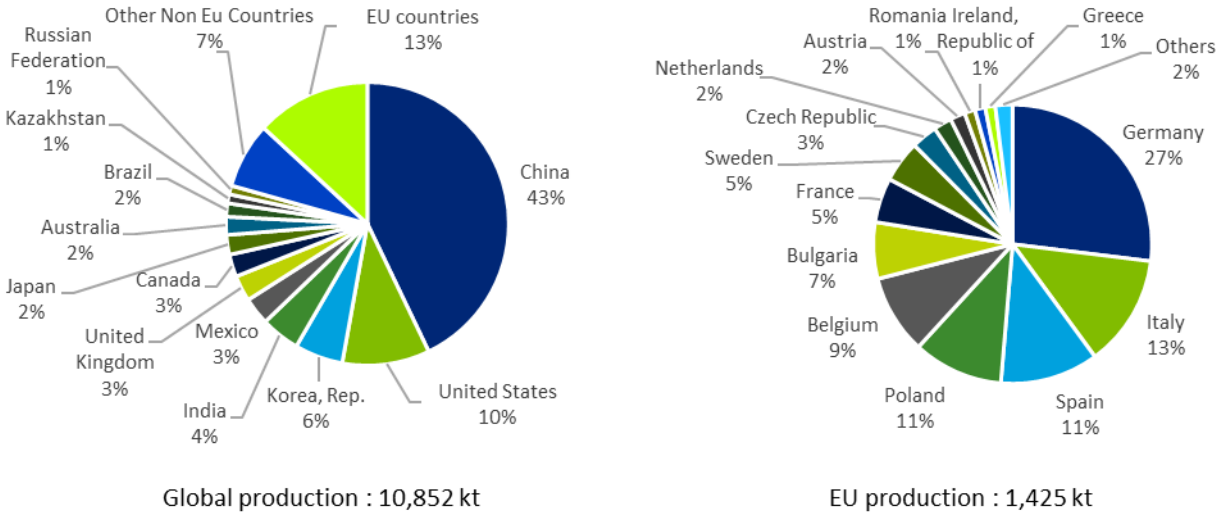


Figure 156: Global (left) and EU (right) refined lead production. Average for the years 2012-2016. (BGS, 2018)

15.5 Other considerations

15.5.1 Environmental and health and safety issues

Lead is a toxic metal. It is classified as toxic for reproduction in the classification, labelling and packaging of substances and mixtures (CLP) Regulation. It is also considered 'persistent bio-accumulative and toxic (PBT)' under the REACH registration notifications.

Existing EU legislation provides a framework for all activities linked to the lead industry, from the extraction of the ore to the recycling of end of life products to reduce health and environmental risks. The End of Live Vehicles (ELV) Directive establishes an exemption for the use of lead in (most) automotive batteries, which is to be reviewed in 2021.

The European Commission amended the lead restrictions under REACH Annex XVII (Entry 63). Under the amended restriction, consumer products that can be mouthed by children may not contain lead concentrations equal to or greater than 0.05% by weight. The new restriction became effective on June 1st, 2016 (ECHA, 2016).

15.6 Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. Supply risk has been analysed at both mine and processing stages. The higher supply risk is for the mining stage. The economic importance score is higher compared to the score in 2017. The application shares for Europe and the value added of the sectors for which the end-use application are relevant have been updated.

The results of this and earlier assessments are shown in Table 77.

Table 77: Economic importance and supply risk results for lead in the assessments of 2011, 2014, 2017, 2020 (European Commission, 2011; European Commission, 2014; European Commission, 2017)

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Lead	Not assessed		Not assessed		3.7	0.1	4.1	0.1

15.7Data sources

15.7.1Data sources used in the factsheet

Avicenne (2019). Current Status and Future Trends for the Lithium-ion Battery Market. [online] available at: https://www.charles-hatchett.com/public/images/documents/2019/Presentation-C-Pillot.pdf

BGS (2018). World Mineral Production 2012-2016. [online] Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.html

Blanpain et al. (2019) Lead Metallurgy is Fundamental to the Circular Economy Policy Brief SOCRATES EU MSCA-ETN (https://etn-socrates.eu/)

Buchholz P., Wellmer F.W., Bastian D., Liedtke M. (2019) Leaning against the wind: Low price benchmarks for acting anticyclically in the metal markets. Mineral Economics. https://doi.org/10.1007/s13563-019-00199-y

ECHA (2016). Registered substances. [online] available at: https://echa.europa.eu/

Eurobat (2015). E-mobility Battery R&D Roadmap 2030. [online] available at: http://www.eurobat.org/images/news/press-releases/eurobat_emobility_roadmap_lores_2.pdf

European Association for Storage of Energy (2019), [online] available at: http://ease-storage.eu/

European Commission (2016). Free trade agreements. [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/

European Commission (2019). Commission staff working document on the evaluation of the Directive 2006/66/EC on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC; SWD(2019) 1300 final. [online] Available at: https://ec.europa.eu/commission/sites/beta-political/files/swd-report-batteries-accumulators-april2019_en.pdf

Eurostat (2019). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2019b). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

Glencore (2017). 2016 annual report. [online] Available at: https://www.glencore.com/

Hammarstrom, J.M.(2002). Environmental geochemistry of skarn and polymetallic carbonate-replacement deposit models

IHS et. al. (2014). The Availability of Automotive Lead-Based Batteries for Recycling in the EU - A joint industry analysis of EU collection and recycling rates 2010-2012. [online] Available at: https://www.ila-lead.org/UserFiles/File/Newsletter%20files/IHS_eurobat_report_lead_LoRes%20FINAL.pdf

International lead association (2019). [online] Available at: http://www.ila-lead.org/

ILZSG (2017). [online] Available at: http://www.ilzsg.org/

ILZSG (2019). World refined lead supply and Usage, July 2019 (Press release). Available at: http://www.ilzsg.org/

IPEN (2016). [online] Available at: http://ipen.org/sites/default/files/documents/IPEN-global-lead-report-final-Oct-2016-en.pdf

Leach, D.L. et al., (2010). A deposit model for Mississippi Valley-Type lead-zinc ores, chap. A of Mineral deposit models for resource assessment: U.S. Geological Survey Scientific Investigations Report 2010–5070–A, 52 p

LME (2017). [online] Available at: www.lme.com. BRGM database.

May G.J., Davidson A., Monahov (2018). Lead batteries for utility energy storage: A review. Journal of Energy Storage, Vol. 15, pp. 145–157.

Minerals4EU (2019). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

Mudd, G.M., Jowitt, S.M., Werner, T.T.(2017). The world's lead-zinc mineral resources: Scarcity, data, issues and opportunities. Ore Geology Reviews 80, pp. 1160–1190.

Nexans (2016). [online] Available at: http://www.nexans.com/

OECD (2016). OECD Export restrictions on Industrial Raw Materials. [online] Available at: http://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

Paradis, S. et al. (2007). Mississippi Valley-type lead-zinc deposits, in Goodfellow, W.D., ed., Mineral Deposits of Canada: A Synthesis of Major Deposit-Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods: Geological Association of Canada, Mineral Deposits Division, Special Publication No. 5, p. 185-203.

Polish Geological Institute (2017). https://www.pgi.gov.pl/en/

Recharge (2019). The Batteries Report 2018. [online] Available at: https://www.rechargebatteries.org/wp-content/uploads/2018/05/RECHARGE-The-Batteries-Report-2018-April-18.pdf

Rudnick, R.L., Gao, S. (2014) Composition of the Continental Crust. Treatise On Geochemistry. Heinrich D. Holland and Karl K. Turekian(ed), 2nd edn. Elsevier, Oxford, pp 1–51.

Singer D. A. (1995) World-class base and precious metal deposits; a quantitative analysis. Economic Geology 90: 88–104

SNL Financial (2017). Exploration budget in perspective. [online] Available at: https://www.snl.com/

The European Council of Vinyl Manufacturers (2016). Stabilisers. [online] Available at: http://www.pvc.org/en/p/stabilisers

The European stabiliser producers association (2016). [online] Available at: http://www.stabilisers.eu/

The European Lead Sheet Industry Association (2016). [online] Available at: http://elsia.org.uk/

Transparency Market Research (2018). Lead Acid Battery Market - Global Industry Analysis, Size, Share, Growth, Trends, and Forecast 2018 – 2026. [online] Available at: https://www.transparencymarketresearch.com/lead-acid-battery-market.html

USGS (2016). Mineral Commodity Summaries. Lead. [online] Available at: https://minerals.usgs.gov/minerals/pubs/commodity/lead/mcs-2016-lead.pdf

15.7.2 Data sources used in the criticality assessment

AA Portable Power Corp. [online] Available at: http://www.batteryspace.com/batteryknowledge.aspx

Avicenne Energy (2017). Lithium ion battery raw material supply and demand 2016-2025. C. Pillot Presentation at the 7th Advanced Automotive Battery Conference Europe, Mainz, Germany, January 2017

BGS (2018). World Mineral Production. 2012-2016.

EC (2017). Study on the review of the list of Critical Raw Materials - Critical Raw Materials Factsheets & Non-critical Raw Materials Factsheets.

Eurostat (2019). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2019b). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

Eurostat (2019c). Contribution of recycled materials to raw materials demand- End-of-life recycling input rates (EOL-RIR). [online] Available at: https://ec.europa.eu/eurostat/databrowser/view/cei_srm010/default/table?lang=en

Gremse F, Krone O, Thamm M, Kiessling F, Tolba RH, Rieger S, et al. (2014). Performance of Lead-Free versus Lead-Based Hunting Ammunition in Ballistic Soap. PLoS ONE 9(7): e102015. https://doi.org/10.1371/journal.pone.0102015

INERIS, 2015. Donnees technico-economiques sur les substances chimiques en France : Plomb, INERIS –DRC-15-136881-10941A ; http://rsde.ineris.fr/

International Lead &Zinc Study Group (ILZSG) (2017). [online] Available at: http://www.ilzsg.org/

IPEN (2014). Alternatives to lead in paint; http://www.unep.org/chemicalsandwaste/Portals/9/CEE_CAsia/10%20Alternatives%20to%20lead%20in%20paint.pdf

Mineralinfo (http://www.mineralinfo.fr/)

Nyrstar, 2009. Introduction to Zinc and Lead Smelting Business. [online] Available at https://www.nyrstar.com/

OECD (2016). OECD Export restrictions on Industrial Raw Materials. [online] Available at: http://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

Other : general knowledge etc., no source readily available

15.8Acknowledgments

This factsheet was prepared by the JRC in collaboration with the French Geological Survey (BRGM). The authors would like to thank the Ad Hoc Working Group on Critical Raw Materials, as well as experts participating in SCRREEN workshops for their valuable contribution and feedback.

16. LIMESTONE

16.1 Overview

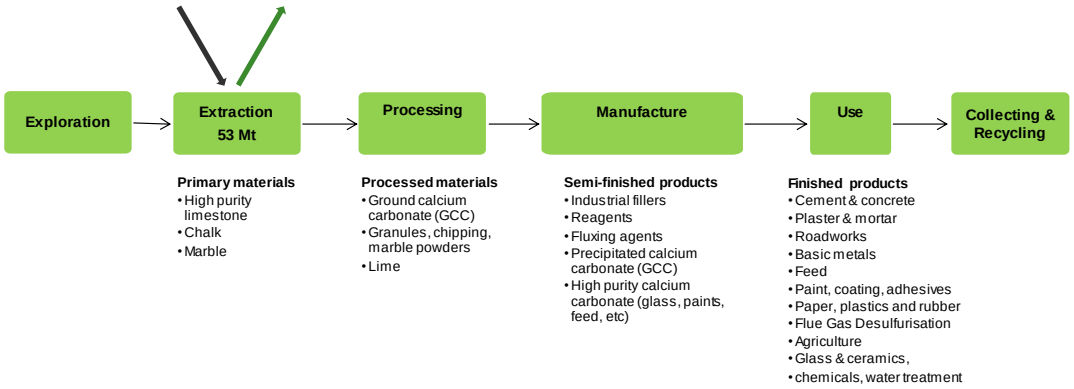


Figure 157: Simplified value chain for limestone for the EU[107], average 2012-2016.

Although Limestone is a very generic term for rocks of sedimentary origin that are composed mainly of calcium carbonate (CaCO3), for the purpose of the assessment only Industrial limestone is considered, e.g. limestone used for purposes other than construction, where chemical properties (generally above 97% $CaCO_3$) and whiteness are important. Due to limited data availability, calculations are focused on Chalk (CN code 250900) and granules, chipping and marble powder (CN code 25174100), as a proxy for a bigger family of commodities . For sub-types of limestone, see glossary in the data section.

Global demand will likely continue to grow, even though the pace of growth is slower in recent years due to the global economic recession and the slowdown in China. Most of the growth in the future is expected in Asia for several industrial sectora. Growth in the European market is expected to be slow. In the EU, almost all countries produce high grade limestone. EU is a net exporter, but trade figures are very small compared to production data. The majority of limestone is sold on the open market and only minor amounts are traded on annual contracts.

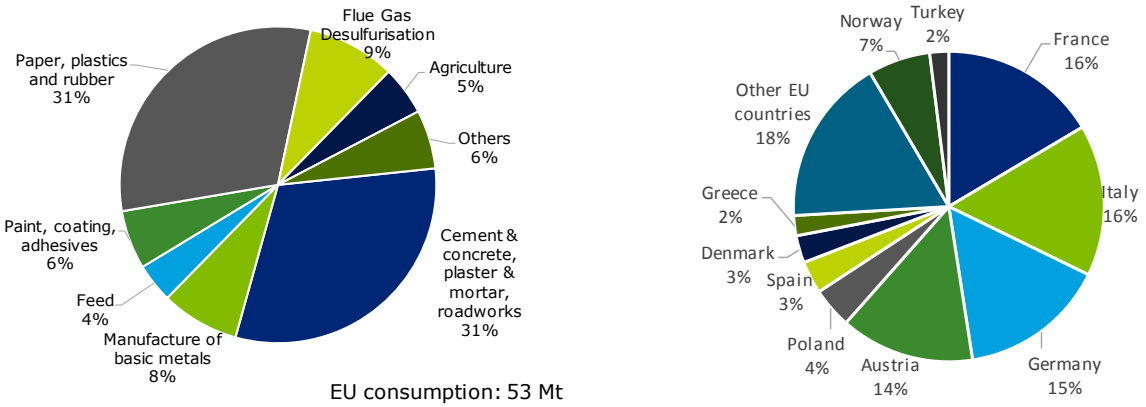


Figure 158: End uses (IMA-Europe, 2018) and EU sourcing[108] of limestone, 2012-16.

[107] JRC elaboration on multiple sources (see next sections)

[108] Chalk (CN code 250900) and granules, chipping and marble powder (CN code 25174100)

According to IMA-Europe (2018) the EU apparent consumption of limestone is estimated at 53 Mt per year over the period 2012-2016 (chalk was 9.7 Mt, while the apparent consumption of granules, chipping and powder of marble was 6.2 Mt). The vast majority of the domestic production was consumed within Europe and it can satisfy the EU industry demand, with no import reliance issues.

High grade limestone is used in a wide range of applications including paper manufacturing, plastic manufacturing, in paints, coatings and adhesives, in container glass, flue gas treatment and many other uses. Substitutes in paper making include kaolin, talc and titanium dioxide. In concrete manufacture, a variety of alternative materials could be used, including alumina trihydrate (ATH), talc, silica, feldspar, kaolin, ball clay and dolomite. In paints, adhesives and coatings, multiple materials are potential substitutes including clays, silica, feldspar, talc, mica, gypsum, barite and others. In plastics and rubber, substitutes include talc, kaolin, wollastonite, mica, silica and alumina hydrate. In environmental applications, marble powder may be used in water treatment.

Limestone contribution to a climate neutral Europe depends on the contribution of the sectors in which it is used, mainly the cement and lime manufacturing. It is known that a large contribution to anthopogenic emissions of carbon dioxide originate from calcination, e.g the breakdown of calcium carbonate ($CaCO_3$) into CO_2. Therefore, carbon neutrality can only be achieved by recapturing this "chemical" CO_2 (ETH, 2018).

Reserves are believed to be large, but data for most countries are not available.

No export restrictions are reported by the OECD Export restrictions on Industrial Raw Materials database (OECD, 2019).

16.2Market analysis, trade and prices

16.2.1 Global market analysis and outlook

High grade limestone demand in the following years is anticipated to grow rather slowly, depending on the state of economies of certain countries and regions including China, the US, and Europe (SCRREEN workshops, 2019).

Table 78: Future supply and demand

Material	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Limestone		✓	+	+	?	+	+	+

16.2.2 EU trade

EU trade flows for calcium carbonate over the period 2012-2016 are reported.

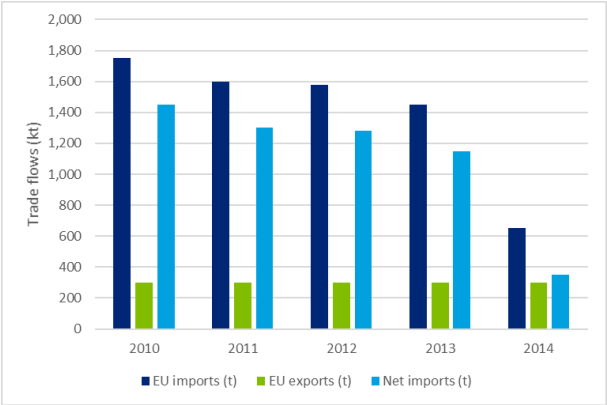


Figure 159: EU trade flows for calcium carbonate (Eurostat, 2019a)

EU trade flows for Chalk (CN 250900) in the period 2012 to 2016 and the EU trade flows for granules, chipping and powder of marble (CN 25174100) are reported too.

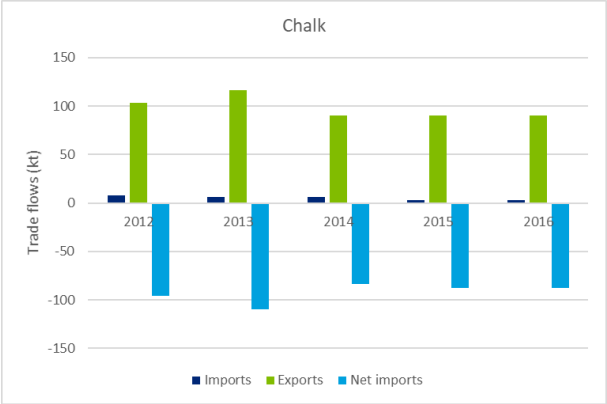


Figure 160: EU trade flows for chalk (Eurostat, 2019)

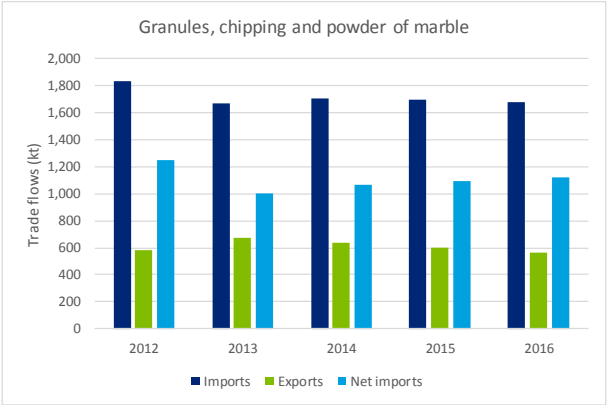


Figure 161: EU trade flows for granules, chipping and powder of marble (Eurostat, 2019)

It is seen from this data the the EU is a net exporter of chalk but trade figures are very small compared to production and consumption. On the other hand, the EU is a net importer of granules, chipping and powder of marble and trade flows are almost 13% of production.

Almost 75% of the imports originate from Norway (~1.3 Mt) and 25% from Turkey (~400 kt). On the other hand 30% of the exports are directed to Tunisia and another 20% to Switzerland. The EU is a net importer of calcium carbonate (Figure 159). However, the net imports for 2016 are sensibly lower than the average in the reported period 2012-2016.

Overall, relatively small qunatities of chalk are traded over longer distances; chalk is mainly consumed by domestic markets. On the other hand, much bigger quantities of granules, chipping and powder of marble are traded over relatively longer distances.

No trade restrictions have been reported over the 2012-2016 period (OECD, 2019). It is mentioned that the EU has free trade agreements in place with Norway and Turkey for calcium carbonate and lime (European Commission, 2019).

16.2.3 Prices and price volatility

No data is available about prices of chalk and granules, chipping and powder of marble. The prices depend on the type and quality of each product as well as on local availability (USGS, 2019). Indicative prices for chalk range between 70-160 €/tonne and for granules, chipping and marble powder 30-65 €/tonne (UN data, 2019).

16.3.EU demand

16.3.1 EU demand and consumption

The EU apparent consumption of high grade limestone over the period 2012-2016 was 53 Mt per year (including chalk 9.7 Mt/y and granules, chipping and powder of marble 6.2 Mt/y). The majority of the domestic production is consumed within Europe and it can satisfy the EU industry demand with no import reliance issues.

16.3.2Uses and end-uses of limestone in the EU

Acording to IMA-Europe, the biggest shares are allocated to the sectors in Figure 162: Cement & concrete, plaster & mortar roadworks, Paper, plastic and rubber, Flue Gas Desulfurisation, Manufacture of basic metals, Paints, Coatings, Adhesive, Agriculture, Feed, Glass and ceramics, Manufacture of chemical product, Water treatment.

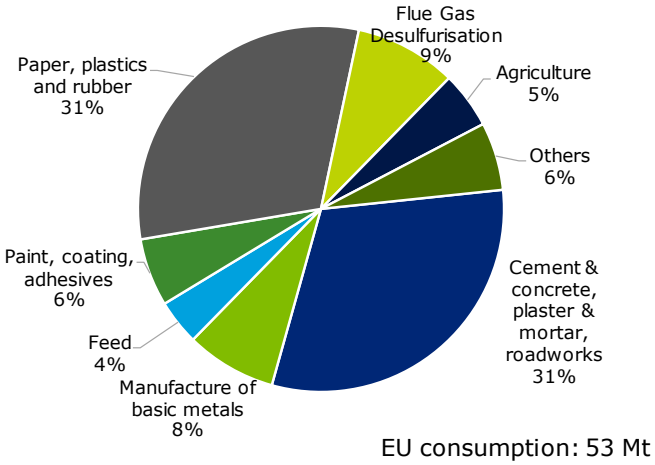


Figure 162: EU end uses of limestone. Average figures for the period 2012-2016. (IMA-Europe, 2018).

The relevant industry sectors are described using the NACE sector codes in Table 79.

Table 79: Limestone applications (IMA-Europe, 2018), 2-digit and associated 4-digit NACE sectors (Eurostat, 2019).

Applications	2-digit NACE sector	4-digit NACE sectors	Value added of sector (M €)
Cement & concrete, plaster & mortar, roadworks	C23 - Manufacture of other non-metallic mineral products	23.61 23.62 23.63 23.64 23.69 23.52	57,255
Manufacture of basic metals	C24 - Manufacture of basic metals		55,426
Feed	C10 - Manufacture of food products	10.89 10.92	155,880
Paint, coating, adhesives	C20 - Manufacture of chemicals and chemical products	20.30	105,514
Paper, plastics and rubber	C20 - Manufacture of chemicals and chemical products	20.16 10.17	105,514
Flue Gas Desulfurisation	E39 - Remediation activities and other waste management services	39. 00	1,301
Agriculture	C20 - Manufacture of chemicals and chemical products	20.15	105,514
Others (Glass & ceramics,chemicals, water treatment)	C23 - Manufacture of other non-metallic mineral products	36.00 23.52	57,255

Chalk as high-purity limestone, is used for the production of lime and portland cement as well as fertilizer. Finely ground and purified chalk, known as whiting, is used as filler, extender, or pigment in numerous materials, including ceramics, putty, cosmetics, crayons, plastics, rubber, paper, paints and linoleum. The main use for chalk whiting is in making putty, to improve its plasticity, oil absorption and aging behaviour.

Marble can be heated in a kiln to remove carbon dioxide and produce calcium oxide (lime), which is used for acidity reduction in soils. When applied in combination with fertilizer, it may increase the yield of a soil.

Mixtures of marble chips and powders with a binder of either cement or resin can be used to produce blocks, which can be cut and processed, decorative tiles and mosaics (after mixing them with other materials), prefabricated products -mainly reinforced concrete structures- and urban furniture, pigments (using coloured marble powders), glues and stuccos, polymers reducing thus the need to use titanium dioxide, glass, ceramics, toothpaste, cosmetics, household detergents, sand-blasting and floral decorations (Ferrari Granulati Marbi sas, 2019).

Marble powder, as well as Powdered limestone are used to produce food supplements for animals because they are softer than the animal's teeth, soluble and rich in calcium. Crushed and pulverized marble, in the form of granules, chipping and powder can be also used to reduce the acidity of soils and aquatic streams, as well as an acid-neutralizing agency in the

chemical industry and for the production of soft abrasives used in bathroom and kitchen surfaces (Ferrari Granulati Marbi sas, 2019).

16.3.3 Substitution

Substitutes of chalk in paper making include kaolin, talc and titanium dioxide. Kaolin is the most important of all and is widely used in this industry. Both talc and titanium dioxide are used in smaller quantities for special applications where extreme whiteness and opacity or pitch control are required. Titanium dioxide is more expensive than chalk (Natural Stone Institute, 2016).

In concrete manufacture, a variety of alternative materials could be used to substitute for chalk or granules, chipping and powder of marble including limestone, dolomite, alumina trihydrate (ATH), slag, talc, silica, feldspar, kaolin, ball clay and dolomite.

In paints, adhesives and coatings, multiple materials are potential substitutes including clays, silica, feldspar, talc, mica, gypsum, barite and others. Limestone is the primary extender and filler due to its low cost and good performance (Natural Stone Institute, 2016).

In plastics and rubber, chalk substitutes include talc, kaolin, wollastonite, mica, silica and alumina hydrate (Natural Stone Institute, 2016).

In environmental applications, marble powder may be used in water treatment. Lime and dolomitic lime are the primary materials used in these applications. Alumina, bentonite, silica and several other mineral-derived chemicals could be used as alternatives (Natural Stone Institute, 2016).

In agriculture, marble powder could be replaced by specific industrial by-products including calcite, lime, certain types of slag, paper mill sludge and flue dust.

There are no quantified 'market sub-shares' for the identified substitutes of chalk and granules, chippings and powder of marble based on global figures. In most cases the uses are based on hypotheses made through expert consultation and literature findings (SCRREEN workshops, 2019).

16.4Supply

16.4.1 EU supply chain

EU production of circa 51.9 Mt per year in the reported period (2012-2016) is much higher than net imports (1.1 Mt/y), which mainly originate from Norway and Turkey (7% and 2% of the EU sourcing, respectively). Imports from other non-EU countries is almost negligible (0.3%). Several EU countries produce chalk, the main producers being France, Poland, Spain and Denmark. The main EU producers of granules, chipping and powder of marble are Austria, Italy, Germany, France and Greece.

There are no trade restrictions to Europe on these commodities.

16.4.2 Supply from primary materials

16.4.2.1 Geology, resources and reserves

Geological occurrence:

Limestones are rocks of sedimentary origin that are composed mainly of calcium carbonate ($CaCO_3$). Chalk is a type of very fine-grained limestone. With an increasing content of magnesium carbonate ($MgCO_3$), limestone grades into dolomite [$CaMg(CO_3)_2$]. Most limestones contain varying amounts of impurities in the form of sand, clay and iron-bearing materials.

Chalk is a soft, fine-grained, easily pulverized, white-to-grayish variety of limestone. Chalk is composed of the shells of marine organisms. The purest chalk contains up to 99% $CaCO_3$. Chalk is extremely porous, permeable, soft and friable. It may contain small amounts of silica and small proportions of clay minerals, glauconite and calcium phosphate (Gale, 2017; Eurostat, 2018).

Extensive chalk deposits occur in Europe, south of Sweden, and in England. Other extensive deposits occur in the United States and in several other countries.

Marble is geologically defined as a metamorphic rock predominately consisting of fine- to coarse-grained, recrystallized calcite ($CaCO_3$), and/or dolomite, ($CaMg(CO_3)_2$); it has a texture of relatively uniform crystals ranging from very large (several cm) to very fine, small, uniform sized crystals. Two aspects of the definition are important to the stone industry, it is metamorphic and recrystallized; thus, many marbles are formed by processes of recrystallization and/or metamorphism and have recrystallized textures that obscure most previous texture and depositional features. Impurities are often confused with other features that can be found in marble, most of which are primary depositional features or artifacts of chemical changes prior to, during, or subsequent to metamorphism and/or re-crystallization (Natural Stone Institute, 2016).

Marble occurs in large deposits that can be hundreds of meters thick and geographically extensive, allowing to be economically mined on a large scale, with some mines and quarries producing millions of tonnes per year. Marble is obtained from quarries with adequate capacity and facilities to meet the specified requirements which are equipped to process the material promptly in order to meet strict specifications.

Marble granules, chipping and powder are the 2943rd most traded product and the 2530th most complex product (out of 4776) according to the Product Complexity Index (PCI). The Economic Complexity Index (ECI) and the Product Complexity Index (PCI) are, respectively, measures of the relative knowledge intensity of an economy or a product. ECI measures the knowledge intensity of an economy by considering the knowledge intensity of the products it exports (OEC, 2019). ECI has been validated as a relevant economic measure by showing its ability to predict future economic growth (Hidalgo and Hausmann 2009), and explain international variations in income inequality (Hartmann et al. 2017.

Global and EU resources and reserves*:*

There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of high-grade limestone (including chalk or marble) in different geographic areas of the EU or globally. Individual companies may publish mineral resource and reserve reports, but reporting is done using a variety of systems depending on the location of their operation, their corporate identity and stock market requirements.

In Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for neither limestone, nor chalk or marble.

There are no global reserves figures, or country-specific figures published by any other data provider. Global reserves and resources figures are expected to be large and are distributed in several regions.

16.4.2.2 World and EU mine production

Mining and processing: High purity limestone is extracted from surface quarries across Europe following conventional quarrying procedures. Processing of limestone includes crushing, grinding, sizing and possibly drying and storage prior to transportation. Depending on the intended end use, processing stages tend to vary accordingly. Ground calcium carbonate is produced in two ground forms, coarse to medium fillers for use in agriculture, animal feeds, asphalt fillers and elsewhere, and in fine to very fine fillers for use in paper, paints and coatings, plastics, food supplements and others. High purity limestone used in glass making, environmental protection applications, sugar refining and ceramics is commonly in crushed form.

Chalk is mined in quarries. The mined chalk is then taken to crushers where it is grounded and pulverized. Primary crushing involves the use of cone or jaw crushers, while secondary crushing involves the use of smaller crushers. Finally, grinding is carried out, mainly in rotating steel drums to remove impurities and produce a high quality fine final product. The resulting chalk is washed clean, dried and packaged.

Marble is also mined in quarries. Most marble is made into either crushed stone or dimension stone using a variety of equiment. Dimension stone is produced by sawing marble into pieces of specific dimensions.

No data is available about the world production of limestone, chalk or granules, chipping and powder of marble, thus only estimates can be used. It is mentioned that Turkey has 40% of the world marble potential. Turkey's visible reserves are 1.6 billion tonnes which means Turkey is able to meet the world's marble need for the next 80 years (Sezginmarble, 2019)

The EU production of chalk over the period 2012-2016 was 9.8 Mt. The major producer was France (25%), with Germany, Italy, Poland, Spain and Denmark following (Figure 163).

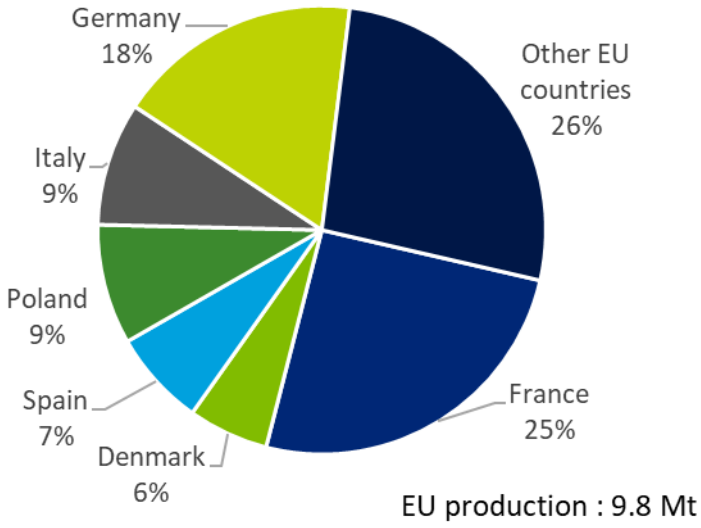


Figure 163: EU production of chalk, 2012-2016 (Eurostat, 2019)

The EU production of granules, chipping and powder of marble the period 2012-2016 was 8.5 Mt per year. The major producer was Austria (32.8%), followed by Italy and Germany. Other smaller producers are France and Greece (Figure 164).

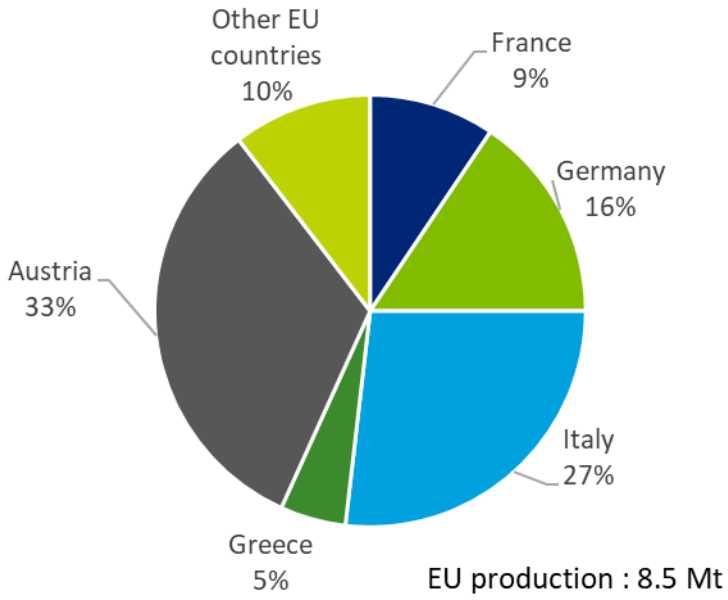


Figure 164: EU production of granules, chipping and marble powder, 2012-2016 (Eurostat, 2019)

16.4.3 Supply from secondary materials/recycling

Limestone and sub-types of limestone can be obtained from secondary sources. For instance, granules, chipping and marble powder may be recovered as by-products or waste rock from ornamental stone quarrying. At end-of-life, products in which limestone is used (e.g chalk and marble powder) are often recycled (IMA-Europe (2018). However, only for a few applications recycling produces secondary materials with the same functions of natural limestone. During the validation workshops (SCRREEN workshops, 2019), it was estimated that the only functional recycling of limestone is in paper and plastic (mainly chalk). In summary: ~60% recycling times 31% share, gives an estimated EoL-RIR of 19%

As an example of non-functional recycling, if chalk is used for the production of lime or cement at the end of life of a building it ends up in contruction and demolition wastes, part of which are recycled. Again, interior and exterior paints which contain chalk are commonly used in buildings. At the end of a building's life, paint is found in construction and demolition waste, often recycled into secondary aggregates. When marble powder is used for the production of construction materials (e.g artificial stones, blocks, tiles, prefabricated products etc) at the end of life of buildings it ends up in C&DW, which is partially recycled.

Marble powder in container glass is recycled through the glass recycling process, however the market share is 2% only (IMA-Europe, 2018).

16.5Other considerations

16.5.1 Environmental and health and safety issues

There are no major issues about health, regulatory or trade restrictions about limestone, including Chalk and granules, chipping and marble powder.

Limestone may be ground to produce fine particles which rarely contain quartz, so there might be some concern about Respirable Crystalline Silica (RCS) in the framework of the EU Directive 2017/2398 on "Protection of workers from exposure to carcinogens or mutagens at work" that implements a set of legal limits on exposure to certain substances in industrial workplaces.

Chalk and marble quarrying and processing, has been strongly debated. Reclamation of quarries is carried out in all developed ountries. Recently, emphasis is given not only to restoration of the anvironment, minimization of the visual impacts and improvement of the aesthetics in the affected areas but also in turning abandoned or exhausted quarries into profitable and sustainable operations (Buondonno et al., 2018; Luna et al., 2016; Pitz et al., 2019). The management of overburden produced in quarries is also an important task and is carried out in a similar matter as in other open pit exploitations (Oggeri et al., 2019).

16.5.2 Socio-economic issues

Similarly to many other raw materials, Limestone, in particular Chalk and marble quarrying are labor intensive operations, have direct economical impact and generate jobs, while most workers live in nearby areas. Unfortunately, quarries have big ecological footprint and visual impact quite similar to other mining activities of similar scale. The transport of raw materials may also lead to additional adverse environmental impacts.

Thus, socio-economic issues are very important for the areas (and the countries) where these raw materials are extracted since they contribute to social welfare and economic growth (Euromines, 2016). On the othe hand, in order to meet the criteria of sutainable growth and environmental protection, sustainable development indicators (SDIs) need be used at all stages, including exploration, mining, and post-mining so that social, economic and environmental improvement is achieved in the areas of concern (Tzeferis et al., 2013; Blengini et al., 2013; Komnitsas et al., 2013). It is mentioned that the socio-economic impact of quarrying can be assessed by using specific methodologies (Sergeant et al., 2016).

16.6Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. In the previous assessment (2017) the supply risk of limestone was calculated, using the Combined Nomenclature (CN) codes 25210000 LIMESTONE FLUX; LIMESTONE AND OTHER CALCAREOUS STONE, OF A KIND USED FOR THE MANUFACTURE OF LIME OR CEMENT and 28365000 CALCIUM CARBONATE. The results of this and earlier assessments are shown in Table 80.

Table 80: Economic importance and supply risk results for limestone

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Limestone	5.95	0.73	5.76	0.38	2.5	0.1	3.5	0.2

16.7Data sources

Production data for high purity limestone are largely not available, or show discrepancies. EU production as well as trade data were obtained from the Eurostat Easy Comext database (Eurostat, 2019). Data on trade agreements was taken from the DG Trade webpages, which included information on trade agreements between the EU and other countries (European Commission, 2017). Information on export restrictions were accessed by the OECD Export restrictions on Industrial Raw Materials database (OECD, 2019).

For trade data the Combined Nomenclature (CN) codes 250900 CHALK and 25174100 GRANULES, CHIPPING AND MARBLE POWDER were used. Trade data was averaged over the five-year period 2012 to 2016.

Several assumptions were made in the assessment of substitutes, especially regarding the allocation of sub-shares. Hence the data used to calculate the substitution indexes were often of poor quality.

16.7.1Glossary

Limestone

Sedimentary rock composed of the mineral calcite (calcium carbonate or CaCO3).

Calcite

Crystalline mineral consisting of calcium carbonates.

Chalk

Soft, fine-grained, easily pulverized, white-to-grayish variety of limestone.

Ground Calcium Carbonate (GCC)

Either limestone or marble may be used as the basis for crushed or ground calcium carbonate (GCC). Three quarters of GCC are manufactured from marble chips. The distribution of particle sizes in a GCC is much broader than for a PCC.

Hydraulic lime (CN 2522.30.0000)

A chemically impure form of lime with hydraulic properties of varying extent, that possesses appreciable amounts of silica, alumina and usually some iron, chemically combined with much of the lime. Used mainly in the construction materials and civil engineering.

Lime

Lime is a generic term, but by strict definition it only embraces manufactured forms of lime – quicklime (CaO) and hydrated lime ($Ca(OH)_2$). It is, however, sometimes used to describe limestone products, which can be confusing. The raw material for all lime-based products is a natural stone: limestone, which is composed almost exclusively of calcium carbonate ($CaCO_3$). When limestone contains a certain proportion of magnesium, it is called dolomite, or dolomitic limestone ($CaMg(CO_3)_2$) (Eula, 2019).

Precipitated Calcium Carbonate (PCC)

Precipitated Calcium Carbonate (PCC) is made by direct carbonation of hydrated lime, known as the milk of lime process. PCC is purer than the limestone from which it is made, and is lower in silica and lead. Most PCC goes in the paper making process.

Quicklime (CN 2522.10.0000)

Lime product consisting mainly of CaO. Produced from limestone from which carbon dioxide has been removed by heating in a kiln.

Slaked lime (CN 2522.20.0000)

Is obtained when calcium oxide is mixed, or 'slaked' with water, $Ca(OH)_2$.

16.7.2 Data sources used in the factsheet

Blengini, G.A., Moltrer, A., Valbusa, M., Komnitsas, K., Agioutantis, Z., Garbarino, E., (2013). Data and methodologies for a resource-efficient planning of primary and secondary aggregates in South East Europe (SEE) countries, Proceedings 6th International Conference "Sustainable Deveoplemt in the Minerals Industry (SDIMI)", 30 June - 3 July 2013, Milos, Greece, http://sdimi2013.conferences.gr/sdimi2013-home.html

Brun, P., Kunz, A., Funke, M. (2013). Buried under gypsum powder, a rear respiratory complication, Respiratory Medicine Case Reports, 8, 36-39.

Buondonno, A., Capra, G.F., Di Palma, D., Grilli, E., Vigliotti, R.C. (2018). Pedotechnologies for the Environmental Reclamation of limestone quarries. A protocol proposal, Land Use Policy, 71, 230-244

Euromines (2016). A Quick Guide to Socio-economic analysis of a mining/quarrying project, http://www.euromines.org/files/quick_guide_socio.pdf

European Commission (2019). DG Trade. Agreements [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/

European Commission (2017). Legal framework for mineral extraction and permitting procedures for exploration and exploitation in the EU, MinPol and partners, May 2017, https://publications.europa.eu/en/publication-detail/-/publication/18c19395-6dbf-11e7-b2f2-01aa75ed71a1/language-en

Eurostat (2019a). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2019b). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

Gale A. (2017). Norman Berry Peake, 1921–2010, a chalk revolutionary, Proceedings of the Geologists' Association, 128(5–6), 829-839.

Industrial Minerals Association (IMA-Europe) (2018). Recycling Industrial Minerals

Komnitsas, K., Agioutantis, Z., Shields, D., Blengini, G.A., Tzeferis, P.G. (2013). Stakeholder identification in the planning phase of aggregate and quarrying projects, Proceedings 6th International Conference "Sustainable Deveoplemt in the Minerals Industry (SDIMI)", 30 June - 3 July 2013, Milos, Greece, pp. 294-301, http://sdimi2013.conferences.gr/sdimi2013-home.html

Luna, L., Pastorelli, R., Bastida, F., Hernández, T., García, C., Miralles, I., Solé-Benet, A. (2016). The combination of quarry restoration strategies in semiarid climate induces different responses in biochemical and microbiological soil properties, Applied Soil Ecology, 107, 33-47

Minerals4EU (2019). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

National Institute for Occupational Safety and Health (NIOSH). (2002). Health effects of occupational exposure to respirable crystalline silica. Department of Health and Human Services, Centers for Disease Control Prevention, National Institute for Occupational Safety and Health, Atlanta, Georgia, 145 p, https://www.cdc.gov/niosh/docs/2002-129/pdfs/2002-129.pdf?id=10.26616/NIOSHPUB2002129.

OECD (2019). OECD Export restrictions on Industrial Raw Materials database. [online] Available at: http://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

Oggeri, C., Fenoglio, T.M., Godio, A., Raffaele Vinai, R. (2019). Overburden management in open pits: options and limits in large limestone quarries, International Journal of Mining Science and Technology, 29(2), 217-228.

Pitz, C., Mahy, G., Harzé, M., Uyttenbroeck, R., Arnaud Monty, A. (2019). Comparison of mining spoils to determine the best substrate for rehabilitating limestone quarries by favoring native grassland species over invasive plants, Ecological Engineering, 127, 510-518

SCRREEN workshops (2019). "Validation Workshop on Critical Raw Materials, 10-12 September 2019, Thon Hotel Brussels City Centre."

Sergeant, A., Poesen, J., Duchateau, P. (2016). A methodological framework to assess the socio-economic impact of underground quarries: A case study from Belgian Limburg, Science of the Total Environment 541, 559-569.

Tzeferis, P., Kavalopoulos, Komnitsas, K., (2013). Production data and Sustainable Development Indicators (SDIs) for the Greek Mining/Metallurgical Industry in the period 2007-2011, Proceedings 6th International Conference "Sustainable Deveoplemt in the Minerals Industry (SDIMI)", 30 June - 3 July 2013, Milos, Greece, pp. 269-276, http://sdimi2013.conferences.gr/sdimi2013-home.html

USGS (2019). Mineral commodity summaries, Dimension stone and Lime, https://www.usgs.gov/centers/nmic/mineral-commodity-summaries

16.7.3 Data sources used in the criticality assessment

Daxueconsulting (2014), https://daxueconsulting.com/the-marble-market-in-china/

ETH (2018). A sustainable future for the European Cement and Concrete Industry - Technology assessment for full decarbonisation of the industry by 2050, https://europeanclimate.org/wp-content/uploads/2018/10/AB_SP_Decarbonisation_report.pdf

Eula (2019a). https://www.eula.eu/about-lime-and-applications/ (accessed 5 June 2019)

Eula (2019b). https://www.eula.eu/publications/glossary/ (accessed 5 June 2019)

European Commission (2016). DG Trade. Agreements [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/

Eurostat (2018). Economy-wide materials flow accounts handbook, ISBN 978-92-79-88337-8

Eurostat (2019a). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2019b). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

Ferrari Granulati Marmi sas (2019), http://www.ferrarigranulati.it/en/applications/

Hartmann, D., Guevara, M.R., Jara-Figueroa, C., Aristaran, M., Hidalgo, C.A. 2017. Linking Economic Complexity, Institutions, and Income Inequality, World Development 93, 75–93.

Hidalgo, C.A., Hausmann, R. (2009). The building blocks of economic complexity, Partha Sarathi Dasgupta (ed), University of Cambridge, Cambridge, United Kingdom, PNAS June 30, 2009 106 (26) 10570-10575; https://doi.org/10.1073/pnas.0900943106

Institute for European Studies (IES, 2018). Industrial Value Chain. A Bridge Towards a Carbon Neutral Europe, Vrije Universiteit Brussel (VUB), https://www.ies.be/files/Industrial_Value_Chain_25sept.pdf

Natural Stone Institute (2016).Marble and Onyx, An excerpt from the Dimension Stone Design Manual, Version VIII (May 2016), Produced and Published by the Marble Institute of America

Observatory of Economic Complexity (OED), 2019. https://oec.world/en/profile/hs92/251741/ (accessed 2 June 2019)

OECD (2019). OECD Export restrictions on Industrial Raw Materials database. [online] Available at: http://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

Sezginmarble, (2019), /http://www.sezginmarble.com/blog-detail/turkey-has-40-world-marble-potential/

UN data (2019). http://data.un.org/Data.aspx?d=ComTrade&f=_l1Code%3A26

16.8Acknowledgments

This factsheet was prepared by the JRC in collaboration with Prof. Konstantinos Komnitsas (Technical University Crete). The authors would like to thank the Ad Hoc Working Group on Critical Raw Materials, in particular Ms. Aurela Shtiza and Ms. Francesca Girardi of IMA-Europe, as well as experts participating in SCRREEN workshops for their valuable contribution and feedback.

17. MAGNESITE

17.1 Overview

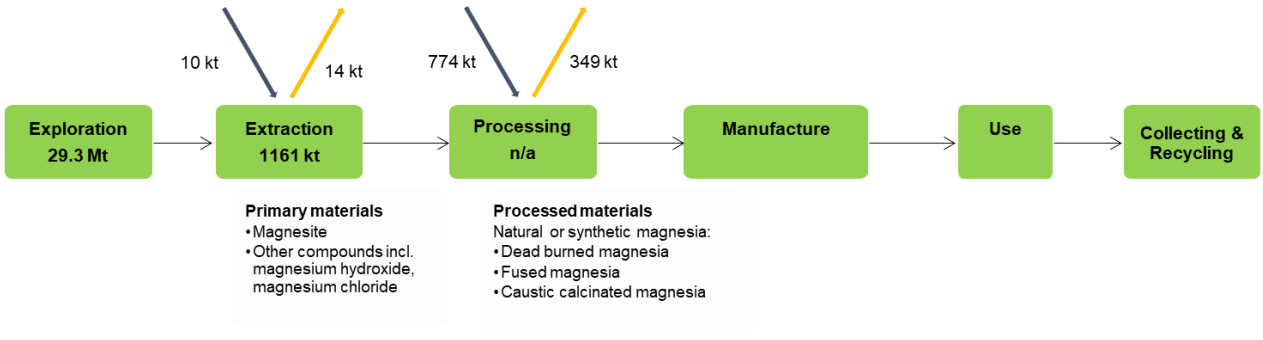
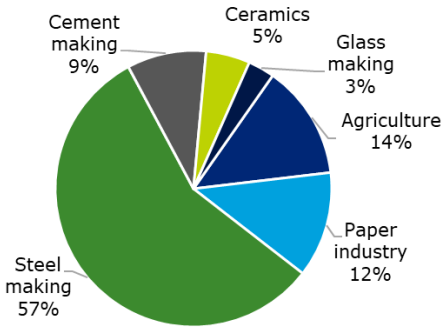


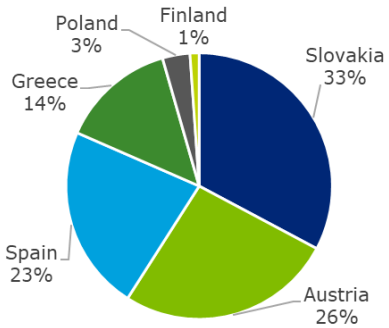
Figure 165: Simplified value chain for Magnesite in the EU, 2012-2016[109])

Natural Magnesite is the common name for the mineral magnesium carbonate ($MgCO_3$). Magnesite is mainly used in magnesia processing and refined in three commercial grades: caustic calcined magnesite (CCM), dead burned magnesite (DBM) and fused magnesia (FM). DBM and FM are predominantly used in the refractory industry for cement, glass, iron and steel making but it is also an important raw material in some advanced electrical application, leather tanning and other similar applications; CCM is mostly used in chemical-based applications such as fertilisers and livestock feed, pulp and paper, iron and steel making, hydrometallurgy and waste or water treatment. In addition to being produced from magnesite (produced material is called natural magnesia), magnesia can be processed from other sources such as magnesium hydroxide, magnesium chloride together with dolomite or lime. The obtained material is called synthetic magnesia. Magnesite was on the list of CRMs in 2014.

For the purpose of the criticality assessment natural magnesite (mine stage) only is considered, whereas information on magnesia is reported in this factsheet.



EU consumption: 1,160 kt (MgO content)



EU sourcing: 1,160 kt (MgO content)

Figure 166: End uses (SCRREEN workshops, 2019) and EU sourcing (WMD, 2019) of Magnesite (average 2012-2016).

[109] JRC elaboration on multiple sources (see next sections) - MgO contained

At mine stage, CN8 trade code 25191000 (Natural magnesium carbonate "magnesite") is used (43% MgO contained, i.e. 26% magnesium contained) (Eurostat Comext, 2019). Data only include magnesite: magnesium chloride, seawater and brines are not included. Although these are used in synthetic magnesia production and therefore may be considered as equivalent to magnesite.

The world production of magnesite averaged over 2012-2016 was around 11,000 kt MgO equivalent per year. Dominated by China (66%), with EU production accounting for 10% of global supply. In the same period, the EU was a net exporter of magnesite (import reliance -0.2%), but a net importer of magnesia (Eurostat Comext, 2019).

The prices of magnesite and magnesia are defined for each grade, based on material purity and the market situation such as magnesia overcapacity and export restrictions from China. The majority of magnesite/magnesia is traded on annual contracts and only small amounts are sold on the open market.

The EU consumption of magnesite between 2012 and 2016 was around 11,600 ktonnes per year (WMD, 2019; Eurostat Comext, 2019), sourced through domestic production, mainly in Slovakia, Austria, Spain, Greece and Poland.

Magnesite and magnesia are mainly used in Steel making (57%), Agriculture (14%), Paper industry (12%), Cement making (9%), ceramics (5%) and glass making (3%) with generally low substitutability. Some substitues exists in steel making only.

Identified world magnesite resources are estimated at over 12,000 million tonnes (MgO contained) with the majority located in China, Russia, North Korea, Australia, Slovakia, Brazil, Turkey, India and Canada (USGS, 2019). According to USGS (2019), world known reserves of magnesite stand at 8,500 million tonnes MgO contained. The largest reserves are located in Russia (27%), North Korea (27%) and China (12%). Known reserves in the EU (Greece, Slovakia, Austria, Spain) represent 8% of the total.

Recycling of refractory materials is possible in the steel industry as well as in the construction industry. Most refractories last from few weeks to several years, depending on service conditions and material performance. However due to the low value of spent refractory materials, and the abundance of primary magnesia, there is little incentive to recycle spent refractory. Other uses do not practically allow recycling. Overall, a recycling rate (EoL-RIR) of 2% was adopted (Bio Intelligence Service, 2015).

Since the end of 2016 there are not export taxes or quotes from China. Such export tax and quotas were considered distortive of Magnesite and magnesia markets[110].

Note: The present factsheet focuses on the value chain of magnesite and magnesia. Magnesite may be used to produce magnesium metal (along with dolomite), and dolomite or brucite may be used to produce magnesia. However the value chain for magnesium (see relevant factsheet) and the value chain for magnesite and magnesia (MgO) are very distinct, in particular in the EU since all magnesite is used for magnesia processing only. Finally, synthetic magnesia is included as magnesia in the factsheet, but few robust data is available.

[110] export quotas on Magnesite (550 000 t) ended in 2010 and export taxes (15%) in 2013

17.2Market analysis, trade and prices

17.2.1Global market analysis and outlook

The main driver for demand for the magnesia sector globally and in Europe is the growth in refractory demand especially from the steel industry but also includes those from glass and cement sectors. Dead burned magnesia (DBM) currently makes up the largest portion of produced magnesia intermediate products. Due to fused magnesia's (FM) superior stability and strength, demand and market share for FM is expected to grow in the future. Revenue from the global magnesium oxide (MgO) market is anticipated to increase at a CAGR of 4% over 2016–2026 due to steady demand from iron and steel refractories and a resurgence of the construction industry which result in additional demand for cement and construction steel (Future Markets Insights, 2016).

The estimations for the outlook for supply and demand of magnesite were provided by industry experts. No information was available regarding the outlook for supply and demand of magnesia.

Table 81: Qualitative forecast of supply and demand of Magnesite

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Magnesite		x	+	+	+	+	+	+

17.2.2EU trade of Magnesite / Magnesia

Trade of magnesite between the EU and the rest of the world is not significant compared to magnesite extraction in Europe. Mainly because the ore is rarely shipped or used in crude form, but is rather processed near the mine site to yield magnesia products. On average, in the 2012 to 2016 period the EU is a net exporter of magnesite (import reliance -0.2%), but not in all single years. The trade balance can therefore be considered in equilibrium.

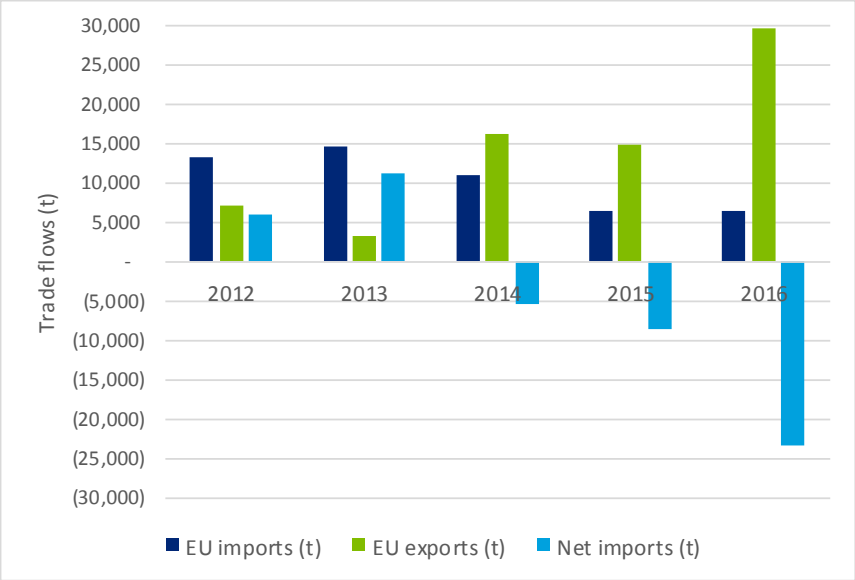


Figure 167: EU trade flows for Magnesite (Eurostat, 2019)

Most of MgO material traded between the EU and the rest of the world occurs under magnesia form. The EU is a net importer of magnesia since the domestic production of magnesite and magnesia does not satisfy the European demand. Imports of magnesia were around 774 kt per year MgO contained between 2012 and 2016, and dead burned magnesia (DBM) concerned the majority of imports: 54% of total imports on average. Imports of magnesia to the EU slightly declinined in the reported period. (Eurostat, 2019)

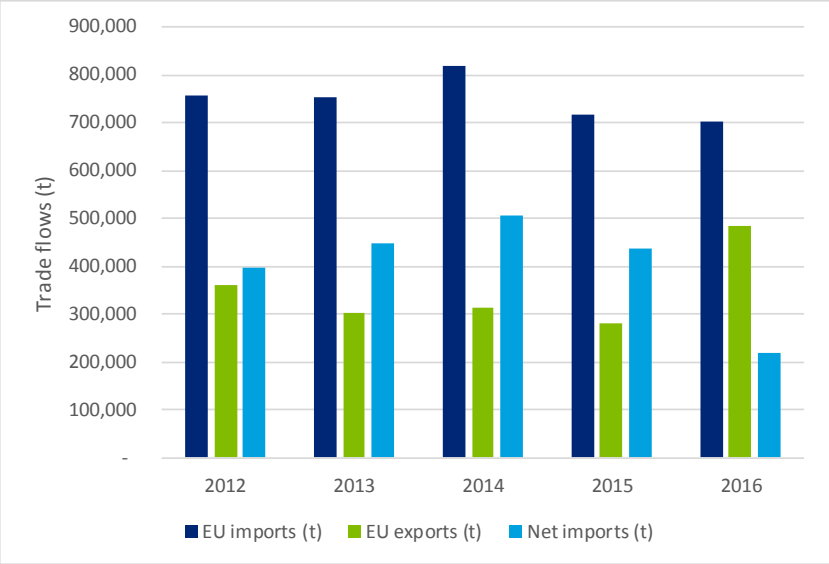


Figure 168: EU trade flows for Magnesia (Eurostat, 2019)

The main importers to the EU are Turkey (87%) and China (7%). At the time of the criticality assessment (2019), there were EU free trade agreements in place with South Africa, Mexico and Morocco (European Commission, 2019). There are no exports, quotas or prohibition in place between the EU and its suppliers (OECD, 2019). China export quotas on magnesite (550 kt) ended in 2010 and export taxes (15%) in 2013 (OECD, 2019). China is the main country supplying magnesia to the EU in the reporting period (2012-2016), and accounts for more than 40% than total imports (Eurostat, 2019). For DBM imports to EU according to Eurostat, Turkey is the main supplier. For CCM (agriculture and industrial uses) and for FM, China is the main supplier.

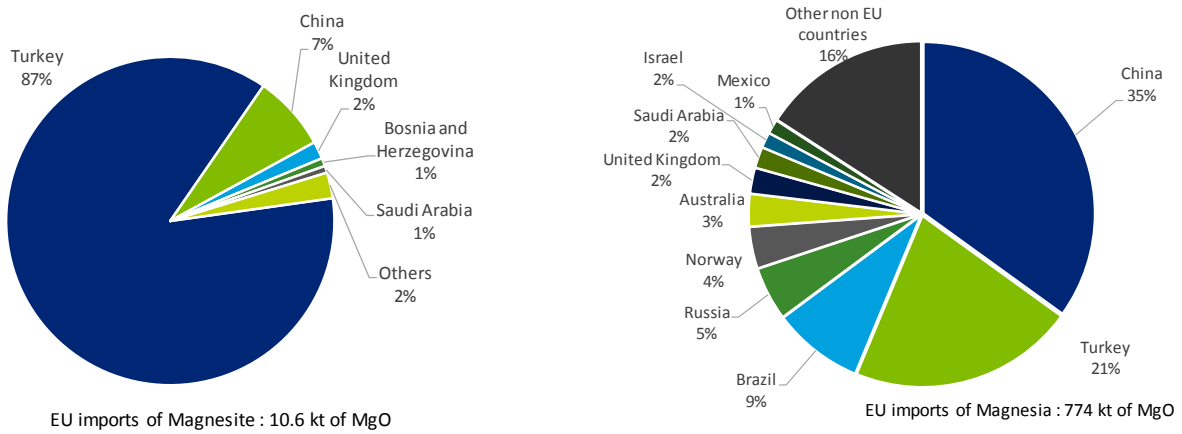


Figure 169: EU imports of Magnesite and Magnesia, average 2012-2016 (Eurostat, 2019)

For magnesia trade data, the following CN codes were used (Eurostat, 2019):

- 25199030 'Dead-burned "sintered" magnesia, whether or not containing small quantities of other oxides added before sintering' (estimation of 85% MgO contained);
- 25199090 'Fused magnesia' (estimation of 85% MgO contained);
- 25199010 'Magnesim oxide, whether or not pure (excl. calcined natural magnesium carbonate)' (estimation of 84% MgO contained).

17.2.3Prices and price volatility

The prices of magnesia are defined for each grade, based on material purity and the market situation such as magnesia overcapacity and export restrictions from China. Prices of magnesia varied as follow (BGR, 2014; SCRREEN workshops, 2019):

- EUR 295 per tonne of calcined magnesia for agricultural industry in Europe;
- USD 473 per tonne of dead burned magnesia on the Chinese market;
- USD 1,050 per tonne of fused magnesia on the Chinese market.

17.3EU demand

17.3.1EU demand and consumption

The EU annual apparent consumption of magnesite totalled 1,157 kt MgO contained, averaged over 2012 to 2016. It was calculated based on reported production of magnesite within the EU (WMD, 2019), as well as imports and exports of magnesite (Eurostat, 2019).

A reasonable estimate of magnesia apparent consumption in the EU was 1,800 kt MgO contained annually, on average between 2012 and 2016. It was estimated based on magnesite apparent consumption, as well as imports and exports of magnesia (both natural and synthetic forms). However synthetic magnesia production is missing (no robust information available).

17.3.2Uses and end-uses of Magnesite in the EU

The main uses of magnesite in the EU are shown in Figure 170.

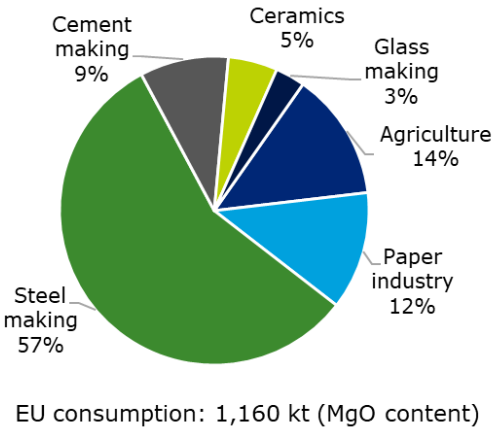


Figure 170: EU end uses of magnesite (SCRREEN workshops, 2019[111]), average 2012-2016.

[111] IMA-Europe and Magnesitas Navarras S.A.

In Europe, magnesite is used in magnesia processing only (SCRREEN workshops, 2019). Therefore there is no need to distinguish between end-uses of magnesite and magnesia. The magnesia end-uses cover end products manufacturing from both synthetic and natural magnesia.

The major uses of magnesite and magnesia in the EU vary depending on the type of magnesia. Dead burned magnesia (DBM) accounts for the largest volumes compared with fused magnesia (FM) and caustic calcined magnesia. It is highly requested in high-duty refractory products, welding electrodes and fluxes, as well as in low duty electrical insulation components for industrial and domestic devices and appliances (electrical grade DBM).

The major use of FM is in refractories, as for DBM. It is also used for electrical insulation in medium and high-duty heating elements (Euromines, 2016).

Finally, caustic calcined magnesia (CCM) is mainly used in agricultural applications, as fertiliser and soil improvers, but also as animal feed supplements. In addition, there is an increasing consumption of CCM in industrial applications such as pharmaceuticals and food, pulp and paper industry, or in specific environmental applications such as in wastewater treatment (Euromines, 2016).

The end-uses of magnesite and magnesia are as follow:

- Steel industry and also applies to cement, glass and ceramics: DBM and FM are used as the main raw material for basic refractories. The magnesia refractories can be classified in shaped and non-shaped. The shaped magnesia refractory bricks are often impregnated with carbon (tar, pitch, graphite) to give optimum properties for corrosion resistance in environments of basic slags, particularly in BOF (basic oxygen furnaces) or slag lines of treatment ladles. Magnesia bricks often in combination with spinel or chrome are also used in ferroalloy and non-ferrous industries (AZoM, 2001). Magnesia is also used in hot metal transport and machinery (JRC, 2013). The unshaped magnesia products are also used in special repair mixes.
- Agriculture: The Magnesium element contained in magnesium oxide is required for plant photosynthesis and is a nutrient contributing to animal health. CCM is the most commonly used source of magnesium for ruminant nutrition, but is also used for sheep and poultry. In addition, CCM is used in various fertiliser applications, especially for crops such as citrus, potatoes, vegetables, fruit and grass pastures (Baymag, 2016).
- Paper industry: CCM is used in the chemical process of wood pulping as raw material for magnesium sulphite production, subsequently used for pulping as a cellulose protector and peroxide stabiliser (after pulp bleaching). The sulphite processes represent 10% of global wood pulp production (Grecian Magnesite, 2013). In addition, magnesia may be used in wastewater treatment that paper and pulping mill operate for the disposal of their water (Van Mannekus & Co, 2016).
- Cement industry: Sorel cement is a strong binder based on magnesia and a magnesium oxychloride formulation. It is fast-hardening and has a number of specific (e.g. industrial floors) and general repair applications. Magnesia is also used as a room temperature curing agent for phosphate cements (AZoM, 2001).
- Ceramics: Magnesia ceramics have high thermal stability, as well as good corrosion resistance, good insulating properties and thermal conductivity. They are mainly used for manufacturing high temperature crucibles, thermocouple tubes, heating elements, and foam ceramic filters for molten metal or in kiln furniture (SubsTech, 2015).
- Glass making: Magnesia is used by the glass industry for its thermal and pyrochemical resistance in melting furnaces and regenerator chambers (JRC, 2013). As constituent in

the glass formulation leads to increased mechanical properties that are required in glass used in modern constructions and other technological applications.

- Other applications of magnesite and magnesia include electrical insulation components (DBM), pharmaceuticals and cosmetics (CCM), sugar refining (CCM), fillers in plastics, rubber, paints and adhesives (CCM), etc. (SCREEN workshops, 2019).

Relevant industry sectors are described using the NACE sector codes (Eurostat, 2019).

Table 82: Magnesite applications (Euromines, 2016; SCRREEN workshops, 2019), 2-digit associated NACE sectors, and value added per sector (Eurostat, 2019)

Applications	2-digit NACE sector	Value added of NACE 2 sector (millions €)
Agriculture	C20 - Manufacture of chemicals and chemical products	105,514
Agriculture	C10 - Manufacture of food products	155,880
Paper industry	C17 - Manufacture of paper and paper products	38,910
Steel making	C24 - Manufacture of basic metals	55,426
Cement making	C23 - Manufacture of other non-metallic mineral products	57,255
Ceramics	C23 - Manufacture of other non-metallic mineral products	57,255
Glass making	C23 - Manufacture of other non-metallic mineral products	57,255

17.3.3Substitution

Substitutes are identified for the applications and end uses of the commodity of interest. In the case of magnesite and magnesia, there are no materials that can replace any of the main uses of magnesite and magnesia without serious loss of end performance or increase of cost. Substitutes are assigned a 'sub-share within a specified application and considerations of the cost and performance of the substitute, as well as the level of production, whether the substitute has a 'critical' status and produced as a co-product/by-product. Exact sub-shares for the substitute materials are unknown and have been estimated.

There is no material for replacement of caustic calcinated magnesia in agriculture and industrial applications, which are the major uses of CCM (SCRREEN workshops, 2019). In agriculture, magnesia is used for its magnesium element and can therefore not be substituted.

Dead burned magnesia has a very high melting point and an excellent resistance to slag attack, thus imparts exceptional properties when used in refractories. Hence, although potential substitutes such as refractory materials made of alumina, silica etc. exist, the substitution of DBM would not be without loss of performance or increase of cost. The only product that has even higher refractory properties is electrofused magnesia (SCRREEN workshops, 2019).

17.4Supply

17.4.1EU supply chain

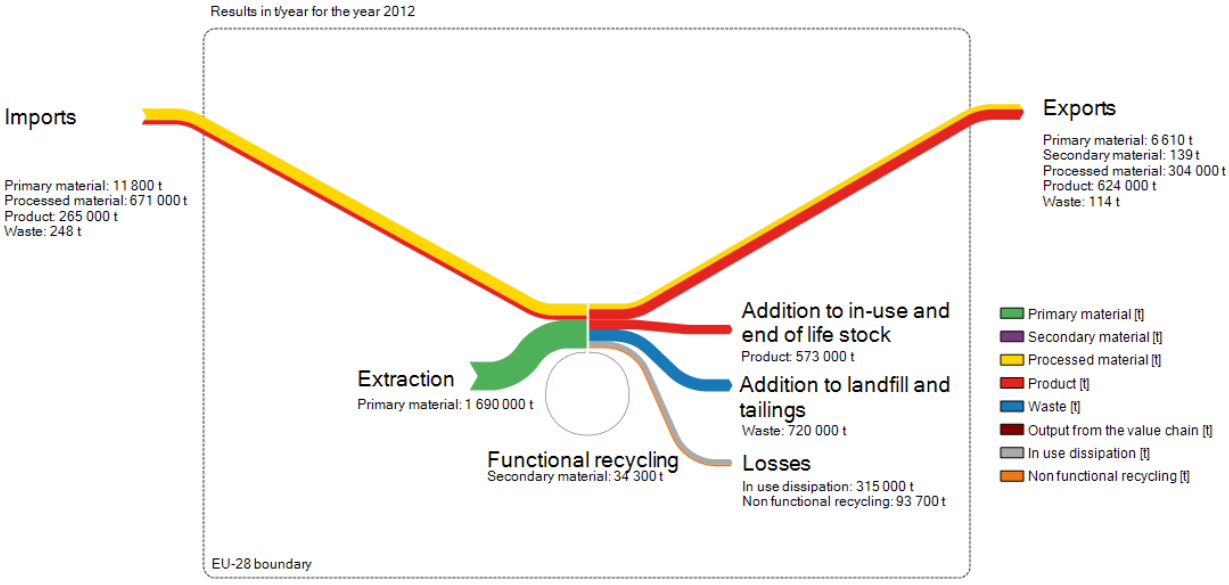


Figure 171: Simplified MSA of magnesite flows in the EU (BIO Intelligence Service, 2015).

The EU supply chain of magnesite and magnesia can be described by the following (averaged over the period 2012 to 2016):

- The 5-year average European production of magnesite was 1,160 kt MgO contained per year, which accounts for 10% of the global production. Producing countries include Slovakia, Austria and Spain, as well as Greece and Poland.
- Magnesite is processed into natural magnesia in Europe. In addition, synthetic magnesia is produced in European countries such as Netherlands and Ireland. However, no robust information is available on synthetic magnesia production.
- There were few magnesium oxide producers in the EU, and thus a correspondingly low number of plants producing magnesia (JRC, 2013).
- The traded quantities of magnesite between the EU and the rest of the world are not significant compared to magnesite extraction in Europe. The EU trade balance can be considered in equilibrium.
- Most of MgO material traded between the EU and the rest of the world occurs under magnesia form. The EU was a net importer of magnesia since the domestic production of magnesite and magnesia did not satisfy the European demand. Net imports of magnesia were of 774 kt MgO contained. China is the main country supplying magnesia, and accounts for 35% (Eurostat, 2019).
- The import reliance for magnesite in Europe was very close to zero; however the import reliance for magnesia in Europe may be estimated around 25% based on data available on magnesite extraction and trade of magnesite and magnesia.
- India imposed an export tax for magnesia, which was at 3.25% in 2014 and was still in place in 2017 (OECD, 2019).

- In 2005 and 2006, the European Commission imposed definitive anti-dumping duty on imports respectively of magnesium oxide and dead burned magnesia from China, which expired in 2010 and 2011 respectively (European Commission, 2016).
- A Customs Union Agreement exists with one of EU major suppliers of magnesite and magnesia, namely Turkey (European Commission, 2016).
- There is no significant recycling of magnesia from end of life products (Bio Intelligence Service, 2015; Euroalliages, 2016; SCRREEN workshops, 2019).

17.4.2 Supply from primary materials

17.4.2.1 Geology, resources and reserves of Magnesite

Geological occurrence:

Magnesia has a concentration of 1,94% in the Earth crust (Fluck und Heumann, 2002). Magnesite is the common name for the mineral magnesium carbonate ($MgCO_3$). Pure, uncontaminated magnesite contains the equivalent of 47.8% magnesium oxide (MgO), and 52.2% of carbon dioxide. Impurities in magnesite are mainly carbonates, oxides and silicates of iron, calcium, manganese and aluminium.

Magnesite occurs mainly in four types of deposits. Crystalline magnesite deposits found in replacement of dolomite vary in size as well as in the level of impurities – from 2-20%. In determining the value of this type of deposit, grade is as critical as size, particularly for the magnesite that will be used to manufacture high purity refractories. Magnesite also occurs as impure crystalline masses replacing ultramafic rocks or as cryptocrystalline masses in ultramafic rocks. Deposits of cryptocrystalline magnesite are generally smaller than crystalline magnesite deposits. They occur as nodules, veins, and stockworks in serpentinised zones of ultramafic rocks, or can be found as small deposits in tuffs. Deposits of this type are as variable in size as those that occur in dolomite. Finally, sedimentary magnesite is a carbonate rock that probably formed by evaporation. This type of magnesite is interbedded with dolomite, clastic rocks, or strata of volcanic origin. Even though some sedimentary deposits contain high grades of magnesite, the thin beds cannot be mined economically (Kramer, 2006).

According to the development and characteristics of deposits, two types of magnesite crystals can be found. Crystalline magnesite forms crystal visible to the eye; cryptocrystalline or microcrystalline magnesite ranges from 1-10 µm. In addition to varying in crystal size, the two types also vary in the sizes of the deposits and in modes of formation. Crystalline magnesite deposits occur in relatively few, but generally large deposits, on the order of several million tonnes. Calcite and dolomite are the main impurities. Cryptocrystalline magnesite is often found in small deposits. Siliceous minerals such as serpentine or quartz are generally present (Kramer, 2006).

On the overall, replacement deposits containing sparry magnesite in carbonate rocks have the highest economic importance, accounting for 80% of the worldwide magnesite extraction. They occur in mainly in Austria, Spain, Slovakia, USA, Korea and China. Cryptocrystalline magnesite, on the other hand, from the decomposition of serpentine rocks, occurring for example in Greece, Serbia and Turkey. Brucite has been exploited in the past for the production of magnesia but is no longer an important source as minable concentrations of brucite are rarely found (Kramer, 2006).

Global resources and reserves[112]: Identified world magnesite resources are estimated at over 12 billion tonnes with the majority located in China, Russia, North Korea, Australia, Slovakia, Brazil, Turkey, India and Canada. Over 90% of magnesite resources are sedimentary-hosted. The balance of the resources (< 10%) occurs as veins or talc-magnesite bodies within ultramafic rocks (Simandl, 2007).

According to USGS (2019), world known reserves of magnesite stand at 8.5 billion tonnes MgO contained, with more than 66% of reserves located in Russia(27%), China (12%) and North Korea (27%). Known reserves in the EU are 8% of total.

Table 83: Global reserves of magnesite in 2018 (USGS, 2019)

Country	Magnesite reserves (kt MgO)
Korea, North	2,300,000
Russia	2,300,000
China	1,000,000
Brazil	390,000
Australia	320,000
Greece	280,000
Turkey	230,000
Slovakia	120,000
India	82,000
Austria	50,000
United States	35,000
Spain	35,000
Other countries	1,400,000
Total	*8,542,000*

EU resources and reserves[113]*:*

Reserves for some EU countries are available (Minerals4EU, 2019), but cannot be summed as they do not use the same reporting code, or do not specify the grade ($MgCO_3$ contained).

[112] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of Magnesite in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template, which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

[113] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for Magnesite. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for Magnesite, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for Magnesite the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019). Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system.

Table 84: EU Resources from the European Minerals Yearbook (Minerals4EU, 2019)

Country	Reporting code	Quantity	Unit	Grade	Code Resource Type
Slovakia	None	21.88	Mt	42.37% $MgCO_3$?	Verified - Economic
Greece	USGS	12.5	Mt	NA	Measured
Poland	Nat. rep. code	4.46	Mt	NA	Measured + Indicated
Ireland	None	2	Mt	33% $MgCO_3$?	Estimate

Table 85: Reserve data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2019)

Country	Reporting code	Quantity	Unit	Grade	Code Reserve Type
Slovakia	None	21.88	Mt	42.37% $MgCO_3$	Verified
Poland	Nat. rep. code	4.18	Mt	NA	Total
Spain	None	3.25	Mt	NA	Proven

17.4.2.2 World and EU mine production

Magnesite mining varies depending on the type of the deposit. Large, massive, near surface deposits are usually worked by open pit methods. Narrow and deep deposits are mined underground. The mined ore is rarely shipped or used in crude form. It is processed near the mine site to yield magnesia products. Invariably some degree of sorting or beneficiation is applied to the ore prior to heat treatment (Kramer, 2006).

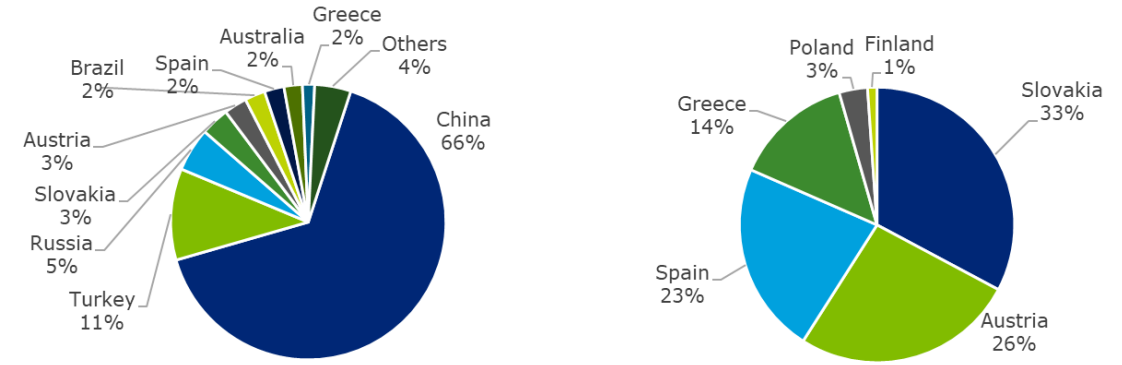


Figure 172: Global and EU mine production of Magnesite. Average for the years 2012-2016. (WMD, 2019)

There are interesting deposits of magnesite in EU. Since 2017, there is a new mining site producing Magnesite, located in the region: Castilla y Leon (Spain) (SCRREEN workshops, 2019).

17.4.3Supply from secondary materials/recycling

17.4.3.1 Post-consumer recycling (old scrap)

Magnesia is poorly recovered from post-consumer waste. Agricultural applications using caustic calcined magnesia are dispersive, thus not allowing for any recovery.

Recycling of refractory materials is possible in the steel industry as well as in the construction industry. Most refractories last from few weeks to several years, depending on service conditions and material performance. However due to the low value of spent refractory materials, and the abundance of primary magnesia, there is little incentive to recycle spent refractory.

Potential reuses in the refractory sector include use of recycled magnesia as repair material. To repair cracks and crevices in the highly erosive zones of the steel furnace; or as foamy slag additive, thus reducing electrical energy consumption and overall refractory consumption (Kwong and Bennett, 2002; Angara Raghavendra, 2008).

On the overall, recycling in the steel and the construction sectors remains quite low, or the magnesia contained in post-consumer products is recycled in other applications (non-functional recycling). Up to 10% of refractory bricks are recycled (BIO Intelligence Service, 2015).

In the refractory use, there are a huge area for R&D, in order to recover and process, shaped and unshaped refractories. It is important to avoid cross-contamination to achieve a secondary raw material for refractory application (it is not feasible for agriculture uses due to heavy metals content). An example of R&D project is LIFE 5REFRACT[114]. A reasonable recovery ratio for waste refractories seems to be: >50% for shape refractories and >15% for unshaped refractories. However, a substantial improvement of the recovery system is needed to also achieve economic viability.

All the above considered, the end-of-life recycling input rate (EoL-RIR) is calculated at 2% for magnesite and magnesia (Bio Intelligence Service, 2015).

Table 86: Material flows relevant to the EOL-RIR of Magnesite

MSA Flow	Value (kt)
B.1.1 Production of primary material as main product in EU sent to processing in EU	1088.6
B.1.2 Production of primary material as by product in EU sent to processing in EU	0.0
C.1.3 Imports to EU of primary material	11.8
C.1.4 Imports to EU of secondary material	0.0
D.1.3 Imports to EU of processed material	671.1
E.1.6 Products at end of life in EU collected for treatment	253.2
F.1.1 Exports from EU of manufactured products at end-of-life	0.1
F.1.2 Imports to EU of manufactured products at end-of-life	0.2
G.1.1 Production of secondary material from post consumer functional recycling in EU sent to processing in EU	0.0
G.1.2 Production of secondary material from post consumer functional recycling in EU sent to manufacture in EU	34.3

[114] https://www.life5refract.eu/en/project/

17.4.4 Processing of Magnesite into magnesia

Magnesite or magnesium hydroxide (brucite) is converted into magnesium oxide by burning (calcining). Magnesite is burnt in horizontal rotary or vertical shaft kilns, normally by direct firing with oil, gas and petcoke. Decomposition of magnesium carbonate to form magnesium oxide and carbon dioxide begins at a temperature above 500°C (Lehvoss 2016).

The temperature and duration of the calcination process determines the grade of magnesia. Grades produced at relatively low temperatures (up to approx. 1,300°C) are called caustic calcined magnesia and have a moderate to high chemical reactivity. Burning at temperatures above 1,600 °C produces dead burnt magnesia and fused magnesia, two magnesium oxide grades with extremely low reactive properties, strength and resistance to abrasion (used as refractory material) (Kramer, 2006; Lehvoss 2016; Euromines, 2016).

Commercial grade of caustic calcined magnesia contains 80% up to 97% MgO. Dead burned magnesia and fused magnesia have a 85% up to 98% MgO purity.

The production capacity of magnesite and magnesia is much higher than the actual production. According to experts (SCRREEN workshops, 2019), the Chinese dead-burned magnesia (DBM) capacity is 11 Mt/y, i.e. 2.2 times the actual production in China, while the electro-fused magnesia (EFM) capacity is 3.6 Mt/y, 2.1 times the actual production in China.

The capacity of EU producers (of DBM from natural magnesite) is about 1 Mt/y of DBM per year, averaged over 2012-2016. EU capacity could increase, if macroeconomic, political and environmental conditions would allow it.

17.4.4.1 Processing of synthetic magnesia from other sources of MgO

Magnesium oxide may also be processed differently than by calcination of magnesite, e.g. by producing magnesium hydroxide or magnesium hydroxide carbonate chemically, then calcined to give synthetic magnesia. Magnesium hydroxide may be obtained from various sources, such as magnesium-rich solutions as precipitate (using dolime, limestone, seawater or magnesium chloride), from $MgCl_2$ pyro-hydrolysis or as a residue remaining after the lime fraction of calcinated dolomite is removed. Magnesium chloride may be recovered after solar concentration of solutions of natural brines for production of salt or potash, or from brines and seawater.

No robust data is available on natural and synthetic magnesia production worldwide or at the EU level. Synthetic magnesia is estimated to represent about 5% of global magnesia production (Bio Intelligence Service, 2015). Historically, the main global producers of high grade dead burnt magnesia were based on synthetic technology, converting magnesium rich seawater or brine into magnesia. However there are several natural dead burnt magnesia producers in Turkey and Australia (Ispat Guru, 2015).

The main countries producing synthetic magnesia are the Netherlands, Ireland, Norway, Israel, Japan, South Korea, Mexico, the US, Russia and reportedly China. In the past, synthetic magnesia was also produced by more producers in Japan, the US, Italy, UK and one other plant in Ireland, among others (Kramer, 2006; Euromines, 2016).

17.5Other considerations

17.5.1Environmental and health and safety issues

There are no major health and regulatory issues about magnesite and magnesia.

Similarly to other minerals and mineral products, the mining of magnesite and its processing into magnesia are subject to all EU environmental, health and safety related legislation in force.

Reducing emissions in the magnesite industry contribute to a performance increase in the characteristics of the magnesia products used in the steel production. For example, an increase of the economic lifetime of the installed refractory linings – magnesia products result in a reduced consumption of refractory products per unit in the production of steel. According to a Euromines report (2016), the specific consumption of refractory materials in the steel industry reduced from the value of 30 kg per tonne of produced steel in the 1980s to a value of 10-15 kg per tonne of produced steel.

17.5.2Socio-economic issues

No specific issues were identified during data collection and stakeholders consultation.

17.6Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. Supply risk has been analysed at mine stages.

Table 87: Economic importance and supply risk results for Magnesite in the assessments of 2011, 2014, 2017, 2020 (EC, 2011, 2014, 2017)

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Magnesite	8.9	0.86	8.28	2.15	3.7	0.7	3.2	0.65

17.7Data sources

17.7.1Data sources used in the factsheet

Angara Raghavendra (2008). Recovery of materials from recycling of spent furnace linings. [online] Available at: http://scholarsmine.mst.edu/cgi/viewcontent.cgi?article=5630&context=masters_theses

AZoM (2001). Magnesia – Magnesium Oxide (MgO) Properties & Applications. [online] Available at: http://www.azom.com/article.aspx?ArticleID=54

Baymag (2016). Agricultural applications. [online] Available at: http://www.baymag.com/applications/agricultural.php

BGR (2014). Deutschland – Rohstoffsituation 2014. [online] Available at: https://www.bgr.bund.de/DE/Themen/Min_rohstoffe/Downloads/Rohsit-2014.pdf?__blob=publicationFile&v=3

BGR (2012). Deutschland – Rohstoffsituation 2012. [online] Available at: https://www.bgr.bund.de/DE/Themen/Min_rohstoffe/Downloads/Rohsit-2012.pdf?__blob=publicationFile&v=11

BGS (2004). Commodity profile – Magnesium.

BGS (2016). World Mineral Production 2010-2014. [online] Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.html

Bio Intelligence Service (2015). Study on Data for a Raw Material System Analysis: Roadmap and Test of the Fully Operational MSA for Raw Materials – Final Report. Prepared for the European Commission, DG GROW.

European Commission (2014). Report on Critical Raw Materials for the EU. [online] Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission (2016). DG Trade Agreements. [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/

Eurostat (2016)a. International Trade Easy Comext Database. [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

Euromines (2016). European magnesite producers position (Euromines). http://www.euromines.org/news/newsletters/1-2016/european-magnesite-producers-position-euromines

Fluck und Heumann (2002). Periodensystem der Element, Wiley, VCH-Verlag, 3. Auflage, 1 page

Future Markets Insights (2016). Global Demand for Magnesium Oxide to Reach 11,182 KT in 2016: FMI Study. [online] Available at: http://www.futuremarketinsights.com/press-release/magnesium-oxide-market

Grecian Magnesite (2013). Pulp and Paper Application of MgO – Research and Development Center Technical Note. [online] Available at: http://www.grecianmagnesite.com/sites/default/files/P%26P%20-%20R%26D%20Technical%20Note_0.pdf

IM (2017). Fused magnesia prices increase in China. [online] Available at: http://www.indmin.com/Article/3709216/Magnesia/Fused-magnesia-prices-increase-in-China.html

Ispat Guru (2015). Magnesia. [online] Available at: http://ispatguru.com/magnesia/

JRC (2013). Best Available Techniques (BAT) Reference Document for the Production of Cement, Lime and Magnesium Oxide. [online] Available at: http://eippcb.jrc.ec.europa.eu/reference/BREF/CLM_Published_def.pdf

Kramer (2006). Magnesium Minerals and Compounds.

Kwong and Bennett (2002). Recycling practices of spent MgO-C refractories. [online] Available at: http://file.scirp.org/pdf/JMMCE20020200001_22452944.pdf

Lehvoss (2016). Production of magnesia. [online] Available at: http://nl.lehvoss.de/143.htm

Minerals4EU (2019). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

OECD (2016). Export restrictions on Industrial Raw Materials database. [online] Available at: http://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

SCRREEN workshops (2019). "Validation Workshop on Critical Raw Materials, 10-12 September 2019, Thon Hotel Brussels City Centre."

Shillito (2015). Relative positioning: Magnesia producers adjust to new industry conditions. [online] Available at: https://www.mgxminerals.com/media/downloads/articles/5-26-2015.pdf

Simandl et al. (2007). Magnesium - Raw Materials, Metal Extraction and Economics - Global Picture. [online] Available at: http://www.empr.gov.bc.ca/Mining/Geoscience/IndustrialMinerals/Documents/Magnesium.pdf

SubsTech (2015). Magnesia ceramics. [online] Available at: http://www.substech.com/dokuwiki/doku.php?id=magnesia_ceramics

USGS (2016). Mineral Commodity Summaries – Magnesium Compounds. [online] Available at: https://minerals.usgs.gov/minerals/pubs/commodity/magnesium/mcs-2016-mgcom.pdf

USGS (2019). Mineral Commodity Summaries – Magnesium Compounds. [online] Available at: https://minerals.usgs.gov/minerals/pubs/commodity/magnesium/mcs-2017-mgcom.pdf

Van Mannekus & Co (2016). Pulp and Paper. [online] Available at: http://www.mannekus.com/pulp-and-paper/

17.7.2Data sources used in the criticality assessment

Bio Intelligence Service (2015). Study on Data for a Raw Material System Analysis: Roadmap and Test of the Fully Operational MSA for Raw Materials – Final Report. Prepared for the European Commission, DG GROW.

Euromines (2017). Communication during the review.

Eurostat (2016a). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

European Commission (2016b). DG Trade. Agreements [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/

NedMag (2016). Communication during the review.

OECD (2016). Export restrictions on Industrial Raw Materials database. [online] Available at: http://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

USGS (2016). Mineral Commodity Summaries – Magnesium Compounds. [online] Available at: https://minerals.usgs.gov/minerals/pubs/commodity/magnesium/mcs-2016-mgcom.pdf

World Mining Congresses (2016). World Mining Data, Volume 31, Minerals Production

17.8Acknowledgments

This factsheet was prepared by the JRC. The authors would like to thank the Ad Hoc Working Group on Critical Raw Materials, in particular Euromines, IMA-Europe and Magnesitas Navarras S.A., as well as experts participating in SCRREEN workshops for their valuable contribution and feedback.

18. MANGANESE

18.1 Overview

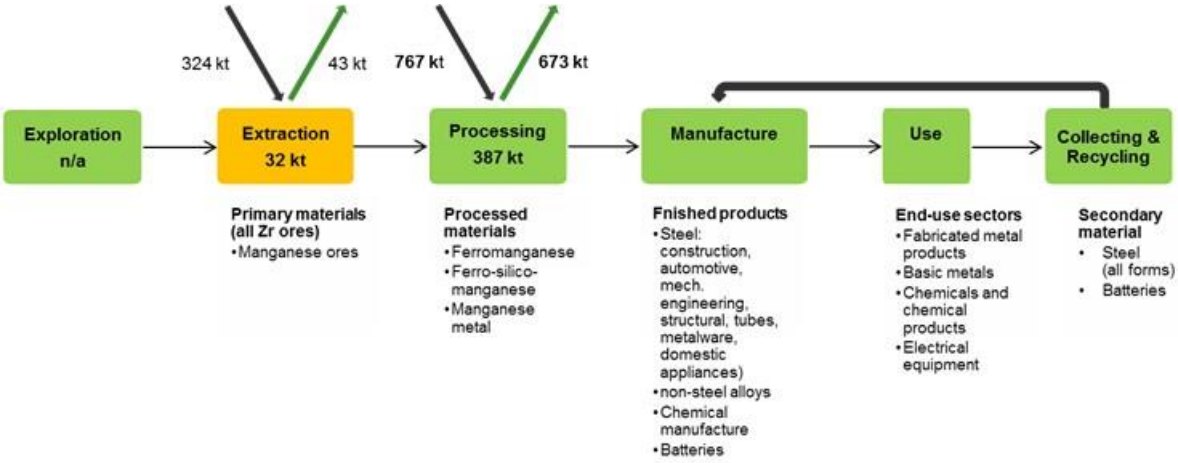
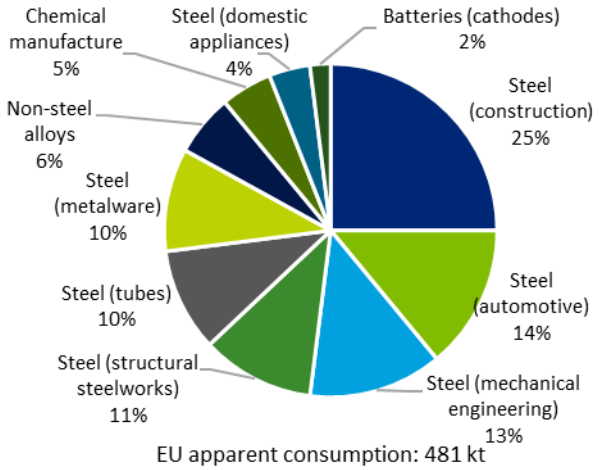
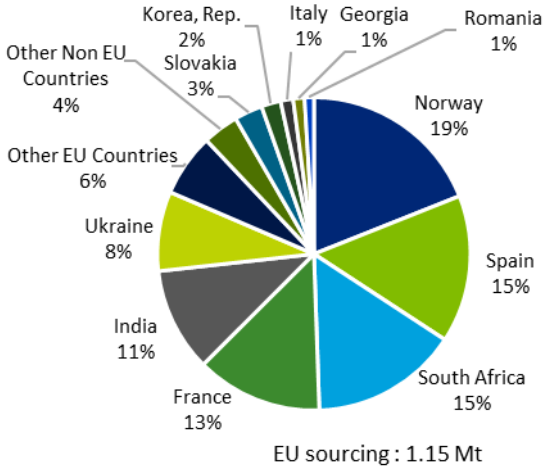


Figure 173: Simplified value chain for manganese in the EU, average 2012-16[115]

Manganese (chemical symbol Mn) is a paramagnetic, relatively hard yet brittle metal. It has a density of 7.21 g/cm^3 and high melting point of 1246 °C. Manganese is the 12th most abundant element in the Earth's uppercrust with an abundance of about 0.1 wt% (Rudnick & Gao, 2003). Manganese is extracted from a number of deposit types (i.e. sedimentary, sedimentary-hydrothermal and supergene). The principal ore mineral of manganese is pyrolusite (MnO_2), although braunite (a manganese silicate), psilomelane (a manganese oxide) and rhodochrosite ($MnCO_3$) may be locally important. Manganese is very efficient at fixing sulphur and acts as a powerful deoxidiser, it is these properties that make it essential in the manufacture of steel (the main application of manganese). It is also used in the production of aluminium alloys, dry cell batteries and pigments. A small amount of manganese is essential to development, metabolism and the antioxidant system in humans. However, over exposure to manganese dusts and fumes is thought to be linked with a number of neurological disorders.





[115] JRC elaboration on multiple sources (see next sections).

Figure 174: EU end uses and EU sourcing of manganese (processing stage), average 2012-16.

For the purpose of this assessment manganese is analysed at both extraction and processing stage. At the extraction stage, manganese is traded in the form of manganese ores, but also contained in iron ores and pig iron. However, the manganese content in pig iron varies in dependence of the Mn content in the iron ore, from which it is produced. Consequently, the variability of the Mn content cannot be estimated properly as the variability of the manganese content in iron ores is too large. At this stage, manganese is assessed in the form of manganese ores and concentrates (CN8 code 2602 00 00).

At processing stage, manganese is considered as ferromanganese (FeMn), and ferrosilico-manganese (FeSiMn)[116], which are produced by smelting processes (reduction of ores/oxides at high temperatures). Ferromanganese is mostly used to improve the hardness and wear resistance of steel. High-carbon ferromanganese (HC FeMn) is produced from carbothermic reduction of lumpy or sintered manganese ore in a three-phase submerged electric arc furnace. Low-carbon ferromanganese (LC FeMn), is traditionally produced by a silicothermic process route and medium-carbon ferromanganese (MC FeMn) is usually produced by decarburisation of HC FeMn in an oxygen-blown converter. Ferrosilicomanganese (FeSiMn) enhances the natural properties of steel, giving it increased strength and function, as well as improved aesthetic appeal. It is produced by smelting in submerged electric arc furnaces.

The related CN codes for FeMn are 7202 11 (HC FeMn), 7202 19 (MC FeMn), and for FeSiMn 7202 30. No trade restrictions were detected for: manganese dioxide (2820 10 00), primary cells and primary batteries: manganese dioxide (8506 10). For foreign trade calculations, manganese ores were estimated to have a manganese content of 25%, while the manganese content of FeMn and FeSiMn were estimated at 78% and 65%, respectively.

The world market of manganese was 13,000 ktonnes (average for period 2012-2016). The global manganese market is dominated by Asia, as almost half of the global supply is from Asia, amended by a third of Africa. At the same time Asia makes up almost 80% of global demand. Europe shows a supply deficit, while South America, Oceania and Africa show a supply surplus. Accordingly, global manganese trade is dominated by exports from Africa and Australia, and the imports of China, Commonwealth of Independent States (CIS), EU and U.S.. The demand for manganese is closely associated with steel production, accounting for well over 90% of global manganese consumption. Consequently, future market dynamics are likely to be driven by global iron and steel production.

Manganese is traded at the Shanghai Metals Market (SMM), and the open market, e.g. the global B2B trade platform FerroAlloyNet[117].

According to data on the InfoMine website (2016), global manganese prices have been declining from a high of almost USD3,500 per tonne in 2012 to just under USD2,000 per tonne in 2016. The price trend for manganese appears to be linked to global steel production, which has also seen a decline in many parts of the world, with the exception of China, since 2011. Electrolytic manganese has been reported to rise again to USD2,211.50 per tonne (average for period May 2018 to April 2019) (DERA, 2019).

[116] Ferro-silico-manganese (Fe-Si-Mn) is also called Silico-Manganese (Si-Mn)
[117] http://www.ferroalloynet.com/

According to the DERA raw materials price monitor and the LMB Bulletin, the manganese metal prices (99.7% electrolytic manganese flakes) have decreased since 2015; as it cost USD2,493 per tonne in average on the period 2011-2015 but only USD1,779 per tonne in average on the period December 2015-November 2016, i.e. a price drop of 28.6%. Electrolytic manganese has been reported to rise again to USD2,211.50 per tonne (average for period May 2018 to April 2019) (DERA, 2019).

Similar trends were reported for ferromanganese (78% manganese), with a price drop of 17.3% since 2015, from €828.6 per tonne in average on the period 2011-2015, but only €685 per tonne in average on the period December 2015-November 2016. Ferromanganese (fob India) (75%) has been reported at higher prices more recently, at USD1,132.90 per tonne (DERA, 2019).

The apparent EU consumption of manganese in processed stage (FeMn, FeSiMn) is around 481 ktonnes per year.

The EU domestic production is calculated as around 387 ktonnes per year (USGS Minerals Yearbook reports), which is 3% of the global production. According to Euroalliage, the average EU production is around 305 ktonnes per year, with clear upward trends (increase by more than 50% for HC FeMn and SiMn) in the period covered. Major EU producers are Spain (46%) and France (39%).
The most important non-EU suppliers of manganese to the EU are Norway, South Africa and India. Together, they make up more than half of the imports of manganese to the EU regarding manganese in processed stage. Sourcing from the EU is dominated by Spain (15%, 176 ktonnes per year) and France (151 ktonnes per year, 13%). The world's main producer of manganese, China, seems to direct its production outside the EU or use the commodity itself.

About 87% of manganese is used in steel production. Manganese has a key role in the production of iron and steel for two important reasons. Firstly, manganese is a powerful desulphurising agent and an effective reductant (i.e. oxygen remover). Secondly, manganese improves the mechanical properties of steel. Steel is used in a wide range of end-uses, which include: automotive body parts, domestic appliance casings, architectural steel (e.g. girders) and hollow-profile steel products (e.g. pipes and tubes).

Manganese is also used in the production of non-steel alloys (i.e. aluminium-manganese alloys) used in the manufacture of aluminium cans and food packaging. The addition of up to 1.5% manganese in these alloys dramatically improves the corrosion resistance of the packaging. Special aluminium alloys containing up to 9% manganese are produced for the aerospace industry. Adding 0.1%-0.3% manganese to copper alloys can improve their strength and hot-workability.

Today, the most important non-metallurgical use of manganese (as manganese dioxide) is in the manufacture of dry-cell batteries, where it is used a depolariser. Manganese belongs to a group of metals that are relevant to meet the future low carbon technology requirements due to their role in electric storage batteries, for which sharp rises are indicated. The World Bank showed in its report "The Growing Role of Minerals and Metals for a Low Carbon Future" that the demand of manganese in these technologies can multiply (Arrobas *et al.*, 2017).

According to USGS, world reserves of manganese are about 630 Mtonnes. Current reserves are adequate to meet global demand for several decades. Global resources in traditional land-based deposits, including both reserves and rocks sufficiently enriched in manganese to be ores in the future, are much larger, at about 17,000 Mtonnes. From a purely geologic perspective, there is no global shortage of proven ores and potential new ores that could be developed from the vast tonnage of identified resources.

Reserves and resources are very unevenly distributed. The Kalahari manganese district[118] in South Africa contains 70% of the global identified resources and about 25% of the global reserves. South Africa, Brazil, and Ukraine together accounted for nearly 65% of the global reserves in 2013.

Global production of manganese between 2012 and 2016 amounted in average to 13,067,589 tonnes per year.

The United Nations Environment Programme (UNEP) estimates end-of-life (EoL) recycling of manganese, predominantly as a constituent of ferrous (e.g. iron and steel) and non-ferrous (e.g. aluminium packaging) scrap, to be greater than 50% (UNEP, 2013). However, the amount of manganese effectively recovered from old scrap is with around 10% much smaller.

Manganese can also be recovered along with iron from slag generated during the production of steel (USGS, 2016). It is recycled incidentally as a constituent of ferrous and nonferrous scrap; however, scrap recovery specifically for manganese was negligible.

18.2Market analysis, trade and prices

18.2.1Global market analysis and outlook

The global manganese market is dominated by Asia, in particular China, as almost half of the global supply is from Asia, amended by a third of Africa. At the same time Asia makes up almost 80% of global demand. Europe, along with Commonwealth of Independent States (CIS) countries, and North America, shows a supply deficit, while South America, Oceania and in particular Africa show a supply surplus. Accordingly, global manganese trade is dominated by exports from Africa and Australia, and the imports of China, CIS, EU and USA.

The demand for manganese is closely associated with steel production, accounting for well over 90% of global manganese consumption. Consequently, future market dynamics are likely to be driven by global iron and steel production, which is set to increase as countries such as China and India continue to develop (Table 88).

Table 88: Qualitative forecast of supply and demand of manganese

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Manganese		x	+	+	+	+	+	+

Beside the supply risks at extraction, production and manufacturing stages, there are growing concerns about a rising market concentration in the commercialising segment, namely the concentration of companies selling ferromanganese to the steel sector.

Though steel will continue to dominate manganese demand, consumption of manganese in batteries is expected to grow rapidly over the next decade. There remain many uncertainties concerning how fast the growth of manganese consumption in batteries will be, and which

[118] A prominent example of an Mn ore mine ramping up production (2014) is United Manganese of Kalahari (UMK)

manganese products and production processes will be required to fulfil the demand from lithium-ion batteries.

18.2.2EU trade

Between 2012 and 2016, the average yearly imported manganese in manganese ores in EU was 324,000 tonnes. With around 767,000 tonnes yearly, the average yearly imported manganese in processed form is about 140% higher (Figure 175).[119]

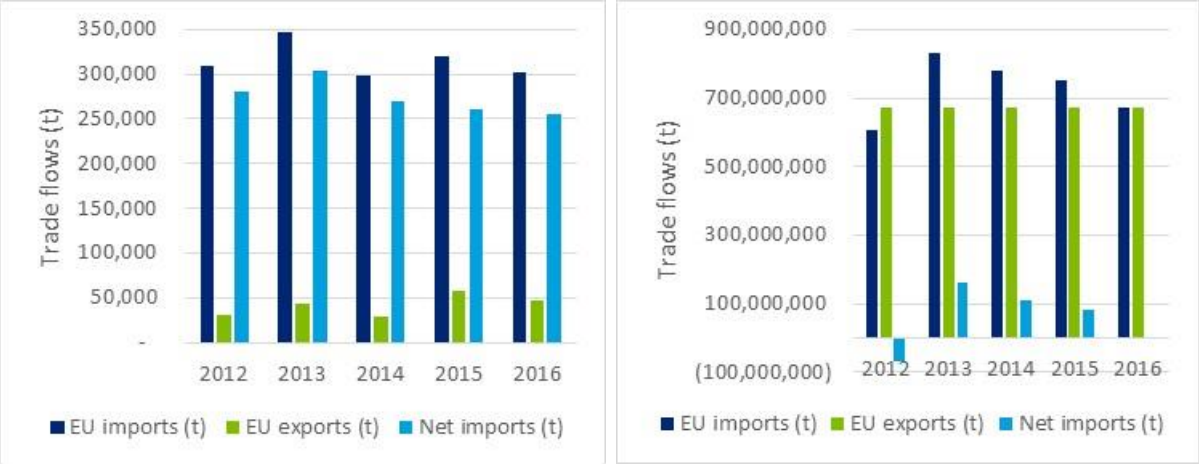


Figure 175: EU trade flows for (left) manganese ores (UN Commodity Trade Statstics, 2019; Ullmann's ecncyclopedia 2012, Jeong et al. 2009), and (right) manganese (processed stage)[120] (UN Commodity Trade Statstics, 2019, Eurostat Comext, 2019)

The EU imports of manganese ores show a strong country concentration. By far the most important suppliers of manganese ore to the EU are South Africa, Gabon and Brazil, with an accumulated import share of 89% (see Figure 176). The import of manganese in processed form (FeMn, FeSiMn) is less concentrated on supplier countries. Here, the main suppliers are Norway (28%), South Africa (23%), India (16%), and Ukraine (12%). The world's main producer of manganese (processed), China, is not a relevant source of EU supply and seems to direct its production to other destinations outside the EU or use the commodity themselves.

At the moment, there are no export quotas or prohibition in place between the EU and its suppliers (OECD, 2016). From the EU's suppliers, only Gabon has an export tax (≤25%) (OECD, 2016).

[119] EU trade is analysed using product group codes. It is possible that materials are part of product groups also containing other materials and/or being subject to re-export, the "Rotterdam-effect". This effect means that materials can originate from a country that is merely trading instead of producing the particular material.

[120] exports are not annual values, but already averaged

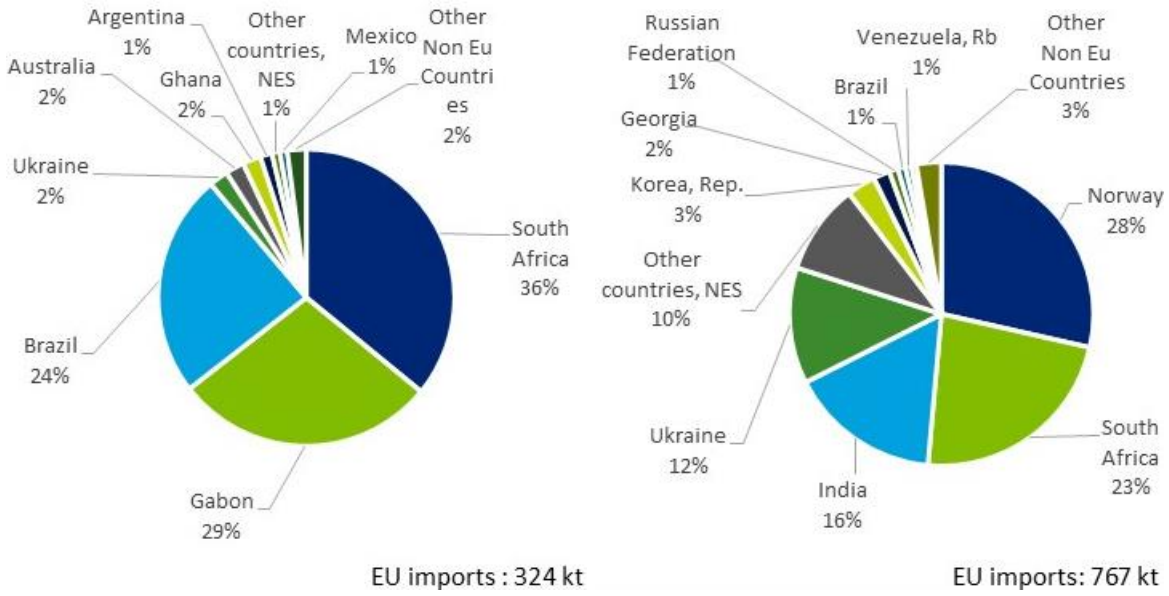


Figure 176: EU imports of manganese ores (left) (UN Commodity Trade Statstics, 2019, Ullmann's ecncyclopedia 2012, Jeong et al. 2009) and manganese metal (right) (UN Commodity Trade Statstics, 2019, Eurostat Comext, 2019), average 2012-2016

18.2.3Prices and price volatility

Manganese is traded at the Shanghai Metals Market (SMM), and the open market, e.g. the global B2B trade platform FerroAlloyNet[121]. For example, Fastmarkets can provide a weekly physical manganese ore spot market price.

According to data on the InfoMine website (2016), global manganese prices have been declining over the last five years from a high of almost USD3,500 per tonne in 2012 to just under USD2,000 per tonne in 2016. The price trend for manganese appears to be linked to global steel production, which has also seen a decline in many parts of the world, with the exception of China, since 2011.

According to the DERA raw materials price monitor and the LMB Bulletin, the manganese metal prices (99.7% electrolytic manganese flakes) have decreased since 2015; the price dropped from USD2,493 per tonne in average on the period 2011-2015 to USD1,779 per tonne in average on the period December 2015-November 2016, i.e. a price drop of 29%. Electrolytic manganese has been reported to rise again to USD2,212 per tonne (average for period May 2018 to April 2019) (DERA, 2019).

The same trend can be observed for ferro-manganese (78% manganese), with a price drop of 17% since 2015 from €829 per tonne in average on the period 2011-2015, but only €685 per tonne in average on the period December 2015-November 2016. Ferromanganese (fob India) (75%) has been reported at higher prices more recently, at USD1,133 per tonne (DERA, 2019).

The long-term prices of ferromanganese are shown in Figure 177. The price curve shows real prices.



Figure 177: Copper prices in USD per tonne. Vertical dashed line indicate breaks in price specification.(Buchholz *et al.* 2019)

18.3EU demand

Annual worldwide consumption of processed manganese is about 16,000 ktonnes per year.

18.3.1EU demand and consumption

The EU apparent consumption of manganese in manganese ores and concentrates was about 314 ktonnes per year during the period 2012–2016. On average one-tenth of this, about 32ktonnes per year, came from domestic production. The import reliance was 90%.

18.3.2Uses and end-uses of Manganese in the EU

EU end-uses of manganese in 2012 are shown in Figure 178 (Euroalliages).

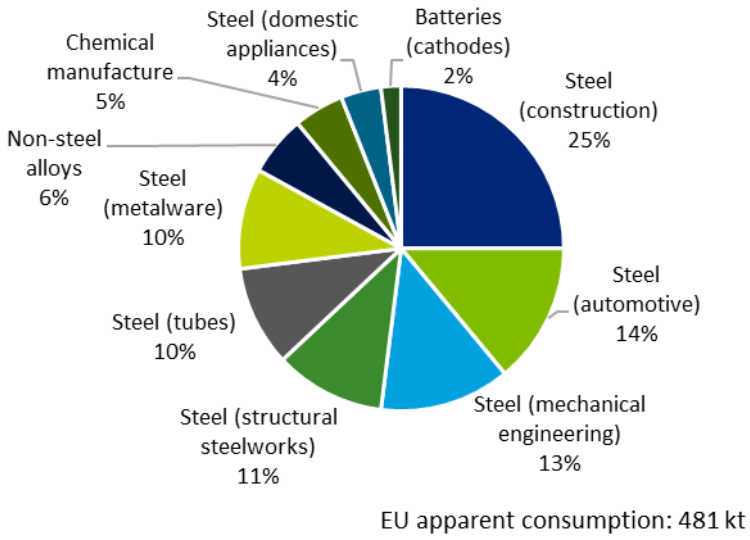


Figure 178: EU end uses of manganese. Figures for 2012 (Euroalliages, SCRREEN 2019)

Manganese has a key role in the production of iron and steel for two important properties. Firstly, manganese is a powerful desulphurising agent and an effective reductant (i.e. oxygen remover). Meaning, it 'captures' oxygen and sulphur, which inhibits the formation of iron sulphide that would otherwise result in the production of weak, brittle steels (IMnI, 2016). For this purpose, ferro-manganese (FeMn) is used, acting as deoxidizer and counteracting the undesired effects of sulfur in steel. Secondly, manganese improves the mechanical properties of steel. For example, the addition of small amounts of manganese (up to 0.8%) improves the workability of steel at high temperatures, while the addition of between 8% and 15% manganese results in steel with a very high tensile strength (Stansbie, 1908; IMnI, 2016). To

this end, both ferrosilicamanganese[122] (FeSiMn) and ferromanganese (FeMn) are used. FeSiMn enhances the natural properties of steel, giving it increased strength and function, as well as improved aesthetic appeal. FeMn is mostly used to improve the hardness and wear resistance of steel.

Due to these material properties, about 87% of manganese is used in the production of steel. The various types of steel are in turn used in a wide range of end-uses, which include: automotive body parts, domestic appliance casings, architectural steel (e.g. girders) and hollow-profile steel products (e.g. pipes and tubes).

As steel dominates the end uses of manganese, these two forms of processed manganese mentioned above are the most relevant forms, i.e. ferromanganese (FeMn) and ferro-silica-manganese (FeSiMn). Consequently, manganese at processing stage is considered in these two forms at the criticality assessment.

Manganese is also used in the production of non-steel alloys (i.e. aluminium-manganese alloys) used in the manufacture of aluminium cans and food packaging. The addition of up to 1.5% manganese in these alloys dramatically improves the corrosion resistance of the packaging. Special aluminium alloys containing up to 9% manganese are produced on a small-scale for the aerospace industry; however, they are too expensive to produce in large quantities. Adding 0.1-0.3% manganese to copper alloys can improve their strength and hot-workability. Some high-manganese copper alloys contain as much as 72% manganese; however, they are only produced in small quantities for use in niche applications such as temperature control devices and in watchmaking (IMnI, 2016).

The most important non-metallurgical use of manganese (as manganese dioxide) is in the manufacture of alkaline and non-alkaline dry-cell batteries, where it is a key ingredient used as depolariser. During discharge of a battery, hydrogen is generated at the electrodes. If this hydrogen would be allowed to accumulate in the battery cell it could seriously impede energy generation. The role of manganese dioxide in this instance is to oxidise the hydrogen to form water, which improves battery function. There are several other types of manganese bearing batteries: lithium- manganese-oxide batteries, and lithium-nickel-manganese-cobalt-oxide (NMC) batteries

Several manganese chemicals are produced, although the most well-known is potassium permanganate, which is a powerful oxidising agent primarily used for its bactericidal and algicidal properties in the treatment of drinking water. Manganese-ethylene bisdithiocarbamate (or maneb) is an organo-chemical agricultural fungicide used for a wide range of pests at various plant types. Manganese oxides and salts are also used as catalysts, pigments and in the purification of uranium ores to produce U_3O_8 (also known as 'yellow cake') (IMnI, 2016). Further uses of manganese are in fertilizer micronutrients (in particular in Brazil), and the creation of color pigments.

There are specific uses that require a very high purity of manganese (5N). The use of manganese in batteries, for example, requires high purity.

The lifespan of manganese in final use applications is variable. For example, the lifespan of batteries is significantly lower than for the other uses, around three years[123].

Relevant industry sectors are described using the NACE sector codes (Eurostat, 2016c).

[122] Ferro-silico-manganese (Fe-Si-Mn) is also called Silico-Manganese (Si-Mn)

[123] according to Prosum project

The calculation of economic importance is based on the use of the NACE 2-digit codes and the value added at factor cost for the identified sectors (Table 89). The value added data correspond to 2013 figures.

Table 89: Manganese applications, 2-digit NACE sectors, associated 4-digit NACE sectors, and value added per NACE 2 sector (Eurostat, 2016)

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (M€)
Steel (construction)	C25 - Manufacture of fabricated metal products, except machinery and equipment	C25.11 Manufacture of metal structures and parts of structures.	148,351
Steel (automotive)	C29 - Manufacture of motor vehicles, trailers and semi-trailers	C29.10 - Manufacture of motor vehicles.	160,603
Steel (mechanical engineering)	C24 - Manufacture of basic metals	C24.52 - Casting of steel.	55,426
Steel (structural steelworks)	C25 - Manufacture of fabricated metal products, except machinery and equipment	C25.11 Manufacture of metal structures and parts of structures.	148,351
Steel (tubes)	C25 - Manufacture of fabricated metal products, except machinery and equipment	*C24.20* *C2599 - Manufacture of other fabricated metal products n.e.c.*	148,351
Steel (metalware)	C25 - Manufacture of fabricated metal products, except machinery and equipment	*C24.10* *C2599 - Manufacture of other fabricated metal products n.e.c.*	148,351
Non-steel alloys	C25 - Manufacture of fabricated metal products, except machinery and equipment	C25.92 - Manufacture of light metal packaging.	148,351
Chemical manufacture	C20 - Manufacture of chemicals and chemical products	C20.59 - Manufacture of other chemical products n.e.c.	105,514
Steel (domestic appliances)	C27 - Manufacture of electrical equipment	C27.51 - Manufacture of electric domestic appliances.	80,745

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (M€)
Batteries (cathodes)	C27 - Manufacture of electrical equipment	C27.20 - Manufacture of batteries and accumulators.	80,745

18.3.3Substitution

There are currently no satisfactory substitutes for manganese in its major applications (i.e. iron and steel) (USGS, 2019).

At a more specific product level, there may be the potential for substitution of manganese in certain uses. For example, in theory, there are technical substitutes to manganese in its use as a mild deoxidizer and desulphuriser; however, there are significant trade-offs (some of which are intended and acceptable) associated with adopting some of these substitutes. Likewise, it may also be possible to substitute manganese in some of the high manganese content steels (e.g. high manganese non-magnetic steels, Hadfield steel, stainless (200 series) steel) with other metals (e.g. Nickel, Boron) to produce alternative steels which confer alternative properties (IMnI, 2018).

For alkaline batteries, manganese is used as a typical cathode material. Another application is as cathode constituent of lithium-ion batteries, whereat the cathode material mainly determines the electrochemical performance of the battery. The most commonly used cathode material with good electrochemical performance is $LiCoO_2$ providing a capacity of around 140 mAh/g. In fact, many different formulations for the cathode materials compete with each other, each showing specific pros and cons, and thus can substitute each other. They consist of mixed metal oxides and phosphates, for example:

- $LiCoO_2$: Cobalt ist vital for a high cathode energy density, but it shows unflavoured supply chain risks;
- the ratio of cathode materials determines the crystal structure and thus influences the battery performance.
    - LMO ($LiMn_2O_4$): manganese spinel is a low-cost alternative;
    - LFP ($LiFePO_4$): iron phosphate ,is safer and has a longer life-cycle;
    - NCA (lithium nickel cobalt aluminium): great specific energy, Al added for higher stability;
    - NMC (nickel manganese cobalt): cobalt is partially substituted by equal shares of manganese and nickel; high battery capacity with decreased costs compared to $LiCoO_2$;
    - layered-layered composite with excess lithium and manganese;
    - since about 2010, increasing complexity for cathode materials:
        - spinel structure, e.g. $LiMn_2O_4$ or LMNO with the lowest raw material costs (Co completely replaced by Mn and Ni at the ratio of 3 : 1;
        - orthosilicate structure, where manganese, iron, and cobalt can substitute each other in the tetrahedral structure.

Competing battery technologies thus imply the substitution cathode and anode materials, respectively. The list of possible substitutes for the metal constituent (cathode material) comprises nickel, cobalt, aluminium, manganese, iron.

18.4Supply

18.4.1EU supply chain

Manganese ores and concentrates are currently mined in only three EU countries: Bulgaria, Hungary, and Romania. The EU produces around 32 ktonnes per year in average for the period 2012-2016, which is less than 1% of the global production.

Based on averages during the period 2012–2016 about 357 ktonnes per year of manganese in manganese ores and concentrates were imported into the EU. The majority being used for blast furnaces in France and Spain, with small amounts going to Italy, Greece, Netherlands and Slovakia.

in 2019, there were no export quotas placed on manganese ores and concentrates exported to the EU from other countries. However, for the period 2012-2016 manganese exports from Gabon and China entering the EU were subject to an export tax of up to 25% (OECD, 2019), however, imports from China are not significant.

Ferromanganese imports amounted about 364 ktonnes per year during the period 2012–2016 (Eurostat, 2016a). The EU produces ferromanganese in plants mainly in Spain and France, and to a minor degree in Slovakia, Italy, Romania and Poland. This ferromanganese production is then consumed in steel manufacturing in Europe (IMnI, 2015; WMD 2018).

18.4.2Supply from primary materials

18.4.2.1 Geology, resources and reserves of manganese

Geological occurrence: Manganese deposits can be broadly divided into four groups:

1. Magmatic manganese deposits
2. Sedimentary manganese deposits
3. Structure-related manganese deposits
4. Metamorphic manganese deposits

Magmatic manganese deposits are a form of sedimentary exhalative (SEDEX) deposit associated with submarine volcanism and the circulation of metal-bearing fluids through the sedimentary sequence. The mineralisation can therefore be associated with a wide variety of rock types, including carbonates, chert, volcanic rocks (e.g. basalt and rhyolite) and organic-rich, black shale. The ore mineralogy of these deposits is complex, but usually comprises a series of manganese oxides (hausmannite), silicates (braunite), and carbonates (rhodochrosite). Important global examples of SEDEX manganese deposits are found in Mexico (Molango District) and India, whilst European examples are found in Spain, Portugal, Switzerland, Hungary, Slovakia and Cyprus (Dill, 2010; Pohl, 2011).

A wide variety of sedimentary manganese deposits have been described, including: (1) stratabound manganese deposits associated with shallow marine carbonates, or clastic sediments (i.e. sandstones and siltstones); (2) manganese deposits hosted by organic-rich, black shales; (3) manganese-rich crusts and nodules that occur on the sea floor; and (4) supergene (lateritic) ore bodies, formed by intense weathering of manganese-rich (ca. 30% manganese) rocks. Manganese deposits are exploited in a number of different countries worldwide, notable stratabound deposits are found in the Ukraine (Nikopol), Georgia (Chiatura) and northern Australia (Groote Eylandt), whilst large supergene deposits, occur in South Africa, Brazil (Minas Gerais), India (Orissa), Gabon (Moanda) and China (Pohl, 2011).

Structure-related deposits of manganese consist of hydrothermal veins that occur within many different rock types (e.g. limestones, granites and gneisses). These veins are typically mineralogically complex, and contain minerals such as: pyrolusite (manganese-oxide); psilomelane (barium-manganese-oxide-hydroxide); manganite (manganese-oxide-hydroxide); hausmannite (manganese-oxide); and braunite (manganese-silicate). Despite the fact that these deposits are generally enriched in a number of other metals besides manganese (e.g. tungsten, uranium and barium) they are not currently of economic interest. Examples of structure-related manganese deposits in Europe are known in Germany and France (Dill, 2010).

Metamorphic manganese deposits, or manganiferous banded iron formations, are economically very important. These deposits generally comprise a series of metamorphosed sediments and volcanic rocks, indicating they may actually be metamorphosed SEDEX deposits. Some of these banded manganese deposits are exceptionally high-grade (up to 50% manganese), comprising complex manganese oxides, silicates and carbonates. Important examples include deposits in the Kalahari Field in South Africa, and deposits in India and Brazil (Dill, 2010; Pohl, 2011).

Global resources and reserves[124]: The USGS reports that global land-based manganese resources are large and very unevenly distributed. They are concentrated in only a few countries, namely South Africa (74%) and Ukraine(10%) (USGS, 2019). Similarly, manganese reserves are very concentrated. The Kalahari manganese district in South Africa contains about 25% of the global reserves. South Africa, Brazil, and Ukraine together account for nearly 65% of the global manganese reserves (USGS 2019). According to USGS, world reserves of manganese are about 760,000 ktonnes (USGS 2019) (Table 90). Since 2016, the reserves in Brazil increased by more than 50,000 ktonnes and in Gabonby 43,000 ktonnes.

Manganese resources can be divided into (a) land-based deposits and districts, and (b) seabed resources located at the ocean floor. Seabed resources are enormous compared to traditional land-based resources, however, they are identified and characterized to varying degrees of detail. In addition, their technological and economic viability is still challenging.

The nature of land-based manganese deposits presents problems for precise quantitative resource estimates. Also, the variety of resource classification schemes applied adds to the fuzziness of resource estimates. Global resources in traditional land-based deposits, including both reserves and rocks sufficiently enriched in manganese to be ores in the future, are about 17,273,000 ktonnes (Cannon *et al.*, 2017).

[124] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of manganese in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template.[124], which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

Table 90: Global reserves of manganese in year 2016 (modified after USGS, 2016)

Country	Manganese Reserves (ktonnes)	Percentage of total (%)
South Africa	230,000	30
Ukraine	140,000	18
Brazil	110,000	14
Australia	99,000	13
Gabon	65,000	9
China	54,000	7
India	33,000	4
Ghana	13,000	2
Kazakhstan	5,000	<1
Mexico	5,000	<1
Malaysia	n/a	
World total (rounded)	760,000	100

EU resources and reserves[125]*:* In Europe, ten countries are known to have manganese resources. These are: Germany, Bulgaria, Spain, Portugal, Finland, the Czech Republic, Hungary, Romania, Kosovo, Greece, and Ukraine. However, the countries use different reporting codes, which makes it difficult to compare (

Table 91). Statistical data for Germany is not available at national level, because data is collected by the authorities of the individual federal states[126] (Minerals4EU, 2019).

Resource data for some countries in Europe are available in the Minerals4EU website (

Table 91) (Minerals4EU, 2019) but cannot be summed as they are partial and do not use the same reporting code. The same applies for reserve data (Minerals4EU, 2019) (Table 92).

Table 91: Resource data for the EU compiled in the European Minerals Yearbook (Minerals4EU, 2019)

Country	Reporting code	Value	Unit	Grade	Code Resource Type
Czech Republic	Nat. rep. code	138,801/ -/-/-	kt	11.29% / n/a / n/a /- manganese ore	Potentially economic/ P1/P2/P3
Finland	none	7	Mt	5.9% manganese	Historic resource estimates

[125] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for manganese. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for manganese, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for manganese the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019). Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However a very solid estimation can be done by experts.

[126] Manganese resources are reported for the following federal states: Hessen, Rhineland-Palatinate, Saxony, Saxony-Anhalt, Thuringia.

Country	Reporting code	Value	Unit	Grade	Code Resource Type
Greece	USGS	0.3/12/ 4/2	Mt	35-40/25-30/ 25/40% manganese ore (MnO_2)	USGS:Measured-Indicated-Inferred; Historic resource estimates
Hungary	Russian Classification	0.25/5.38/ 33.9/30.2	Mt	17.8/18.4/ 17.2/17.4% carbonatic manganese ores	A/B/C1/C2
		0/0.02/ 1.87/0.71	Mt	-/31.17/ 26/26.55% oxidic manganese ore for concentrate	A/B/C1/C2
		0/1.32/ 3.89/1.48	Mt	-/17.74/ 16.41/16.96% oxidic manganese ore unsuitable for concentrate	A/B/C1/C2
Kosovo	Nat. rep. code	6.5	Mt	n/a	Historic resource estimates
Portugal	none	4.834	Mt	9.38% manganese	Historic resource estimates
Romania	UNFC	1	Mt	-	333
Spain	none	74,000	t	-	Demonstrated
		200,000	t	-	Inferred
Ukraine	Russian Classification	317.8/-/ -/-	kt	n/a / n/a / n/a /- iron-manganese ore, mixed	P1/P2/P3/-
		300/ 12,504/-/-	kt	n/a / n/a / n/a / - manganese	P1/P2/P3/-

Table 92: Reserves data for Europe compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2019)

Country	Reporting code	Value	Unit	Grade	Code Reserve Type
Kosovo	Nat. rep. code	790,836/ 596,350	t	22.21%/- manganese	A+B/C1
Romania	UNFC	1/17	Mt	manganese	111/121
Ukraine	Russian Classification	141,139/ 510,802/ 1,085,931	kt	n/a / n/a / n/a manganese ore, carbonate	A/B/C1
		98,528.6/ 70,537.5/ 106,465.4	kt	n/a / n/a / n/a manganese ore, oxide	A/B/C1
		35,563/ 65,610/ 55,385.9	kt	n/a / n/a / n/a manganese ore, oxide-carbonate	A/B/C1
		283,230.6/ 646,949.5/ 1,254,228.546	kt	n/a / n/a / n/a manganese ore, total	A/B/C1

18.4.2.2 World and EU mine production

Global manganese extraction is geographically widespread. Within the reporting period 2012-2016, extraction took place in 31 countries. Average annual production of manganese was about 18,000 ktonnes. However, production was concentrated with more than 60% of global supply coming from just three countries: South Africa (28%), Australia (17%), and China (17%). Notable mine production also occurs in Gabon (10%), Brazil (7%), and India (5%) (Figure 179). The production of China and Kazakhstan dropped massively, by around 40-50%, between 2012 and 2016. Primary manganese supply in Europe comes from Bulgaria, Hungary and Romania, although jointly this accounts for less than 1% of total global supply.(WMD, 2019)

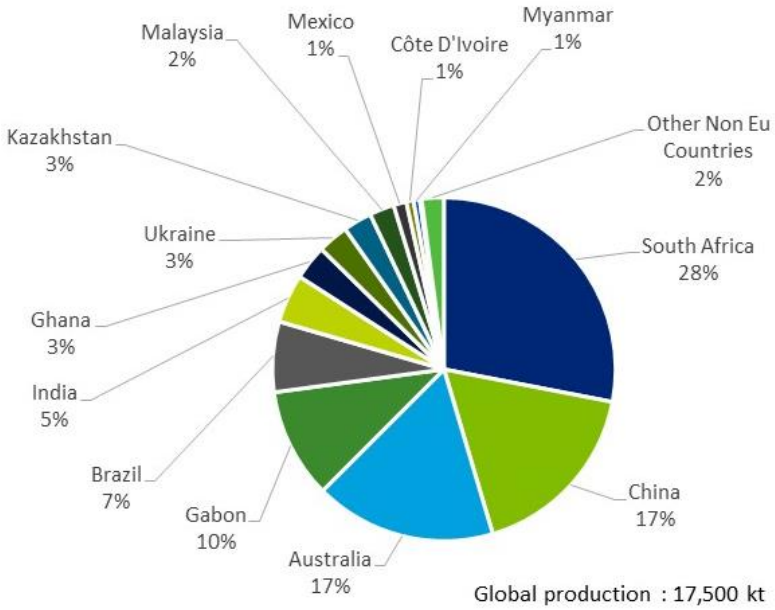


Figure 179: Global mine production of Manganese in tonnes and percentage. Average for the years 2012-2016 (WMD, 2019)

18.4.3Supply from secondary materials/recycling

18.4.3.1 Post-consumer recycling (old scrap)

The United Nations Environment Programme (UNEP) estimates end-of-life (EoL) recycling of manganese, predominantly as a constituent of ferrous (e.g. iron and steel) and non-ferrous (e.g. aluminium packaging) scrap, to be higher than 50% (UNEP, 2013). However, the amount of manganese effectively recovered from old scrap is only 10%. In 2014, the Ad-hoc Working Group on defining Critical Raw Materials estimated 12% (EC, 2014; NTUA, 2012). In 2020, the end-of-life recycling input rate (EoL-RIR) was determined by means of a Material System Analysis (MSA) on manganese (Table 93). The EoL-RIR for manganese derived from these figures is 9%.

Table 93: Material flows relevant to the EoL-RIR of Manganese, average 2012-2016[127] (European Commission, 2019)

MSA Flow	Value (t)
B.1.1 Production of primary material as main product in EU sent to processing in EU	200,605
B.1.2 Production of primary material as by product in EU sent to processing in EU	0
C.1.3 Imports to EU of primary material	626,322
C.1.4 Imports to EU of secondary material	0
D.1.3 Imports to EU of processed material	1,034,670
E.1.6 Products at end of life in EU collected for treatment	652,149
F.1.1 Exports from EU of manufactured products at end-of-life	868
F.1.2 Imports to EU of manufactured products at end-of-life	0
G.1.1 Production of secondary material from post consumer functional recycling in EU sent to processing in EU	0
G.1.2 Production of secondary material from post consumer functional recycling in EU sent to manufacture in EU	159,624

18.4.3.2 Industrial recycling (new scrap)

Manganese can be recovered along with iron from slag generated during the production of iron and steel (USGS, 2016). It is recycled incidentally as a constituent of ferrous and nonferrous scrap; however, scrap recovery specifically for manganese was negligible. In contrast, manganese slag is recycled only sporadically, but rather circulating in blast furnaces (reported in few countries, including Sweden).

18.4.4Processing of Manganese

Manganese is mainly extracted as a primary product. Mining methods employed to extract manganese largely depend on the deposit type. For example, near-surface ore deposits may be exploited by open-pit mining methods, whereas deeply-buried ore bodies are likely to be mined underground by conventional mining methods.

Regardless of the mining method employed, primary manganese ores are crushed and milled before ore minerals are separated from the gangue (non-ore minerals) by physical (e.g. gravity) and/or chemical (e.g. froth floatation) separation techniques. The selection of these individual processes will depend on the composition of the mined ore.

Generally, manganese concentrates are further refined in a pyrometallurgical process, whereby the concentrate is converted to ferromanganese (with a typical manganese content of ca. 76%) by roasting with a reductant (carbon) and flux (calcium oxide) at high temperature (ca. 1,200 °C). The composition of ferromanganese can be altered by adding differing amounts of carbon, iron and/or silicon (Zhang and Cheng, 2007). Depending on the carbon content, three different types of ferromanganese are distinguished, each with a specific production route. High-carbon ferro-manganese (HC FeMn) is produced by the carbothermic reduction of lumpy or sintered manganese ore in a three-phase submerged electric arc furnace. Low-carbon ferro-manganese (LC FeMn), is traditionally produced by a silicothermic process route. Finally, medium-carbon ferromanganese (MC FeMn) is usually produced by decarburisation of HC FeMn

[127] The work carried out in 2019 increased the resolution of the MSA system. Therefore, there are changes in flows in comparison with the previous MSA methodology. B1.1 and B1.2 in the table is the result of the EU extraction after exports (MSA flows B1.1 + B1.2 – B1.3); C1.4 incorporates all secondary raw material imported to the EU both for the processing and manufacturing stages (MSA flows C1.4 and D1.9). D1.3 Incorporates imports to the EU of both semi-processed and processed material stages (MSA flows D1.3 and C1.8).

in an oxygen-blown converter. There is a global trend that an increasing production share is produced by electric arc furnaces. Ferrosilicomanganese is produced by smelting processes in submerged electric arc furnaces.

The average global production of processed manganese in the period 2012-2016 was about 13,100 ktonnes. This figure relates to manganese content in ferromanganese and ferrosilicamanganese, see Figure 180.

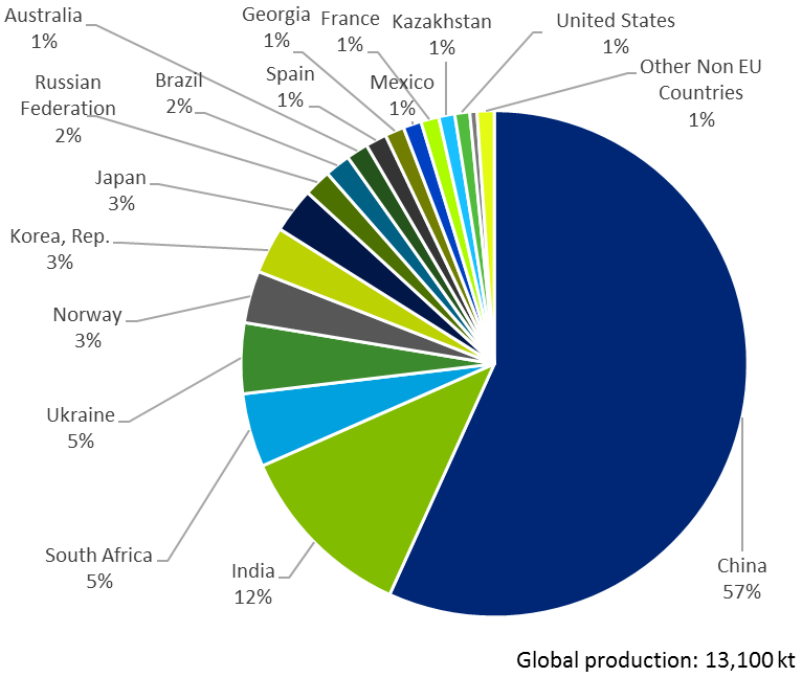


Figure 180: Global production of manganese (processing stage), average 2012–2016 (Mineral Yearbook - Manganese advanced release, 2019)

18.5 Other considerations

18.5.1 Environmental and health and safety issues

The major anthropogenic sources of environmental manganese include municipal wastewater discharges, sewage sludge, mining and mineral processing (particularly nickel), emissions from alloy, steel, and iron production, combustion of fossil fuels (WHO, 2004). Manganese concentrations in air tend to be highest in source-dominated areas, where values can reach 8000 ng/m^3. Annual averages of manganese concentrations may rise to 200–300 ng/m^3 in air near foundries and to over 500 ng/m^3 in air near ferro- and silicomanganese industries.

Toxic manganese concentrations in crop plant tissues vary widely, with critical values ranging from 100 to 5000 mg/kg. Manganese toxicity is a major factor limiting crop growth on acidic, poorly drained, or steamsterilized mineral soils. There is a wide range of variation in tolerance to manganese between and within plant species.(WHO, 2004)

The risk of exposure to manganese compounds for the population from environmental, anthropogenic and occupational sources has become a concern. For that reason, extensive research has been started to address related health effects in affected populations (Röllin, 2011). A study on a population in a manganese mining district with lifetime exposure identified

blood manganese as increasing the risk of deficient cognitive performance (Santos-Burgoa *et al.*, 2001).

Occupational safety and health (OSH)The toxicity of manganese has been well documented from numerous studies performed on workers with a high level of manganese exposure, like in the mining industry, related to welding or other occupational settings (Röllin and Nogueira 2011). As a consequence, EU occupational safety and health (OSH) requirements exist to protect workers' health and safety. Employers need to identify which hazardous substances they use at the workplace, carry out a risk assessment and introduce appropriate, proportionate and effective risk management measures to eliminate or control exposure, to consult with the workers who should receive training and, as appropriate, health surveillance[128].

At EU level, occupational exposure limit values[129] (OELs) are set for manganese to prevent occupational diseases or other adverse effects in workers exposed to manganese in the workplace. Workers' and employers organisations should be kept informed by member states about the indicative occupational exposure limit values[130] (IOELVs) (Skowroń, 2017), which is set for manganese at Community level[131]

18.5.2Socio-economic issues

Numerous industries are heavily dependent on manganese production and use, in particular the steel industry, as alloying addition for aluminium, but also for the manufacture of dry cell and other batteries.

The first global study on the socio-economic value of manganese applied a top-down analysis of the related key supply chains. The global production of manganese ore in 2013 was estimated USD10.2-11.1 billion, while this increased up to USD21-23 billion by including the multiplier effects in the supply chain. Direct employment was estimated at 44,000-78,000 people worldwide, plus 33,000-59,000 jobs created through indirect and induced employment effects.(Clarke and Upson, 2017)

18.6Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. Supply risk has been analysed at both mine and processing stages. The higher supply risk is for the mine stage.

The results of this and earlier assessments are shown in Table 94.

[128] https://ec.europa.eu/social/main.jsp?catId=148

[129] "OEL means the limit of the time-weighted average of the concentration of a chemical agent in the air within the breathing zone of a worker in relation to a specified reference period" (Skowroń 2017)

[130] as set out by Council Directive 98/24/EC

[131] IOELVs from Directive 91/322/EEC, which was based on an earlier legal framework (Directive 80/1107/EEC), are being scientifically reviewed, as foreseen in art. 3 of the abovementioned Directive 98/24/EC, and, where appropriate, have been or will be transposed into successive lists.

Table 94: Economic importance and supply risk results for manganese in the assessments of 2011, 2014, 2017, 2020 (European Commission, 2011; European Commission, 2014; European Commission, 2017)

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Manganese	9.80	0.45	7.78	0.43	6.1	0.9	6.7	0.93

The Economic Importance decreased between 2011 and 2017[132], but increased modestly in 2020. The supply risk doubled from 2014 to 2017, while before and after the supply risk was stable.

18.7Data sources

Production data for manganese ores and concentrates was taken from World Mining Data (2019). Trade data were taken from the Eurostat COMEXT online database (Eurostat, 2019) using the Combined Nomenclature (CN) code 2602 00 00 (manganese ores and concentrates, including. ferruginous manganese ores and concentrates with a manganese content of ≥ 20% calculated on dry weight) and the codes ferromanganese (7202 11, 7202 19) and ferro-silica-manganese (720230). Data were averaged over the period 2012–2016. Other data sources have been used in the assessment and are listed in the sections below.

18.7.1Data sources used in the factsheet

Arrobas, D. La Porta, Hund, K.L., Mccormick, M.S., Ningthoujam, J., Drexhage, J.R. (2017). The Growing Role of Minerals and Metals for a Low Carbon Future (English). Washington, D.C.: World Bank Group. http://documents.worldbank.org/curated/en/207371500386458722/The-Growing-Role-of-Minerals-and-Metals-for-a-Low-Carbon-Future

BGS (2016). World Mineral Production 2010-2014 [online]. Keyworth, Nottingham British Geological Survey, Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.html

Buchholz P., Wellmer F.W., Bastian D., Liedtke M. (2019) Leaning against the wind: Low price benchmarks for acting anticyclically in the metal markets. Mineral Economics. https://doi.org/10.1007/s13563-019-00199-y

Cannon, W.F., Kimball, B.E., Corathers, L.A. (2017). Manganese. Chapter L of Schulz, K.J., DeYoung, J.H., Jr., Seal, R.R., II, and Bradley, D.C., eds., Critical mineral resources of the United States—Economic and environmental geology and prospects for future supply: U.S. Geological Survey Professional Paper 1802, p. L1– L28, https://doi.org/10.3133/pp1802L.

Clarke, C., Upson, S. (2017). A global portrait of the manganese industry – A socioeconomic perspective. *NeuroToxicology* 58, 173-179

[132] Although it appears that the economic importance of manganese has reduced between 2014 and 2017 this is a false impression created by the change in methodology at this time. The value added used in the 2017 criticality assessment corresponds to a 2-digit NACE sector rather than a 'megasector' used in the previous assessments and the economic importance figure is therefore reduced. The supply risk indicator is higher than in the previous years, which is due to the methodological modification and the way the supply risk is calculated. Hence differences between the assessment results are largely due to changes in methodology (as outlined above), as no major changes in the manganese market have occurred during the period 2010-2014.

DERA (2019). Volatilitätsmonitor. Oktober 2019. [online] Available at: https://www.deutsche-rohstoffagentur.de/DERA/DE/Rohstoffinformationen/Rohstoffpreise/Volatilitaetsmonitor/volatilitaetsmonitor_node.html, accessed 17.11.2019

Dill, H.G. (2010). A "chessboard" classification scheme of mineral deposits: mineralogy and geology from aluminum to zirconium. Earth-Science Reviews. 100. 1–420.

European Commission (2011). Critical raw materials for the EU [online]. Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission. (2014). Report on Critical Raw Materials for the EU. Non-Critical Raw Materials Profiles [online] Brussels European Commission, Available at: http://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical/

European Commission (2016). DG Trade. Agreements [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/

European Commission (2019). Draft MSA on Manganese. Preliminary results of the Manganese MSA Study. Internal document – not published. Reference date: 23 December 2019.

Eurostat (2016a). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016b). Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016c). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

InfoMine Commodity and Metal Prices [online]. Available at: http://www.infomine.com/investment/metal-prices/

International Manganese Institute (IMnI) [online]. Available at: http://www.manganese.org/about-mn/applications/

International Manganese Institute (IMnI) [online]. Available at: http://www.manganese.org/images/uploads/publications/Manganese_SEA_-_Complete.pdf

Minerals4EU (2019). European Minerals Yearbook [online]. Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

NTUA (2012). NTUA Report: Raw Material Factsheets for Ramintech.

OECD (2019). Export Restriction database [online]. Available at: http://www.oecd.org/tad/benefitlib/export-restrictions-raw-materials.htm (Accessed 21.08.2019)

Pohl, W.L. (2011). Economic Geology, Principals and Practice. Oxford: Wiley-Blackwell, 678.

Röllin, H. (2011). Manganese: Environmental Pollution and Health Effects. In: Editors: Nriagu, J.O. (Ed.) Encyclopedia of Environmental Health. Burligton, Elsevier

Röllin, H., Nogueira, C. (2011). Manganese: Environmental Pollution and Health Effects*. Encycl Environ Health*. 617-629.

Rudnick, R.L., Gao. S. (2003). Composition of the Continental Crust. In: Treatise on Geochemistry, Volume 3. Editor: Roberta L. Rudnick. Executive Editors: Heinrich D. Holland and Karl K. Turekian. pp. 659. ISBN 0-08-043751-6. Elsevier, p.1-64.

Santos-Burgoa, C., Rios, C., Mercado, L. A., Arechiga-Serrano, R., Cano-Valle, F., Eden-Wynter, R. A., Texcalac-Sangrador, J. L., Villa-Barragan, J. P., Rodriguez-Agudelo, Y., Montes, S. (2001). Exposure to Manganese: Health Effects on the General Population,a Pilot Study in Central Mexico. *Environmental Research Section* A 85, 90-104, doi:10.1006/enrs.2000.4108. Available online at http://www.idealibrary.com

SCRREEN (2019). Validation workshop on Critical Raw Materials, 10-12 September 2019, Thon Hotel Brussels City Centre, Brussels.

Stansbie, J.H. (1908). Iron and Steel. New York: Van Nostrand, 408.

UNEP (2013). Metal Recycling - Opportunities, limits and infrastructure. A Report of the Working Group on the Global Metal Flows to the International Resource Panel [online]. Available at: http://www.unep.org/resourcepanel/publications/metalrecycling/tabid/106143/default.aspx

USGS (2016). Mineral Commodity Summary. Manganese [online]. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/manganese/

USGS (2019). Mineral Commodity Summary. Manganese [online]. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/manganese/

Zhang, W. and Cheng, C.Y. (2007). Manganese metallurgy review. Part 1. Leaching of ores/secondary materials and recovery of electrolytic/chemical manganese dioxide. Hydrometallurgy, 89(3–4), 137–159.

18.7.2Data sources used in the criticality assessment

BGS (2016). World Mineral Production 2010-2014 [online]. Keyworth, Nottingham British Geological Survey, Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.html

Eurostat (2019). COMEXT database [online]. Available at: http://ec.europa.eu/eurostat/data/database

OECD (2019). Export Restriction database [online]. Available at: http://www.oecd.org/tad/benefitlib/export-restrictions-raw-materials.htm

WMD (2019). World Mining Data 2019. Reichl, C.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels. Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx

18.8Acknowledgments

This Factsheet was prepared by the JRC.

The authors appreciate the support of Luca Ciacci, University of Bologna, for valuable input from the Material System Analysis (MSA), which was conducted at the same time in parallel. They also thank the Ad Hoc Working Group on Critical Raw Materials as well as experts participating in the manganese session of the SCRREEN workshop for their valuable contribution and feedback, notably Nadia Vinck (Euroalliages), Katia Lacasse (European Copper Institute, ECI), Nikos Arvanitidis (Swedish Geological Survey, SGU) and Aurelio Braconi (Eurofer).

19. MOLYBDENUM

19.1 Overview

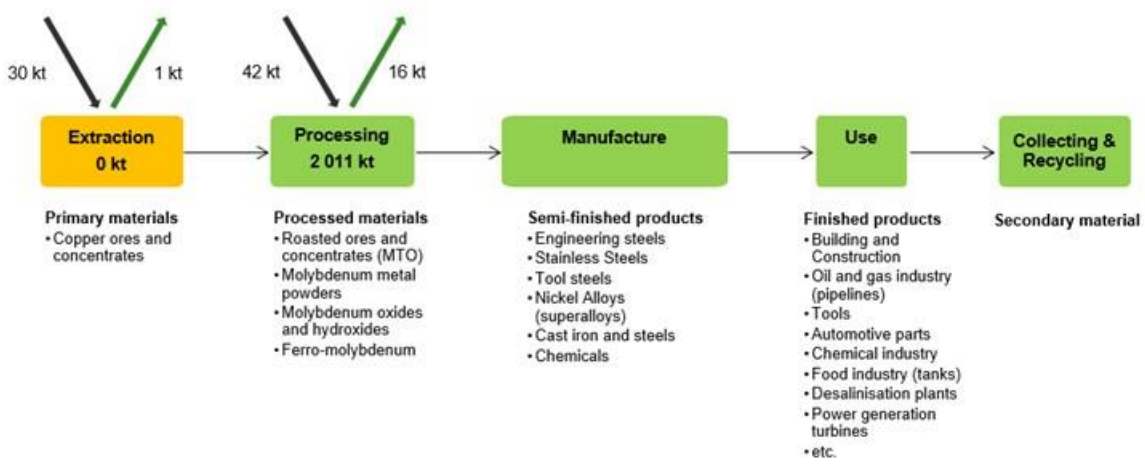


Figure 181: Simplified value chain for molybdenum concentrates[133] for the EU, averaged over 2012 to 2016

Molybdenum (chemical symbol Mo) is a shiny silvery refractory metal with a high melting point at 2,623ºC. It has the lowest thermal expansion coefficient of all engineering materials, high corrosion resistance and a fairly high thermal conductivity. Its density (10.22 g/cm3) is lower than most other high-melting point metals.

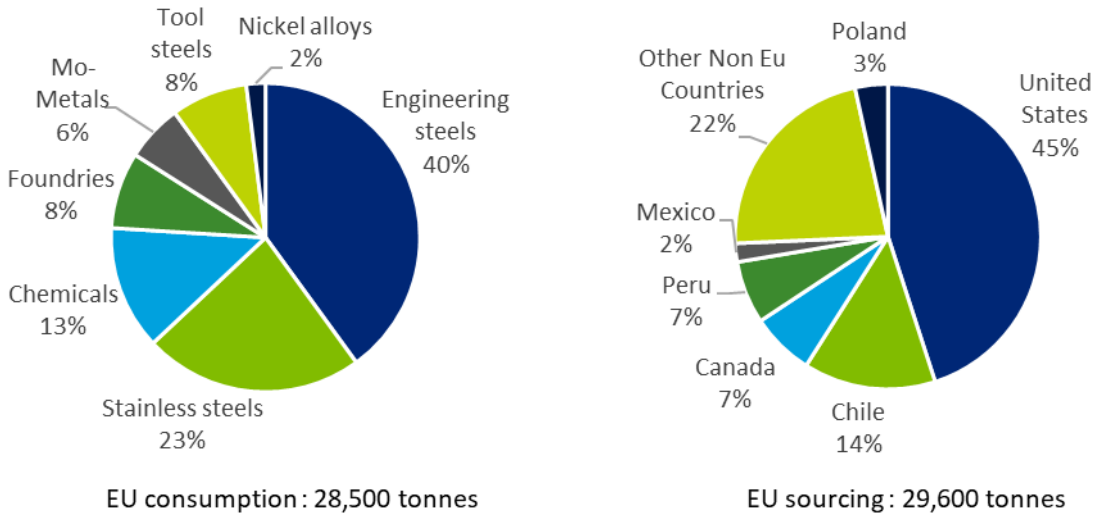


Figure 182: End uses and EU sourcing of molybdenum, annual average 2012-2016 (IMOA, 2017; BGS, 2018; Eurostat, 2019)

[133] JRC elaboration on multiple sources (see next sections). The orange box of the extraction stage means that extraction activities are not undertaken within the EU.

For the purpose of this assessment molybdenum is analysed at both extraction and processing stages. Mine production is expressed in terms of metal content. At the mining stage, trade data is analysed using CN codes 2613 90 00 which is labelled "Molybdenum ores and concentrates – excluding roasted" (60% Mo). At the processing stage, trade data include CN codes 26131000 "Roasted ores & concentrates" (57% Mo), 72027000 "Ferro-molybdenum" (65% Mo), 81021000 "Molybdenum powders" (100% Mo), and 28257000 "Molybdenum oxides and hydroxides" (67% Mo). Production and trade data are yearly averages over the period 2012-2016. (Eurostat Comext, 2019) .

Global use of molybdenum rose to 264,000 tonnes (metal content) in 2018 (International Molybdenum Association). Molybdenum demand is driven by oil and gas drilling activity and infrastructure spending. Oversupply drove molybdenum prices down from an annual average of USD 28,200 per tonne in 2012 to USD 14,450 per tonne in 2016.

The EU apparent consumption of molybdenum concentrates between 2012-2016 was 28,500 tonnes per year which were entirely sourced through imports, mostly from the United States (13,800 tonnes; 45%). Import reliance of the EU was 100% over the period 2012-2016. There is not enough data to calculate the apparent consumption of processed material.

Molybdenum is used primarily as an alloy agent in carbon steels and iron and stainless steels, the rest being used in chemicals. The addition of molybdenum to steels and stainless steels increases resistance to corrosion and strength and wear at higher temperatures. Substitution of molybdenum in current applications is low as alternatives are associated to and/or loss in performance and higher cost.

Usage of molybdenum in steels, iron and stainless steels helps to reduce the quantity of steel used, allows engines to run hotter and, thereby, reduce emissions.

Molybdenum mostly occurs as molybdenite MoS_2. Identified world molybdenum resources are approximately 25,000,000 tonnes (metal content). World known reserves of molybdenum are estimated at around 17,000 tonnes (USGS, 2019). China has the world's largest molybdenum reserves (48%). Porphyry deposits are the world's most important source of molybdenum.

The world production of molybdenum concentrates was 274,000 tonnes per year on average for the year 2012-2016, with China accounting for 47% of the total production, followed by Chile (17%) and the United States (16%). The EU did not produce molybdenum concentrates (WMD 2018) but processed imported material into technical molybdenum oxide, ferromolybdenum, chemicals and metal.

One molybdenum-containing product is present on the REACH SVHC list: lead chromate molybdate sulphate red (C.I. Pigment Red 104), due to the toxicity of lead and chromate.

19.2Market analysis, trade and prices

19.2.1Global market analysis and outlook

Molybdenum demand is driven by oil and gas drilling activity and infrastructure spending. Demand from the oil and gas sector is the biggest source of molybdenum demand volatility.

According to the International Molybdenum Association (IMOA, 2019), global molybdenum use decreased from 237,000 tonnes in 2012 to 233,000 tonnes in 2016. Oil prices recovered in 2017, driving renewed activity in the oil and gas sector and demand for molybdenum. Global molybdenum use is estimated to have risen by 4% in 2018 to 264,000 tonnes, following a 9%

rise in 2017. In 2017, China accounted for 37% of the total consumption, followed by Europe (25%), the United States (10%) and Japan (10%).

The rise in demand combined with a lack of supply growth has led to a tightening in market conditions and the market moved to deficit in 2018 (ITA, 2019).

Demand growth is expected to continue in the oil and gas sector with the development of liquefied natural gas (LNG) and deep oil production. The rising demand for higher quality steel containing molybdenum in Asia is expected to accelerate over the longer term. China's average intensity of use rose 5% from 2007 to 8.6 kg of molybdenum per 100 tonnes of steel in 2016, but remained well below the global average of 14.3 kg molybdenum per 100 tonnes.

The rising demand in the electric vehicles sector for copper will boost copper mining production and therefore the availability of molybdenum which is mainly a by-product of copper mining.

Key players operating in the global molybdenum market include Freeport-McMoRan, Group Mexico, Codelco, China Molybdenum, Jinduicheng Molybdenum.

Table 95: Qualitative forecast of supply and demand of molybdenum

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Molybdenum		x	+	+	+	+	++	++

19.2.2EU trade

The EU is a net importer of molybdenum concentrates. Imports amounted to 29,600 tonnes per year on average over the period 2012-2016. 47% of the ores imported to the EU came from the United States, followed by Chile (14%), Canada (7%) and Peru (7%). (Eurostat Comext, 2019)

Although the EU did not import molybdenum concentrates from China during the 2012-2016 period, it is worth mentioning that China has cancelled export duties and quotas on molybdenum, and removed restrictions on the trading rights on molybdenum exporters in 2015 (OECD, 2019).

The EU exported 1,000 tonnes per year of molybdenum concentrates mainly to Brazil (56%) and Vietnam (36%), averaged over 2012 to 2016. The EU industry reliance on imports of molybdenum concentrates was 100% during the period 2012-2016.

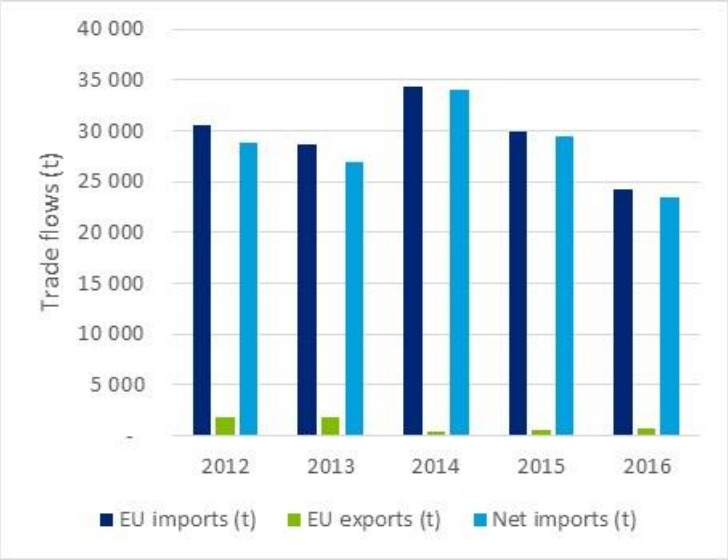


Figure 183: EU trade flows for molybdenum concentrates (Eurostat, 2019)

By 2019 the EU has free trade agreements with Chile, Canada, Peru, Mexico and South Korea (European Commission, 2019).

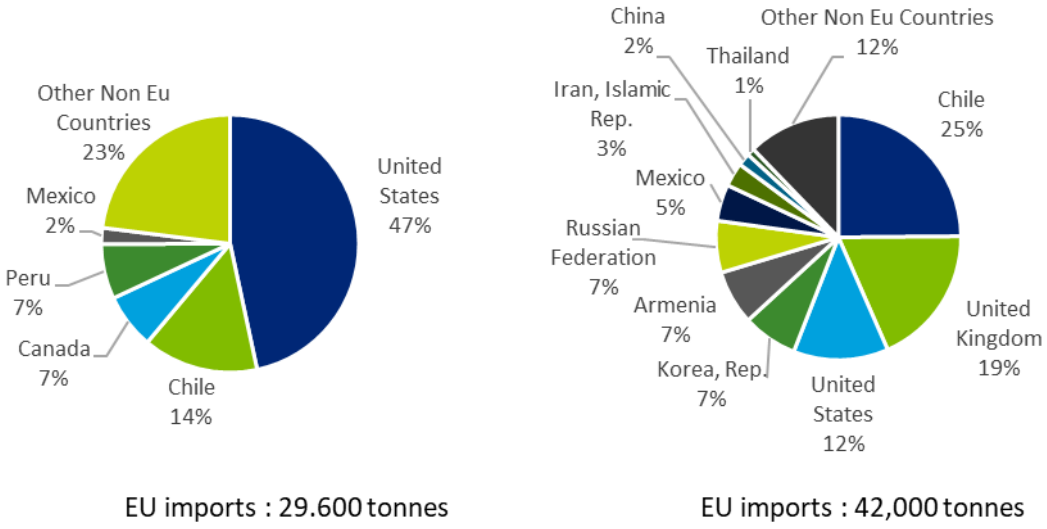


Figure 184: EU imports of molybdenum concentrates (left) and processed molybdenum products (right) (annual average over 2012-2016) (Eurostat, 2019)

The EU imported around 42,000 tonnes per year of processed products including technical molybdenum oxide, ferromolybdenum, molybdenum powders (100% Mo), and molybdenum oxides and hydroxides. The main suppliers were Chile (25%), the United Kingdom (19%) and the United States (13%).

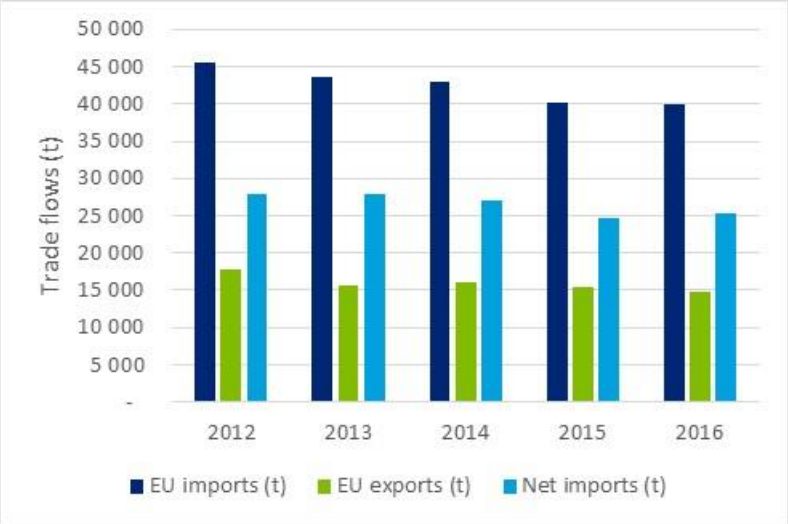


Figure 185: EU trade flows for refined molybdenum products (Eurostat, 2019)

19.2.3Prices and price volatility

Molybdenum price is correlated to oil and gas prices and stainless steel market dynamics. Molybdenum roasted concentrates or technical molybdenum oxide (TMO) is traded on the London Metals Exchange (LME). The LME introduced a contract on roasted concentrates with molybdenum content of 57 to 63% in 2010. Each contract represented 6 tonnes of molybdenum and was quoted in USD. These physical contracts have been discontinued and replaced by a cash settled contract in March 2019 which represents 2,205 pounds and is quoted in USD.

Oversupply drove molybdenum prices down from an annual average of USD 28,200 per tonne in 2012 to USD 14,450 per tonne in 2016. Between August 2014 and November 2015 molybdenum prices plunged below USD 10,000 per tonne with oil price contraction. Oil price began to recover in late 2016 and molybdenum price stabilized in 2017. The strengthening demand, combined with cutbacks in production by major molybdenum producers, pushed molybdenum prices over USD 25,000 per tonne in 2018 for the first time since 2014 (Roskill, 2019).

Ferromolybdenum (65-75% Mo) and molybdenum metal (99.95% Mo) prices averaged about USD 29,000 per tonne and USD 38,900 per tonne respectively for 2018 (DERA, 2019).

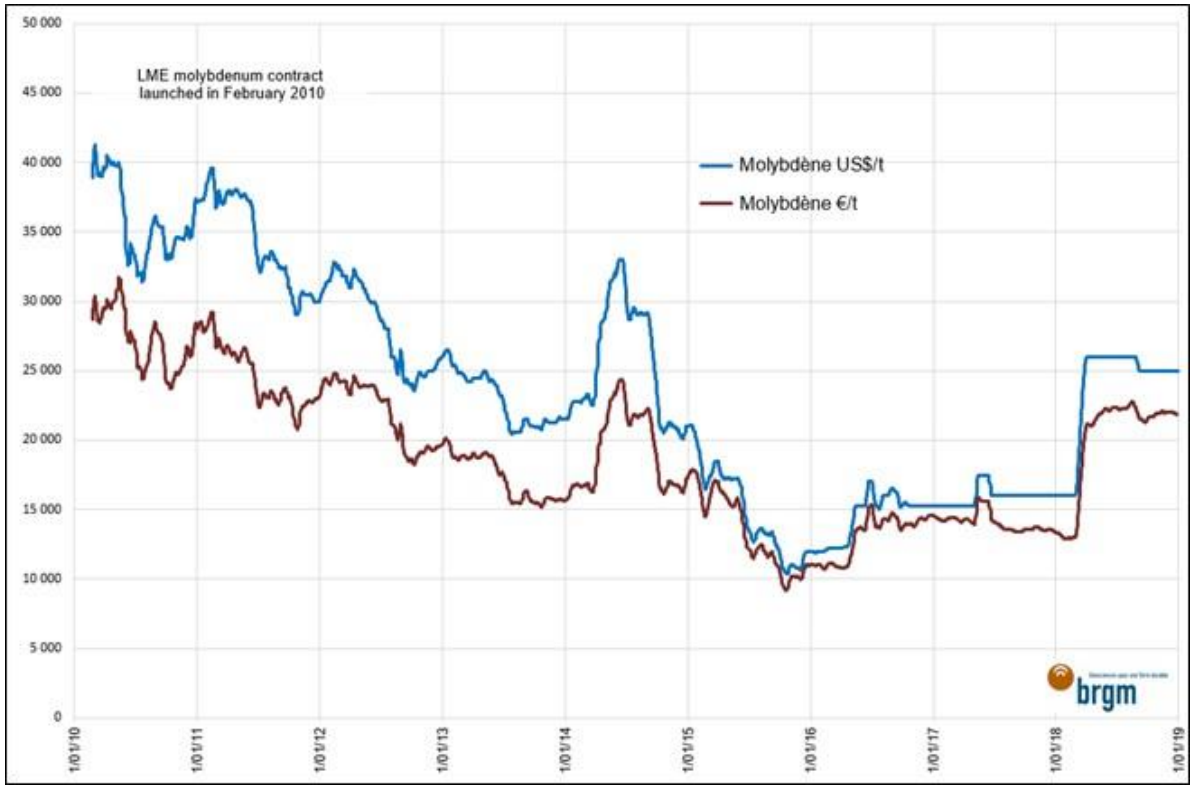


Figure 186: Molybdenum roasted concentrates (TMO) prices (USD/t, 7–day moving average) from February 2010 to December 2018 (LME, 2019)

19.3EU demand

19.3.1EU demand and consumption

The EU apparent consumption of molybdenum concentrates was 29,000 tonnes per year which were entirely sourced through imports, mostly from the United States (14,000 tonnes; 47%) and Chile (4,000 tonnes; 14%). The EU apparent consumption of molybdenum metal could not be estimated due to lack of data. However, the EU imported 42,000 tonnes per year of refined molybdenum over the years 2012-2016, mostly from Chile, 25% of imported refined molybdenum, or equal to 11,000 tonnes per year.

19.3.2Uses of molybdenum in the EU

Molybdenum is used primarily as an alloy agent in carbon steels and iron and stainless steels, the rest being used in chemicals (Figure 187).

Engineering steels (carbon steels) accounted for 40% of the demand of primary molybdenum in 2017 (International Molybdenum Association, 2019). Engineering steel is a steel with a small amounts of one or more alloying elements such as manganese, silicon, molybdenum. This produces specific properties that are not found in regular carbon steel. Engineering steels with a high amount of molybdenum will have a greater resistance to corrosion and strength at higher temperatures. Typical molybdenum contents in the steels does not exceed 1%. They are used in a wide range of marine environment applications (e.g. offshore oil rigs), as well as oil and gas pipelines.

About 23% of the molydnemum demand is used to make molybdenum grade stainless steel. The most widely used grade is an austenitic stainless steel containing 2-3% molybdenum (Type 316). The addition of molybdenum strengthens the stainless steels and inhibits corrosion. Among many other uses, molybdenum grade stainless steels are used in tanks and piping in food handling and processing, pulp and paper mills, ocean tankers, desalination plants and pharmaceuticals.

Molybdenum in tool steels (8%) increases their hardness and resistance to wear. Regular tool steels contain up to 3% molybdenum. High-speed tool steels containing 5 to 10% molydenum are used to make drills and cutting tools.

Molybdenum increases the strength, hardness, temperature and pressure tolerance of cast iron and steels, which are used in automobile engines (more specifically to make cylinder heads, motor blocks, and exhaust manifolds). These applications account for about 8% of molybdenum demand.

High purity molybdenum metal and alloys (6%) which have high strength and mechanical stability at high temperatures are used in many applications, including high temperature heating elements, glass melting furnace electrodes etc.

Molybdenum is also used in nickel alloys (2%) to increase their corrosion or high-temperature resistance. These high performance superalloys containing up to 28.5% molybdenum (B-3® alloy) are used in the production of jet engines, turbochargers, power generation turbines and in chemical and petroleum industries.

About 13% of molybdenum extracted is not used in metal products but in chemicals, most often in catalysts for petroleum refineries and plastics industries. Molybdenum disulfide MoS_2 (molybdenite), which is the most common molybdenum mineral, is used as a dry lubricant additive in greases, friction materials etc. after purification. Other uses include inks for circuit boards, pigments and electrodes.

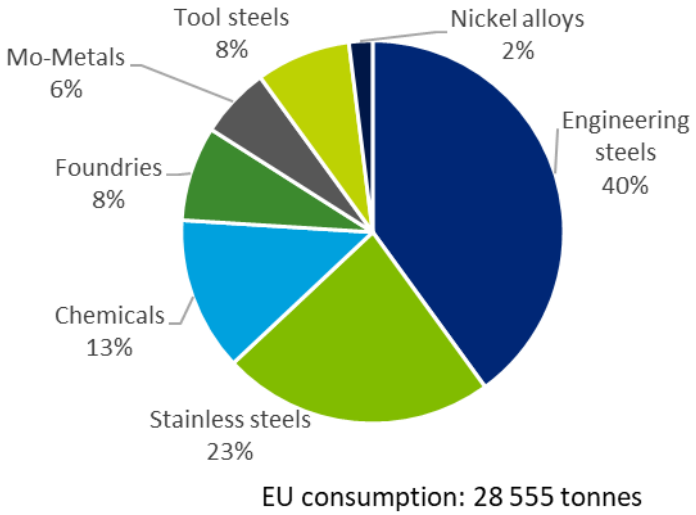


Figure 187: EU end uses of molybdenum in 2015 (IMOA, 2019).

Relevant industry sectors are described using the NACE sector codes (Eurostat, 2019b).

Table 96: Molybdenum applications, 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2019b)

Applications	2-digit NACE sector	Value added of NACE 2 sector (M€)	4-digit NACE sectors
Engineering steels	C25 - Manufacture of fabricated metal products, except machinery and equipment	148,351	C25 11
Stainless steels	C19 - Manufacture of coke and refined petroleum products	17,289	C19.20 Refined petroleum products
Chemicals	C20 - Manufacture of chemicals and chemical products	10,5514	C20.12 Manufacture of dyes and pigments
Foundries	C28 - Manufacture of machinery and equipment n.e.c.	182,589	28.11 Engines and turbines, except aircraft, vehicle and cycle engines; 28.92 Machinery for mining, quarrying and construction
Mo-Metals	C28 - Manufacture of machinery and equipment n.e.c.	182,589	28.21 Ovens, furnaces and furnace burners
Tool steels	C28 - Manufacture of machinery and equipment n.e.c.	182,589	C28.15 Manufacture of bearings, gears, gearing and driving elements
Super alloys	C28 - Manufacture of machinery and equipment n.e.c.	182,589	C28.1.1 - Manufacture of engines and turbines, except aircraft, vehicle and cycle engines

19.3.3Substitution

Substitution of molybdenum in current applications is rather low be due to the fact that most of the alternative applications are associated to and/or loss in performance, higher cost and potential harmfulness of possible substitutes (MSP-Refram, Moly factsheet, 2014)

Potential substitutes for molybdenum in some of its applications include:

- Chromium, vanadium, niobium and boron in alloy steels;
- tungsten in tool steels;
- graphite, tungsten, and tantalum for refractory materials in high temperature electric furnaces;
- chrome-orange, cadmium-red, and organic-orange pigments for molybdenum orange.In pigments there are possible substitution by harmful toxic substances based on chromium and cadmium (MSP-Refram Ref. Ares(2016)6763191 - 02/12/2016).

19.4Supply

19.4.1EU supply chain

The EU did not produce molybdenum concentrates (WMD 2018) but processed imported material into technical molybdenum oxide, ferromolybdenum, chemicals and metal.

19.4.1.1 Geology, resources and reserves of molybdenum

Geological occurrence:

Molybdenum concentration in the Earth continental upper crust is estimated to be 1.1 ppm (Rudnick & Gao, 2014). Molybdenite (MoS_2) is the main molybdenum mineral.

Porphyry deposits are the world's most important source of molybdenum and account for more than 95% of the world production. Molydneumum is mainly produced from two types of porphyry deposits, porphyry-copper deposits which are associated with continental volcanic arcs and porphyry molybdenum deposits. Porphyry Cu-Mo deposits defined as containing <0.05 wt% molybdenum and molybdenum/copper-ratios <1 are now supplying about 60% of the molybdenum world production as a by-product (Chile, Peru). Porphyry molybdenum deposits represent large-scale mineralization which contain molybdenum grades >0.05 wt% and Mo/Cu-ratios >1 (Carten et al., 1993) and produce molybdenum as the primary product. This type of deposits includes the giant Climax-type porphyry molybdenum deposits exemplified by the Climax and Henderson deposits in Colorado and Chinese deposits (Taylor et al., 2012) for porphyre molybdenum Global resources and reserves[134]*:*

Global reserves of molybdenum at the end of 2018 were estimated at around 17,000,000 tonnes (USGS, 2019), with China accounting for almost half of the total (48%), followed by the United States (16%) and Peru (14%) (Table 97). Identified world molybdenum resources are approximately 25,000,000 tonnes (USGS, 2019).

Table 97: Global reserves of molybdenum in year 2018 (USGS, 2019)

Country	Molybdenum Reserves (ktonnes)
China	8,300
United States	2,700
Peru	2,400
Chile	1,400
Russia	1,000
Turkey	700
Mongolia	210
Armenia	150

[134] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of molybdenum in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template.[134], which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

Country	Molybdenum Reserves (ktonnes)
Mexico	130
Argentina	100
Canada	100
Uzbekistan	60
Iran	43
World total (rounded)	*17,000*

EU resources and reserves[135]*:*

Resource data for some countries in Europe are available at Minerals4EU (2019) but cannot be summed as they are partial and they do not use the same reporting code.

Table 98: Reserve data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2019)

Country	Reporting code	Quantity	Unit	Grade	Code Resource Type
Greenland	NI 43-101	52.9	Mt	0.23%	Measured
Ireland	None	0.24	Mt	0.13%	Historic Resource Estimate
France	None	42	kt	0.02-0.03%	Historic Resource Estimate
Poland	Nat. rep. Code	0.29	Mt	0.05%	C2+D
Greece	USGS	12	kt	0.25%	Measured
Turkey	NI 43-101 JORC	168	Mt	0.006%	Indicated
		51	Mt	0.0125%	Inferred
Norway	None	200	Mt	0.14%	Historic Resource Estimate
Sweden	FRB-standard	509.1	Mt	19 g/t	Measured
Finland	None	9.6	Mt	0.1%	Historic Resource Estimate

[135] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for molybdenum. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for fmolybdenum, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for molybdenum the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019). Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However a very solid estimation can be done by experts.

The EU potential includes include porphyry molybdenum deposits in the Tertiary igneous Province of East Greenland (Malmbjerg) and the Myszków Molybdenum and tungsten porphyry deposit in Poland.

19.4.1.2 World and EU mine production

Around 60 percent of global molybdenum supply comes as a by-product of copper smelting form porphyry copper-molybdenum ores, with most of the remainder coming from primary sources, i.e. from the processing of ores extracted from porphyry molybdenum deposits. After extraction, molybdenum concentrate is produced by a flotation technique which separates the gangue from the molybdenum minerals. Most molybdenum concentrate contain 85-93% molybdenite.

During the period 2012-2016, 274,000 tonnes of molybdenum (metal content in ore; World Mining data, 2018) were mined on average annually, in the world. China was the main producer and accounted for 44% of the global mine production, followed by the United States (19%), Chile (16%), Peru (7%) and Mexico (4%).

Global mine production of molybdenum dropped in 2015 and again in 2016 as producers of primary ore - i.e. extracted from porphyry molybdenum deposits - curtailed output in response to the price weakness in the United-States and China. Freeport McMoran reduced production by 14% in 2016, largely from the Climax and Henderson mines in the US. By-product molybdenum producers consequently increased their share of global production to over 70% for the first time in 2016 (Roskill, 2017).

There is no molybdenum mine output in the EU and therefore all the Union needs rely on imports.

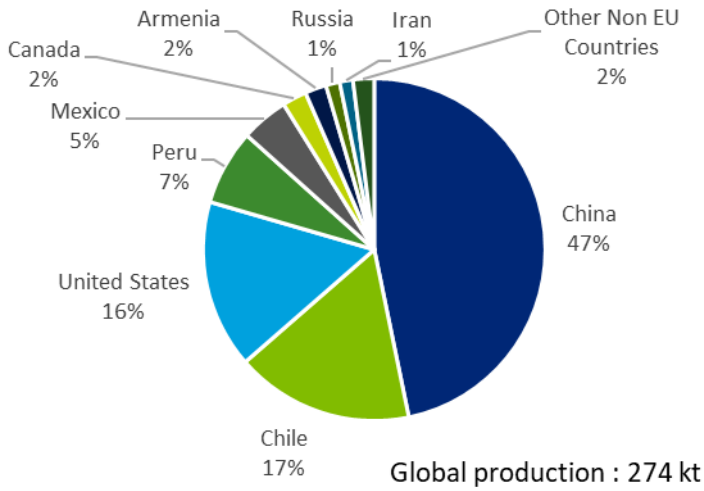


Figure 188: Global mine production of molybdenum in kt and percentage. Average for the years 2012-2016. (WMD 2018)

19.4.2Supply from secondary materials/recycling

According to IMOA, about 25% (80 kt) of all molybdenum used in 2011 was recycled, mostly in the form of steel scrap.

19.4.2.1 Post-consumer recycling (old scrap)

About one-third of the scrap were end of use scraps and blends. molybdenum scrap is used to produce stainless and engineering steels. Engineering steels which contain less than 0.5% molybdenum are not recycled for their molybdenum content but are put back in general steel production of lower quality. Molybdenum is also recovered from spent catalysts used in chemical and petrochemical industries. The global end-of-life recycling rate of molybdenum has been estimated at 20% (Henckens et al., 2018) and 30% (UNEP, 2011). The recycling efficiency of molybdenum is not expected to increase significantly as long as cheaper alternatives are available in the form of relatively cheap primary molybdenum.

19.4.2.2 Industrial recycling (new scrap)

Two-third of the molybdenum scraps used in 2011 were revert scraps produced during the steel making process and new scrap generated by steel fabrication.

19.4.3Processing of molybdenum

A small fraction of molybdenite concentrate is purified and used in MoS_2 lubricants. The concentrate is mostly processed into technical molybdenum oxide MoO_3 (TMO) by roasting in air at temperatures between 500 and 650°C. The roasted concentrate MoO_3 contains a minimum of 57% molybdenum.

Between 30 and 40% of the production of technical molybdenum oxide (MTO) is processed into ferromolybdenum (FeMo) which contains between 60 and 75% Mo. Another 25% is processed into a number of chemical products such as pure grade molybdenum trioxide, ammonium and sodium molybdates, and metal. Molybdenum metal is produced by hydrogen reduction of pure grade molybdenum trioxide or ammonium molybdate (IMOA, 2019).

World production data of technical molybdenum oxide, ferro molybdenum and Mo chemicals are not available or incomplete and data for the EU are very scarce. The major manufacturers of MTO are Molymet, Freeport-McMoRan, Codelco, Jinduicheng Molybdenum Group and China Molybdenum.

Molydenum oxide, ferromolybdenum and chemicals are all produced in the EU. MTO is produced in Belgium by Sadaci NV, a Molymet subsidiary, and in the Netherlands by Climax Molybdenum B.V, a Freeport-McMoRan subsidiary, which also produces ammonium dimolybdate and pure molybdic oxide on the Rotterdam site (FreeportMcMoRan, 2014). Treibacher Industrie AG in Austria is the only Ferro Molybdenum producer in the Union with an annual average production of 4,000 kt during the period 2012-2016 (BGS, 2017). According to the REACH Molybdenum Consortium there is one company in the Netherlands and potentially one in Germany (if production from the latter has not been relocated to the USA), which manufacture pure grade molybdenum trioxide (Carey, 2014). The chemicals and downstream production/supply chains in Europe will have sufficient capacity for most products once the Belgian-based company (Sadaci) will start the production of hyper-pure Moly oxide according to Euroalliages.

19.5Other considerations

19.5.1Environmental and health and safety issues

One molybdenum-containing product is present on the REACH SVHC list: lead chromate molybdate sulphate red (C.I. Pigment Red 104), due to the toxicity of lead and chromate.

Molybdenum release into the environment due to extraction activity is unavoidable. Molybdenum metal can be released at elevated concentrations as sulfidic waste rock weathers and can produce toxic effects at elevated environmental concentrations. Molybdenum is particularly harmful to ruminants which are susceptible to molybdenosis. To prevent any environmental and social damage that Molybdenum-associated activities may cause, all mining activity must be conducted in accordance with the regulations set forth in European Directive 85/337/CEE concerning Environmental Impact Assessment. Directive 2006/21/EC also provides several references for measures, procedures and guidance to reduce any adverse effects on the environment (water, soil, air, fauna, flora and landscape) stemming from extractive industry waste management activities. One of the objectives of this Directive is for Member States to take the necessary measures to ensure that extractive waste is managed without endangering human health and without using processes or methods which could harm the environment. Uncontrolled disposal of extractive waste must also be avoided (Refram, Moly factsheet).

19.6Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. Supply risk has been analysed at both mine and processing stages.

The results of this and earlier assessments are shown in Table 99. The value of economic importance has slightly increased in comparison with the value in criticality 2017, although remained quite high. The change was related to the end-use application of molybdenum.

The supply risk for molybdenum was evaluated in both ores and concentrates and refined stage. The supply risk for molybdenum at refined stage was assessed with EU supply approach since there was no data available for the global supply. There was a high concentration of global supply of molybdenum at ores and concentrates stage, especially with the share of China (48%). The supply risk reported in Table 5 refers to ores and concentrates stage, a combination of global supply and EU supply risk.

Table 99: Economic importance and supply risk results for molybdenum in the assessments of 2011, 2014, 2017, 2020 (European Commission, 2011; European Commission, 2014; European Commission, 2017)

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Molybdenum	8.9	0.5	5.9	0.9	5.2	0.9	6.16	0.94

19.7Data sources

In this assessment, the supply risk for molybdenum was evaluated in both ores and concentrates and refined stage. No data was available for global supply and EU production of

molybdenum at refined stage, therefore it was not possible to calculate the apparent consumption of processed material.

19.7.1 Data sources used in the factsheet

Audétat, A. , Li, W. (2017). Review The genesis of Climax-type porphyry Mo deposits: Insights from fluid inclusions and melt inclusions. Ore Geology Reviews, Vol. 88, pp. 436–460.

BGS (2018). World Mineral Production 2012-2016. [online] Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.html

Carten, R.B., White, W.H., Stein, H.J. (1993). High-grade granite-related molybdenum systems: Classification and origin. In: Kirkham, R.V., Sinclair, W.D., Thorpe, R.I.,Duke, J.M., (Eds.), Mineral deposit modeling. Geological Association of Canada, Special Paper, Vol. 40, pp. 521–554.

Cometal (2012). [online] Available at: http://www.cometalsa.com/

DERA (2019) Preismonitor, December 2018. [online] Available at: https://www.deutsche-rohstoffagentur.de/DE/Themen/Min_rohstoffe/Produkte/Preisliste/pm_18_12.pdf?__blob=publicationFile&v=2

European Commission (2019). Free trade agreements. [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/

Eurostat (2019). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2019b). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

FreeportMcMoRan (2014) https://www.fcx.com/sites/fcx/files/documents/fast_facts/ClimaxMoly_Brochure_2014.pdf

Henckens, M.L.C.M., Driessen, P.P.J., Worrell, E (2018). Molybdenum resources: Their depletion and safeguarding for future generations. Resources, Conservation and Recycling, Vol. 134,pp.61-69.

International Molybdenum Association (IMOA) (2019). Global molybdenum production and use (2013,2017, 2019). [online] Available at: https://www.imoa.info/molybdenum-media-centre/latest-news/latest-news.php

Leach, D.L. et al., (2010). A deposit model for Mississippi Valley-Type molybdenum-zinc ores, chap. A of Mineral deposit models for resource assessment: U.S. Geological Survey Scientific Investigations Report 2010–5070–A, 52 p

LME (2017). [online] Available at: www.lme.com. BRGM database.

Minerals4EU (2019). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

OECD (2019). [online] Available at: http://www.oecd.org/trade/topics/trade-in-raw-materials/documents/oecd-industrial-raw-materials-complete-data.xlsx

Prometia (2017). Towards a strong and sustainable European refractory metals supply-chain. MSP-REFRAM final Report. [online] Available at: http://prometia.eu/wp-content/uploads/2014/02/MSP-REFRAM-FINAL-REPORT-WEB.pdf

OECD (2016). OECD Export restrictions on Industrial Raw Materials. [online] Available at: http://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

Polish Geological Institute (2019). Molybdenum-tungsten-copper ores. [online] Available at: http://geoportal.pgi.gov.pl/surowce/metaliczne/rudy_mo-w-cu/2018

Roskill (2017 & 2019). News. [online] Available at: https://roskill.com/news/

Rudnick, R.L., Gao, S. (2014) Composition of the Continental Crust. Treatise On Geochemistry. Heinrich D. Holland and Karl K. Turekian(ed), 2nd edn. Elsevier, Oxford, pp 1–51.

Sinclair, W.D., 2007, Porphyry deposits, in Goodfellow, W.D., ed., Mineral Deposits of Canada: A Synthesis of Major Deposit-Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods: Geological Association of Canada, Mineral Deposits Division, Special Publication No. 5, p. 223-243.

Sillitoe, R.H. (2010). Porphyry Copper Systems. Economic Geology, Vol.. 105, pp. 3–41.

Singer D. A. (1995) World-class base and precious metal deposits; a quantitative analysis. Economic Geology 90: 88–104.

Taylor, R.D., Hammarstrom, J.M., Piatak, N.M., and Seal, R.R. II (2012). Arc-related porphyry molybdenum deposit model, chap. D of Mineral deposit models for resource assessment: U.S. Geological Survey Scientific Investigations Report 2010–5070–D, 64 p.

UNEP, 2011b. International Resource Panel, 2011, Recycling Rates of Metals, a Status Report.

USGS (2016 & 2017). Mineral Commodity Summaries. Molybdenum. [online] Available at: https://www.usgs.gov/centers/nmic/molybdenum-statistics-and-information

World Mining Data (2018). [online] Available at: https://www.world-mining-data.info/wmd/downloads/PDF/WMD2018.pdf

19.7.2Data sources used in the criticality assessment

EC (2017). Study on the review of the list of Critical Raw Materials - Critical Raw Materials Factsheets & Non-critical Raw Materials Factsheets.

Eurostat (2019). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2019b). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

Eurostat (2019c). Contribution of recycled materials to raw materials demand- End-of-life recycling input rates (EOL-RIR). [online] Available at: https://ec.europa.eu/eurostat/databrowser/view/cei_srm010/default/table?lang=en

General Moly (2018). http://www.generalmoly.com/news-release/general-moly-reports-on-molybdenum-price-resilience-and-demand-drivers/

OECD (2016). OECD Export restrictions on Industrial Raw Materials. [online] Available at: http://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

Bruno, J. et al., (2016) Deliverable 1.5 MSP Reframe European Funded Project, 2016

World Mining Data (2018). [online] Available at: https://www.world-mining-data.info/wmd/downloads/PDF/WMD2018.pdf

Other : general knowledge etc., no source readily available

19.8Acknowledgments

This factsheet was prepared by the JRC in collaboration with BRGM. The authors would like to thank the Ad Hoc Working Group on Critical Raw Materials as well as experts participating in SCRREEN workshops for their valuable contribution and feedback.

20.NATURAL CORK

20.1Overview

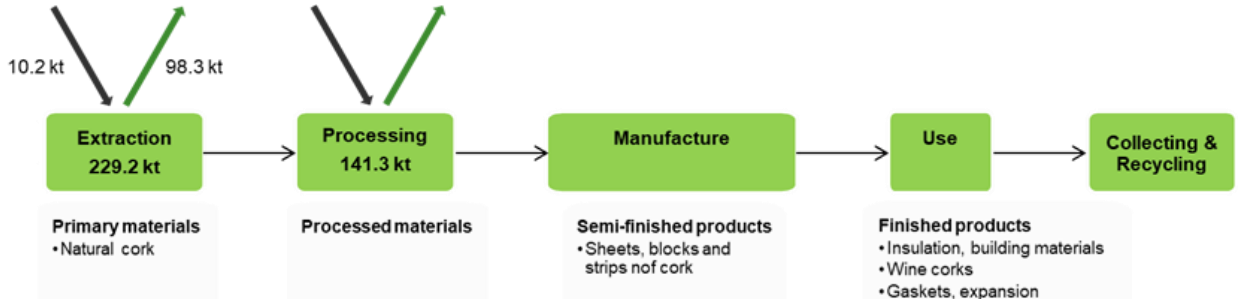


Figure 189: Simplified value chain for natural cork, 2012-2016, (Eurostat, 2019)

Cork is the bark of the cork oak (*Quercus suber*). 100% natural plant tissue, consisting of a hive of microscopic cells containing air and coated primarily with suberin and lignin. It has a range of applications associated with its attributes (e.g. gas impermeability) that no technology has yet managed to emulate, match or exceed Natural cork was not on the list of CRMs in 2011, 2014, 2017. For the purpose of this assessment, natural cork is considered to be represented by CN trade codes: 4501 and 4502.

The average world production and consumption of natural cork between 2013 and 2017 was about 267.1 kt, possibly worth around USD 500 million (APCOR 2018). It is not traded on any centralised exchange, so reported prices come from publicly reported over-the-counter transactions (APFC, 2019).

Close to 90% of the existing resource (i.e. global production of natural cork) is located within the EU. Portugal and Spain are the major producers, with Portugal producing 132.6 kt and Spain 81.6kt. The EU sourcing between 2012 and 2016 was 239.7 kt and consumption was 141.3 kt.

Natural cork is not recycled on a large scale from end products. The amount of recycled cork replacing demand for new cork is only 8%, given the economics of cork recycling operations compared to primary production.

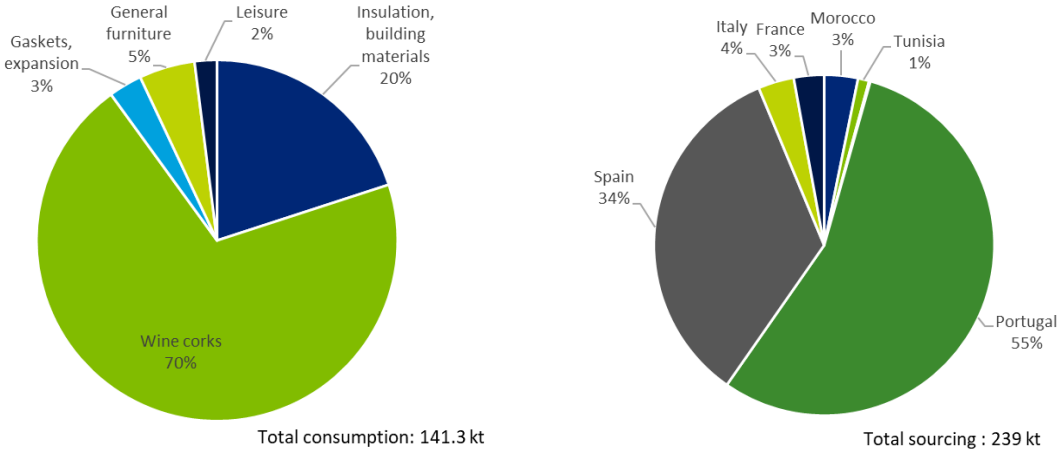


Figure 190: End uses and EU sourcing of Natural cork, average 2012 to 2016. (Eurostat, 2019b)

20.2Market analysis, trade and prices

20.2.1Global market analysis and outlook

The market outlook forecast for world natural cork demand is increasing from the current baseline, rising to 300 thousand tonnes by 2020 if production trends in recent years will continue. (see Table 100). Forecast in later years are also based on a continuation of this trend.

There are signs that demand of natural cork may indeed continue to rise steadily in the coming decade. The material could function as a remittance to environmental concerns, since it is a highly recyclable and reusable material with a low environmental impact. At the same time: growth in supply of natural cork is still dependent by its main use in wine corks and insulating material. Future uses that may influence the outlook of natural cork include innovative areas such as Design for Sustainability and Eco-Design (APCOR 2015).

Table 100: Qualitative forecast of supply and demand of natural cork

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Natural cork		x	+	+	+	+	+	+

20.2.2EU trade

The limited imports to the EU of natural cork come mostly from Morocco 73%. An association agreement exists between the EU and Morocco, Algeria and Tunisia (European Commission 2019). There are no exports taxes, quotas or prohibitions related to products of natural cork (OECD 2019).

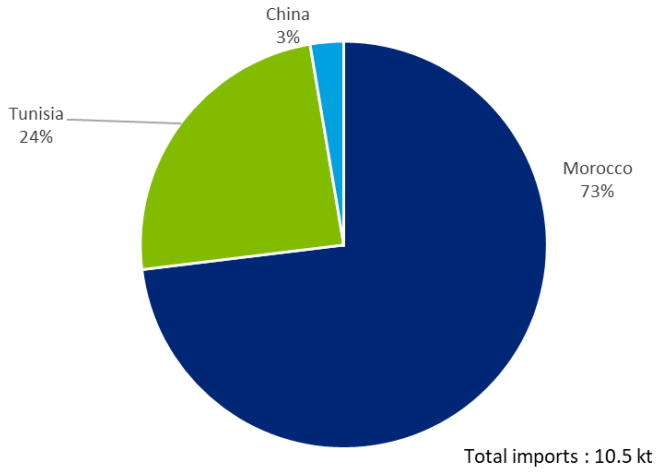


Figure 191: EU imports of natural cork, average 2012 to 2016 (Eurostat 2019b)

20.2.3Prices and price volatility

Natural cork is not traded at a central location. The price of natural cork is expressed per 15kg, a measure called an "arroba". Since 2003 the average price of cork fell dramatically, from €44.80 per "arroba" piled cork to €24,93 in 2012,. The price has increased since then and achived €40.26 per "arroba" in 2018 (APF, 2019). The harvesting costs are around €4 per 15kg (Pereira 2011).

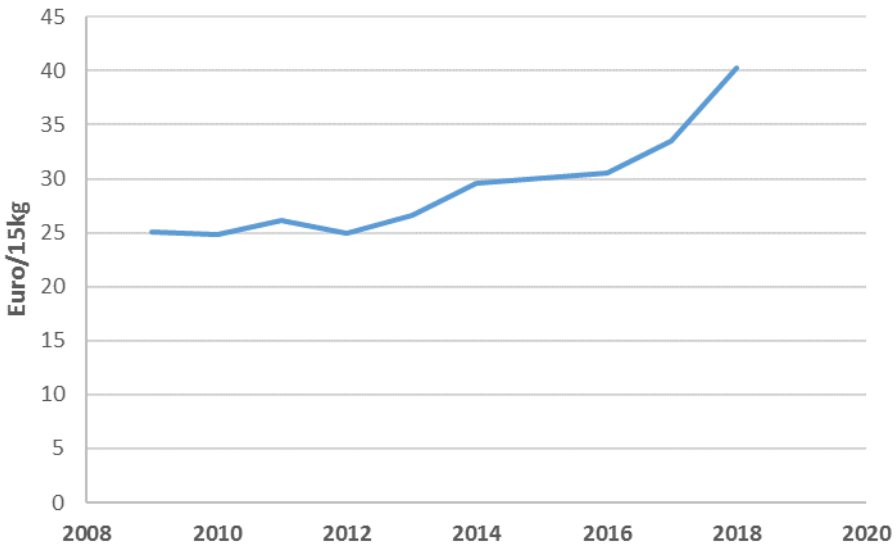


Figure 192: Average selling price of and "arroba" of debarker cork (APF, 2019).

20.3EU demand

20.3.1EU demand and consumption

The average annual EU consumption between 2013 and 2017 of natural cork is 141.3 kt. About 70% of the natural cork used in the EU goes into stoppers.

20.3.2Uses and end-uses of natural cork in the EU

Cork is 100% natural plant tissue, consisting of a hive of microscopic cells containing air and coated primarily with suberin and lignin. It has a range of applications associated with its attributes (e.g. gas impermeability) that no technology has yet managed to emulate, match or exceed (APCOR 2016).

Cork has some properties that make it very specific. It weighs only around 200kg/m^3, it is impermeable to most fluids and gases, it is elastic, it has a low conductivity for heat and sound, making it suitable for insulation) and it is slow burning.

Due to these intrinsic properties, insulation cork board (ICB) is used in the construction industry as insulation(Lança, 2010)(Sierra-Pérez, 2014).

The main end uses of natural cork are as wine corks or as insulation material. A small but valuable use of cork is within sectors related to machinery and transport equipment, such as for engine gaskets and other seals. Figure 193 presents the main uses of natural cork in the EU. The percentages represent the weight/volume of extracted raw material that is eventually used for these main uses. The large share of wine corks is therefore explained by the large volume of industrial waste that is created during the manufacturing of the actual wine cork. This requires a relatively large amount of extracted natural cork.

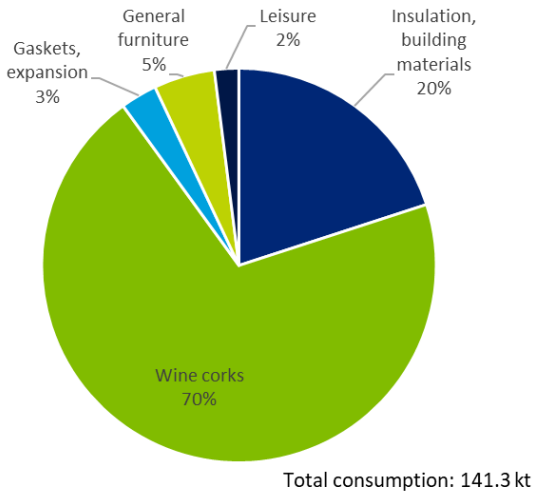


Figure 193: EU end uses of natural cork. Average for 2013-2017. (Eurostat, 2019b), (APCOR 2016)

The 3% share in end-use allocations of gaskets are allocated over NACE sector 28, 29 and 30 with 1% each respectively, since they are applied in all kinds of transport equipment and machinery (M.C. Varela 2019). Relevant sectors are shown in Figure 193 and Table 101.

Relevant industry sectors are described using the NACE sector codes (Eurostat 2019a) in Table 101.

Table 101: natural cork applications, 2-digit and associated 4-digit NACE sectors and added value per sector (Eurostat 2019a)

Applications	2-digit NACE sector	Value added of 2-digit NACE sector (M€)	4-digit NACE sectors
Wine corks	C11 - Manufacture of beverages	38 996	C11.01 - Manufacture of wine from grape
Insulation, building materials	C16 - Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	31 600	C16.29 - Manufacture of other products of wood; manufacture of articles of cork
Gaskets, expansion	C28 - Manufacture of machinery and equipment n.e.c.	197 977	C28.99 - Manufacture of other special-purpose machinery n.e.c.
Gaskets, expansion	C29 - Manufacture of motor vehicles, trailers and semi-trailers	180 180	C29.32 - Manufacture of other parts and accessories for motor vehicles
Gaskets, expansion	C30 - Manufacture of other transport equipment	56 768	C30.12 - Building of pleasure and sporting boats
General furniture	C31 - Manufacture of furniture	29 806	C31.09 - Manufacture of other furniture
Leisure articles	C32 - Other manufacturing	43 937	C32.99 - Other manufacturing n.e.c.

20.3.3Substitution

Substitution of natural cork might lead to a loss of performance for a specific function, for instance the combination of elasticity, weight and insulation properties. The economic possible substitution rate of natural cork is high, which contributes to the fact that the material is not assessed as critical.

Cork can be substituted up to 50% for all construction purpose by other matrials, such as the ones indicated in the next list and both metal (screw caps) and plastic for beverage purposes (Sierra-Pérez, Boschmonart-Rives, and Gabarrell 2014)(De Oliveira et al., 2017). There is an increasing trend for cork wine stoppers to be substituted, for two main reasons: firstly, there is an 8% failure rate in natural cork wine stoppers, so that wines are spoiled. Secondly, world wine production and consumption are increasing faster than cork production.

Alternative materials for the properties provided by natural cork:

- Stone Wool or Glass Wool
- Expanded Polystyrene or Extruded Polystyrene
- PUR
- Several other plastics

20.4Supply

20.4.1EU supply chain

The NACE4-digit code "Manufacture of other products of wood; manufacture of articles of cork, straw and plaiting materials" had a value added of close to 3 billion EUR (Eurostat 2019b). As expected, it is strongly represented in Portugal, but also in France and Germany.

The EU is not dependent on imports for natural cork. Agricultural activity surrounding natural cork is important for local communities, given the fact that the agricultural workers who harvest cork are among the highest paid agricultural field workers in the world (Pereira 2011). There is a diverse and sizeable group of European companies involved in the value chain, and product innovation, associated with natural cork. However, the harvesting, marketing and initial processing form an oligarchic market.

20.4.2Supply from primary materials

20.4.2.1 Production locations of natural cork

Geographical occurrence:

The tree cork oak (*Quercus suber*) grows typically in the summer months of the Northern hemisphere, depending on the geophysical circumstances. The coldest months should have a temperature that remains above -5ºC at a minimum (Pereira 2011). It takes each cork oak 22 years before it can be stripped for the first time and thereafter only every nine years. It is only from the third harvest that the cork will have reached the high quality need for stoppers. The first two tours usually provide raw material for insulation, floors or other purposes. The trees can produce cork for over 200 years.

Global resources and reserves

The current land use of natural cork is shown in Table 102.

Table 102: Global reserves of natural cork in year 2018 (APCOR 2018).

Country	Natural cork Reserves (ha)	Percentage of total (%)
Portugal	736,775	34
Spain	574,246	27
Morocco	383,120	18
Algeria	230,000	11
Tunisia	85,771	4
France	65,228	3
Italy	64,800	3
World total (rounded)	*2,139,942*	*100*

EU resources

Apart from Portugal and Spain, France and Italy report some regional economic activity in the production of natural cork. There is also mentioning of small-scale production in Greece, but could not be confirmed by available data sources.

20.4.2.2 World and EU production

The world annual production of natural cork in average between 2013 and 2017 is around 267.1 thousand tonnes (see Figure 194).

The global producers of natural cork are concentrated in the western Mediterranean area, with a dominant role for the Iberian Peninsula, see Figure 194.

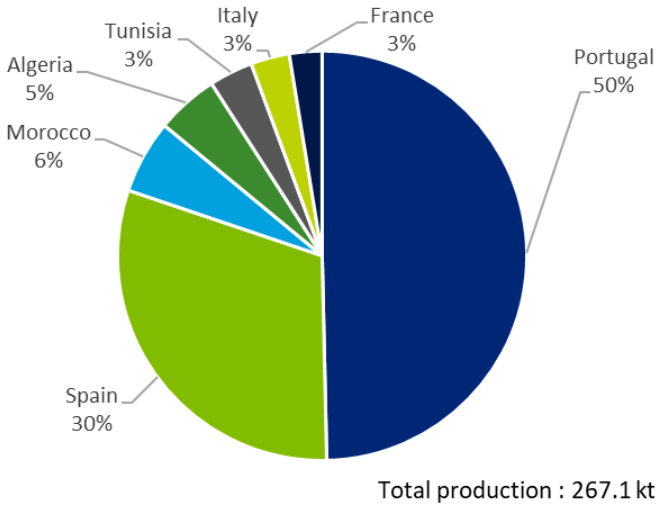


Figure 194: Global production of natural cork in percentage. Average for the years 2013-2017 (APCOR 2018), (Eurostat 2019b)

20.4.3Supply from secondary materials/recycling

20.4.3.1 Post-consumer recycling (old scrap)

End-of-life recycling input rate for natural cork is estimated to be 8%, based on APCOR (APCOR 2015); (Amorim and Sgps 2008).

Only for construction purposes can processed secondary cork replace primary cork. Recycling of natural cork with the purpose to use them again as wine corks is not possible mainely due to health and safety issues. Eventhen, recycled cork should not be used in stoppers again, they may be used in the production of other materials for coverings, insulation, memo boards, high competition kayaks, badminton rackets, tennis and cricket balls, car and aircraft components, design and fashion items and a multitude of other uses (APCOR, 2019). Currently, the most important aim of the collection efforts is to raise awareness of the importance of ecological and social opportunities to use recycled cork. Potential for more extensive recycling is not yet reported.

20.4.3.2 Industrial recycling (new scrap)

Waste scrap of natural cork is traded as a commodity and basically a raw material for other applications. It is treated as a raw material in the assessment including product group “cork waste; crushed, powdered or ground cork”.

20.5Other considerations

20.5.1Environmental and health and safety issues

Natural cork is not related to any reported health problem. The environmental issues relate to vulnerability of the production system from pressures from the environment rather than the other way around. This makes them more vulnerable to pathogens such as the fungus P. Cinnamomi, which then can enter the tree and cause chronic disease or rapid dieback (Moreira, 2002).

Cork has a significantly lower environmental impact than plastic and aluminium for use in the beverage industry (Amorim and Sgps 2008). Natural Cork requires less water, can harbour a greater biodiversity and avoid Aeolian (wind) erosion (Amorim and Sgps 2008).

20.5.2Socio-economic issues

It should be mentioned that cork is considered to be among the types of EU produce that has the strongest link to vulnerable agricultural communities and cork processing workers (CREOAK Project, 2006).

20.6Comparison with previous EU assessments

The assessment has been done using the same methodology as used in the assessment for the CRM list 2017.

There are only the results of the previous assessment available to compare the current analysis of natural cork (see Table 103).

Table 103: Economic importance and supply risk results for natural cork in the assessments of 2011, 2014, 2017, 2020

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Natural cork	N.A.	N.A.	N.A.	N.A.	1.5	1.1	1.59	0.98

The economic importance has increased slightly from 1.5 in 2017 to 1.6 in 2020, due to changes in the added value of the NACE sectors. The Supply Risk has slightly decreased from 1.1 in 2017 to 0.98 in 2020.

20.7Data sources

The CN codes used are 4501 1000, 4501 9000 and 4502 0000, which are labelled "Natural cork, raw or simply prepared merely surface-worked or otherwise cleaned", "cork waste; crushed, powdered or ground cork" and "Natural cork, debarked or roughly squared, or in square or rectangular blocks, plates, sheets or strip, incl. sharp-edged blanks for corks or stoppers".

The data has a moderate coverage. There are many gaps and for a number of parameters data are not available, estimated or qualitative only. The production data are not from an official, independent source. At the same time, they are updated at regular intervals. The production data are only available on an annual basis; however, basic time-series can be created by analysing the series of annual reports. The source describes global production and is publicly available.

20.7.1 Data sources used in the factsheet

Amorim, C., & Sgps, S. (2008). Evaluation of the environmental impacts of Cork Stoppers versus Aluminium and Plastic Closures (October), 1–126. Retrieved from http://amorimcork.com/media/cms_page_media/218/Amorim_LCA_Final_Report.pdf

APCOR. (2015). Realcork – Recycling. Retrieved November 5, 2019, from http://www.apcor.pt/en/cork/recycling/

APCOR. (2016). Realcork – Statistics. Retrieved November 5, 2019, from http://www.apcor.pt/en/media-center/statistics/

APCOR. (2018). Anuario APCOR 2018.

APFC. (2019) Associação de Produtores Florestais, MERCADO EXTERNO DA CORTIÇA CAMPANHA DE EXTRAÇÃO DE CORTIÇA 2018 PERSPECTIVAS CAMPANHA 2019

De Oliveira, H., Yoon, B., Michaud, V., Nam, J. Do, & Suhr, J. (2017). All natural cork composites with suberin-based polyester and lignocellulosic residue. Industrial Crops and Products, 109, 843–849. https://doi.org/10.1016/j.indcrop.2017.09.044

European Commission. (2011). Critical raw materials. Retrieved July 8, 2019, from https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission. (2014). Report on critical raw materials for the EU - Critical raw materials profiles. Retrieved from https://ec.europa.eu/docsroom/documents/11911/attachments/1/translations/en/renditions/pdf

European Commission. (2017). Study on the review of the list of critical raw materials. Non-critical raw materials factsheets. https://doi.org/10.2873/876644

European Commission. (2019). Negotiations and agreements - Trade. Retrieved July 7, 2019, from http://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/

Eurostat. (2019a). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). Retrieved July 7, 2019, from https://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

Eurostat. (2019b). Easy Comext database. Retrieved from http://epp.eurostat.ec.europa.eu/newxtweb/

Lança, M. C., Brandt, M., Neagu, E. R., Dias, C. J., & Marat-Mendes, J. N. (2010). Dielectric spectra of natural cork and derivatives. Journal of Non-Crystalline Solids, 356(11–17), 763–767. https://doi.org/10.1016/j.jnoncrysol.2009.09.042

M.C. Varela. (2019). Cork and the cork oak system. Retrieved November 5, 2019, from http://www.fao.org/3/x1880e/x1880e08.htm

OECD. (2019). Export restrictions on Industrial Raw Materials. Retrieved July 5, 2019, from https://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

Pereira, H. (2011). Cork: Biology, Production and Uses: Biology, Production and Uses. Retrieved from http://books.google.pt/books/about/Cork_Biology_Production_and_Uses.html?id=5uiycUoRmFkC&pgis=1

Project, C. (n.d.). Conservation and restoration of european cork oak woodlands : a unique ecosystem in the balance | CREOAK Project | FP5 | CORDIS | European Commission. Retrieved November 6, 2019, from 2019 website: https://cordis.europa.eu/project/rcn/68944/factsheet/en

Sierra-Pérez, J., Boschmonart-Rives, J., & Gabarrell, X. (2014). Environmental implications in the substitution of non-renewable materials by renewable materials. website: http://www.jornadesambientals.com/uploads/2/3/9/7/23973214/p%C3%B2ster_10_environmental_implications_in_the_substitution_of_non-renewable_materials_by_renewable_materials..pdf

20.7.2Data sources used in the criticality assessment

APCOR. (2015). Realcork – Recycling. Retrieved November 5, 2019, from http://www.apcor.pt/en/cork/recycling/

APCOR. (2016). Realcork – Statistics. Retrieved November 5, 2019, from http://www.apcor.pt/en/media-center/statistics/

APCOR. (2018). *Anuario APCOR 2018*.

De Oliveira, H., Yoon, B., Michaud, V., Nam, J. Do, & Suhr, J. (2017). All natural cork composites with suberin-based polyester and lignocellulosic residue. *Industrial Crops and Products*, *109*, 843–849. https://doi.org/10.1016/j.indcrop.2017.09.044

CIF (2019). Cork Industry Federation. Cork Products [online] Available at: http://www.cork-products.co.uk/products.html

European Commission (2019). Free trade agreements. [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/[Accessed May 2019]

Eurostat. (2019a). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). Retrieved July 7, 2019, from https://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

Eurostat. (2019b). Easy Comext database. Retrieved from http://epp.eurostat.ec.europa.eu/newxtweb/

Lança, M. C., Brandt, M., Neagu, E. R., Dias, C. J., & Marat-Mendes, J. N. (2010). Dielectric spectra of natural cork and derivatives. *Journal of Non-Crystalline Solids*, *356*(11–17), 763–767. https://doi.org/10.1016/j.jnoncrysol.2009.09.042

20.8Acknowledgments

This factsheet was prepared by the JRC in collaboration with TNO. The authors would like to thank the Forest Stewardship Council (FSC) and Aleš Straže for their contribution.

21. NATURAL TEAK WOOD

21.1 Overview

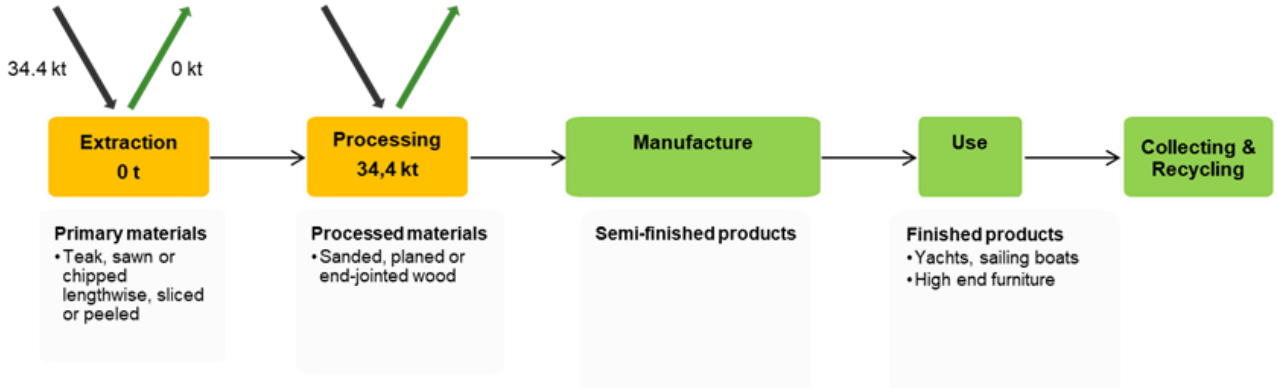


Figure 195: Simplified value chain for natural teak wood, 2012-2016

Teak wood comes from a tropical tree named *Tectona grandis L.f*. Natural teak wood, from natural or partly managed forests, is not to be confused with planted teak wood. It is one of the most expensive types of wood on the planet. Natural teak wood was not on the list of CRMs in 2011 and 2014 and was first assessed in 2017. For the purpose of this assessment, natural teak wood is not considered to be represented by any HS-CN trade code. The product groups that describe natural teak wood (e.g. 4407 29) contain many other types of tropical wood and therefore can't be regarded as a representation of this material alone.

There are studies (Kollert & Cherubini, 2012; FAO, 2018) that have mapped the global production of teak wood, resulting in a relatively accurate estimation of production potential. The growth time of a typical natural teak tree varies around a hundred years.

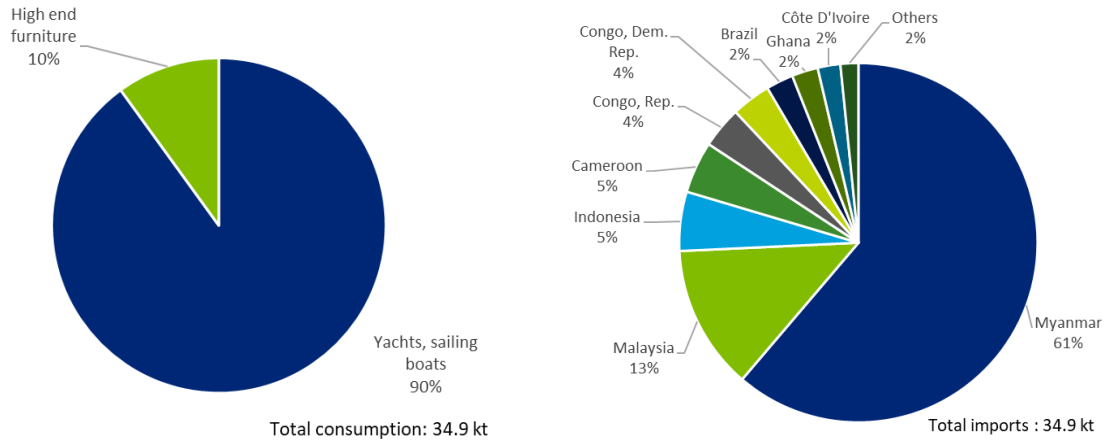


Figure 196. End uses and EU sourcing of Natural Teak Wood. (Midgley et al., 2015; Eurostat, 2019b; FSC, 2019)

The average world production of natural teak wood between 2013 and 2017 is roughly estimated to be about 539 kt representing as much as D1 to 2 billion production, which is

expected to grow modestly towards 2020[136]. Fows of wood are expressed in roundwood equivalent cubic metres(. It is not traded on any centralised exchange, so reported prices come from publicly reported over-the-counter transactions.

Annual average global consumption of natural teak wood between 2013 and 2017 is estimated to be 539 kt, compared to 3000 kt of plantation teak wood.

For most applications of natural teak wood, material substitutes exist. Several other tropical woods and obviously plantation teak woods can be used as a substitute. There is however a high likelihood of reduced performance of any of the substitution options available, depending on the precise application and performance required.

World resources of natural teak are around 3 Mt. No resources or reserves of natural teak wood can exist in the geophysical climate of the EU.

The world annual production of natural teak wood, estimated around 539 kt, originates mostly from India, Indonesia and Myanmar. Most of the world's market (over 80%) is located in India.

Natural teak wood is recycled from end-of-life finished products, but not to the same primary application as the frist use.

The extraction of natural teak wood, as for many tropical woods, is strongly connected with sustainable forestry practices, of the country or region where natural teak wood is sourced. There is little evidence that extraction of natural teak wood is directly impeding natural forests, but available data and information should be treated with caution. Only one type of natural teak wood is listed as critically endangered on the IUCN Red list (Madulid, et al., 2008).

21.2Market analysis, trade and prices

21.2.1Global market analysis and outlook

Given physical properties, combined with its ability to grow in plantations, teak has grown into and remained to be a world-wide favourite tropical wood. With its superb stability, good strength properties, easy workability and most of all, its outstanding resistance to decay, these features have resulted in teak ranking among the most desired woods in the world (Wood-database, 2019). The heartwood is rated as very durable with respect to decay fungi and termites; not immune to marine borers (USDA 2019).

Given these properties, the global market outlook forecast for natural teak wood demand is expected to follow the current baseline, rising to 600 kt tonnes by 2020. According to (Van Benthem, et al., 2018), the demand for natural teak wood products will increase for the next 10 years, as well as for the supply (see Table 104). The forecast over 20 years is based on a continuation of this trend.

Philippines teak may have potential as a genetic resource for future teak breeding programmes aimed at improving supplies of this highly popular wood (Madulid et al., 2008). See Table 104.

[136] http://www.fao.org/news/story/en/item/1073713/icode/ en https://www.accoya.com/wp-content/uploads/2011/06/SCION-20-08-2010.pdf

Table 104: Qualitative forecast of supply and demand of natural teak wood

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Natural teak wood		x	+	+	+	+	+	+

21.2.2EU trade

Europe imports 100% of the natural teak wood used in the EU (about 34.4 kt per year between 2013 to 2017). The forms of natural teak wood that are imported are sanded planks, slabs or relatively unworked wood.

The exports from the EU are, without exception, re-exports or mostly shipped to non-EU European countries. The HS-CN product group that describes teak import and export is heterogenous. It covers over thirty types of tropical wood.

The main suppliers of the EU are Myanmar (61%) and Malaysia (13%), although there is evidence that most of Malayan EU imports originate from Myanmar (FSC 2019). Although the aim here was to research natural teak wood only and to exclude plantation teak, it is important to highlight that some of the amounts of the imported teak may be mixtures of natural teak and plantation teak.

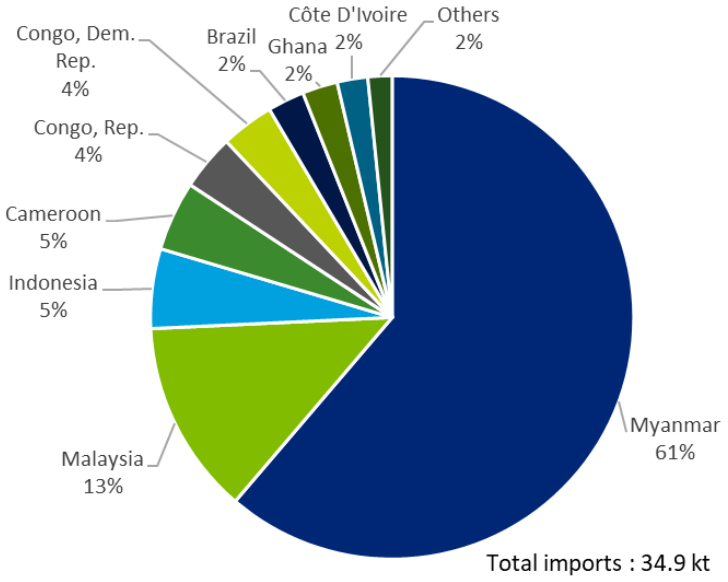


Figure 197: EU imports of natural teak wood (Midgley et al. 2015); (Eurostat 2019b); (FSC 2019)

No free trade agreements exist at this time between the EU and the main exporting countries (European Commission 2019). Nonetheless, there are no exports taxes, quotas on or prohibitions of natural teak wood (OECD 2019).

21.2.3Prices and price volatility

Natural teak is not traded in a centralised commodity market structure, and prices are therefore based on individual over-the-counter transactions.. On average, prices of teak seem

to be between 2,000 and 5,000 USD per m^3 in the EU. Markets in smaller Member States seem to set much higher prices than EU-28 countries with main seaports (Kollert and Kleine, 2017).

21.3EU demand

The average world market demand for natural teak wood between 2013 and 2017 was 539 kt, representing as much as USD 1 to 2 billion.

21.3.1EU demand and consumption

The annual EU consumption of natural teak wood is estimated at 34.4 kt, less than 10% of the world market. About 90% of the natural teak wood used in the EU goes into yacht building. This end-use estimation is based on sectoral uses of natural teak wood in India.

21.3.2Uses and end-uses of natural teak wood in the EU

Teak wood is harvested from a tropical tree named *Tectona grandis L.f*, from the Verbenaceae family. Erroneous equivalents are afro teak, yang-teak en iroko-teak, since none of these are teak wood (Houtvademecum 2011; CIRAD, 2015). Above all, plantation teak is not a real equivalent for natural teak, since the growth accelerating measures used during the plantation make the technical properties of planted teak inferior to those of natural teak.

The heartwood (core) tends to be a golden or medium brown, with colour darkening with age. An adult tree is about 30-45m tall with a trunk diameter of 1-1.5m (Wood-database 2019 - Teak, 2019).

Common uses in the EU of natural teak wood are as veneer, for applications in: boatbuilding; furniture; exterior construction, and carving of small wood objects (marquetry).

An unusual disparity is observed between teak used in advanced economies and in local, teak-producing areas. In countries like Myanmar and the Philippines, construction wood is cut for house posts; an estimated 25% of the global teak production is utilised that way. (Madulid, et al., 2008).

The calculation of economic importance is based on the NACE 2-digit codes and the added value at factor cost for the identified sectors (Table 105). Figure 198 presents the main uses of natural teak wood in the EU.

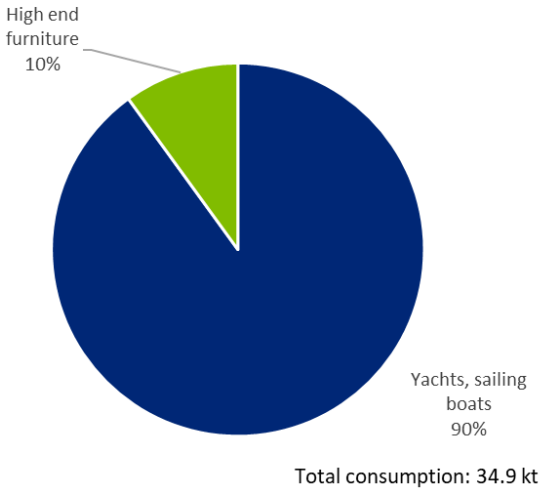


Figure 198: EU end uses of natural teak wood. (TNO 2019)

The end-uses of natural teak wood are based on expert judgement, considering the uses of the Indian market (TNO 2019) and expected to be:

- Yachts and sailing boats, especially parts exposed to sunlight and water
- Expensive and/or outdoor furniture.

There are also examples of use of natural teak for construction purposes, but this use is assumed to be the currently not relevant. This is because these examples relate to older buildings and the price of natural teak combined with the available material substitutes makes it unlikely for natural teak to be used on a relevant scale in construction.

Relevant industry sectors are described using the NACE sector codes (Eurostat 2019a) in Table 105. The added value data correspond to 2012-2016 averages.

Table 105: natural teak wood applications, 2-digit and associated 4-digit NACE sectors and value added per sector (Eurostat 2019a)

Applications	2-digit NACE sector	Value added of 2-digit NACE sector (M€)	4-digit NACE sectors
Yachts	C30 - Manufacture of other transport equipment	56768.5	C30.12 - Building of pleasure and sporting boats
High-end furniture	C31 - Manufacture of furniture	29806.2	C31.09 - Manufacture of other furniture

21.3.3Substitution

Teak is a tropical wood, and as with many tropical wood, it is generally considered to be substitutable by other woods. For most applications, certain other wood types will be available. However, performance loss is to be expected, for instance decolouring, less hardness or durability, deformation (FAO 2018); (ITTO 2018); (TNO 2019); (USDA 2019). A decision factor will be the availability of the required amount and size of natural teak wood, reflected in volatile prices.

Alternate materials for the properties provided by natural teak wood:

- Several tropical woods, such as Shorea, Iroko and Mahagony (FSC 2019); (TNO 2019).

21.4Supply

21.4.1EU supply chain

The EU has many manufacturers of boats and furniture that are produced from raw natural teak wood. At the same time, Europe and North America are the world's largest importers of natural teak wood furniture and parts of furniture (Midgley et al. 2015).

Although several tropical woods are subject to trade restriction, the product group containing teak has no associated trade restrictions with those other woods. "Burmese Teak" was a famous example of a conflict related material in the 20th century, but that situation has changed decades ago.

21.4.2Supply from primary materials

21.4.2.1 Production locations of natural teak wood

Geographical occurrence:

Teak is easily distinguishable by its flaky bark (Wood-database, 2019). There are three main species in the genus Tectona: *Tectona grandis* (common teak, Burmese teak or plantation teak), *Tectona hamiltoniana* (Dahat teak) and *Tectona philippinensis* (Philippine teak).

Plantation teak includes the commercial teak *Tectona grandis*, one of the few tropical timbers successfully grown as a plantation crop. This teak, also known as Burmese teak, is used to differentiate natural-grown trees from teak grown on plantations. *Philippinensis* is found in the Philippines, mainly in coastal to lowland limestone forest. *Tectona grandis* tends to dominate the semi-deciduous forests and occurs in association with *Terminalia polyalthia*. Other associated species are *Vitex parviflora*, *Tamarindus indicus*, *Mangifera indica*, *Ceiba pentandra*, *Syzygium*, *Parkia roxburghii*, and *Ficus*. (IUCN, 2019).

There are many wood types called teak that are not actually *Tectona grandis* teak. Much like the many names and synonyms of mahogany, the name "teak" has been affixed and assigned to a number of different woods seeking acclaim. The usual procedure was to take a wood bearing any degree of resemblance to teak and insert a geographical location in front of the name. For instance, *Cumaru* is sometimes referred to as Brazilian teak, while Rhodesian teak bears little botanical relation to real teak (Wood-database, 2019).

Global resources and reserves

There are studies (Kollert & Cherubini, 2012; FAO, 2018) that have mapped the global production of teak wood, resulting in a relatively accurate estimation of production potential. The growth time of a typical natural teak tree varies around a hundred years.

Table 106: Global reserves of natural teak forests in year 2016 (Kollert & Cherubini, 2012; FAO, 2018)

Country	Teak reserves (000 ha)	Percentage of total (%)
India	2,561	37
Indonesia	1,470	21

Country	Teak reserves (000 ha)	Percentage of total (%)
Thailand	836	12
Other Asia	814	12
Africa	538	8
Myanmar	390	6
Latin America	278	4
World total (rounded)	*6,887*	*100*

EU resources and reserves

There is no viable economic land resource in the EU that could support natural teak production.

21.4.2.2 World and EU production

The world annual production of natural teak wood on average between 2013 and 2017 was around 539 kt, mainly in India and Indonesia, see Figure 199. The dominant role of Asia is clearly shown, which was also reflected in the overview of the current acreage of teak.

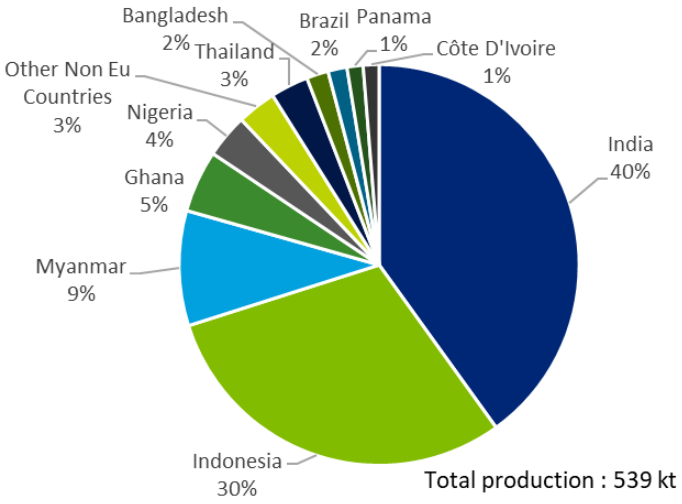


Figure 199: Global production of natural teak wood in percentage. Average for the years 2013-2017. (Midgley et al. 2015; IUFRO 2017)

These estimates shows a decline in world production from the 2010-2015 average by around 100 kt.

21.4.3Supply from secondary materials and recycling

21.4.3.1 Post-consumer recycling (old scrap)

Natural teak wood is recycled from end-of-life finished products, but not to the same primary application as the frist use. Industrial recycling (new scrap)

Activities that can produce secondary teak wood, that replaces demand for primary production, exist within the supply chain. Examples are large chippings and removed parts that are delivered in smaller shapes.

21.5Other considerations

21.5.1Environmental and health and safety issues

Natural teak is not related to any reported health problem. In some countries its harvesting is part of unsustainable forestry practices".

Myanmar is the only country that still officially exports teak from natural forests. Legality and sustainability (to ensure perpetual supply of both tangible and intangible benefits accrued from the forests for the present and future generations) remain key pillars for using this wood species.

Teak wood species are not listed in the CITES Appendices (CITES 2019) but in the *Philippinensis* type of natural teak is listed as critically endangered in the IUCN Red list (IUCN, 2019). A conservation programme is needed to re-establish a stable natural population, particularly of the *T. Philippinensis* in its known habitat. A rapid assessment of the species and long-term ecological research is required to determine the physical and biological characteristics of the habitat, coupled with a recovery and management programme, public education, community consultation and resource stewardship, and policy initiatives (IUCN, 2019).

The European Union "Timber Regulation" (EUTR) became effective in March 2013. This law provides a general 'prohibition' against the 'placing on the EU market of illegally harvested timber or timber products derived from such timber'. The Action Plan which includes this law, Forest Law Enforcement Governance and Trade (FLEGT), has been part of the EU's policy response to combat illegal logging and associated trade since 2003.(European Commission).

21.5.2Socio-economic issues

To gain access to the EU, shipments of natural teak wood need to be cleared in any EU port. Almost all natural teak into the EU is shipped through Italian ports by a limited number of major import companies. Further down the supply chain, natural teak processing enterprises can refer to the importer for due diligence issues. However, this does not release them (as operator or trader) from due-diligence responsibilities.(EFI, 2019).

However, reports of illegal logging exist on the natural teak wood value chain (EIA, 2019). Illegal logging activities include the harvest, transportation, purchase or sale of timber in violation of national laws. The harvesting procedure itself may be illegal, including using corrupt means to gain access to forests; extraction without permission or from a protected area; the cutting of protected species; or the extraction of timber in excess of agreed limits. This illegal logging is usually carried out by poor rural people who need the income and, despite legislation, will probably continue to do if they don't have alternative incomes (EC, 2007).

The bottleneck for supply of teak wood is, for any tropical wood, associated with the land use, extensive production times and environmental and social issues (FAO 2018).

21.6Comparison with previous EU assessments

The assessment has been done using the same revised methodology as used in the assessment for the CRM list 2017. Natural teak was assessed for the first time in 2017.

The results of this and earlier assessments are shown inTable 107.

Table 107: Economic importance and supply risk results for natural teak wood in the assessments of 2011, 2014, 2017, 2020

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Natural teak wood	N.A.	N.A.	N.A.	N..A	2.0	0.9	1.95	1.89

The economic importance of natural teak wood slightly decreased between 2017 and 2020 from 2.0 to 19.5, respectively. The supply risk has increased from 0.9 to 1.89. The supply risk has increased given the World Governance Index (WGI) scores of the source countries. The economic importance has slightly diminished given the wider range of substitution options, including economic substitution, that were made parts of the assessment.

21.7Data sources

The CN codes used for the this assessment are 4407 2915, 4407 2925, 4407 2945 and 4407 2960. As mentioned previously, they all comprise many tropical timbers, including natural teak wood. To name a few: keruing, ramin, kapur, jongkong, merbau, jelutong, kempas, azobé, abura, afrormosia, ako, andiroba, geronggang, ipé, jaboty, jequitiba, maçaranduba, mahogany, mengkulang, merawan, merpauh, mersawa, moabi, niangon, nyatoh, onzabili, orey, ovengkol, ozigo, padauk, paldao, pulai, punah, quaruba, saqui-saqui, sepetir, sucupira, suren, tauari and tola.

They are discerned in case the wood is end-jointed, planed or sanded or none of those. These products can still be regarded as non-processed goods (TNO 2019). The last product group 4403 4995, only lists wood in the rough.

The data are of poor quality in general. The global Teak study of 2017 from IUFRO is a however a great improvement in terms of information compared to the previous assessment.

The data used in this assessment are not from an official source, but comes from governmental institutes (FAO, ITTO, IUFRO, Australian government) that are known to produce good quality data. The data are updated at intervals. The production data is only available on an annual basis; however, basic time-series can be created by analysing the series of annual reports. The source describes global production and is publicly available.

21.7.1Data sources used in the factsheet

CIRAD. (n.d.). Tropix 7. Retrieved November 5, 2019, from 2019 website: https://tropix.cirad.fr/en

CITES. (2019). Appendices | CITES. Retrieved November 5, 2019, from https://www.cites.org/eng/app/appendices.php

EFI. (2019). Policy Support Facility | European Forest Institute. Retrieved November 7, 2019, from https://www.efi.int/policysupport

EIA (2019). Environmental Investigation Agency - German firm reported for Myanmar teak imports violating Europe's legal timber rules https://eia-international.org/news/german-firm-reported-for-myanmar-teak-imports-violating-europes-legal-timber-rules/

European Commission. (2007). COMMISSION STAFF WORKING DOCUMENT Accompanying document to the Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL determining the obligations of operators who make timber and timber products available on the Market IMPACT ASSESSMENT Report on additional options to combat illegal logging

European Commission. (2011). Critical raw materials. Retrieved July 8, 2019, from https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission. (2014). Report on critical raw materials for the EU - Critical raw materials profiles. Retrieved from https://ec.europa.eu/docsroom/documents/11911/attachments/1/translations/en/renditions/pdf

European Commission. (2017). Study on the review of the list of critical raw materials. Non-critical raw materials factsheets. https://doi.org/10.2873/876644

European Commission. (2019). Negotiations and agreements - Trade. Retrieved July 7, 2019, from http://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/

Eurostat. (2019a). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). Retrieved July 7, 2019, from https://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

Eurostat. (2019b). Easy Comext database. Retrieved from http://epp.eurostat.ec.europa.eu/newxtweb/

FAO. (2018). Global Forest Resources Assessment 2018. Retrieved from www.fao.org/forestry

FSC. (2019). Species. Retrieved November 4, 2019, from https://www.lesserknowntimberspecies.com/species

Houtvademecum. (2011). Centrum Hout Almere. Sdu uitgevers bv, den Haag. ISBN 978 90 125 82162, NUR 833/835.

ITTO. (2018). Review and Assessment of the World Timber Situation | ITTO | The International Tropical Timber Organization. Retrieved November 5, 2019, from https://www.itto.int/annual_review/

Madulid, D.A., Agoo, E.M.G. & Caringal, A. M. (2008). Tectona philippinensis (Philippine Teak). The IUCN Red List of Threatened Species. Retrieved from https://www.iucnredlist.org/species/32123/98839585

Midgley, S., Somaiya, R. T., Stevens, P. R., Brown, A., Kien, N. D., & Laity, R. (2015). Planted teak: global production and markets, with reference to Solomon Islands. Australian Centre for International Agricultural Research (ACIAR), 92.

OECD. (2019). Export restrictions on Industrial Raw Materials. Retrieved July 5, 2019, from https://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

TNO. (2019). Expert judgement Jan de Jonge.

USDA. (2019). Forest Products Laboratory - USDA Forest Service. Retrieved November 5, 2019, from https://www.fpl.fs.fed.us/research/centers/woodanatomy/techsheets_display.php?geo_category_id=4&genus_commonname_criteria=c&sorting_rule=1a

Van Benthem, M., Kremers, J., Oldenburger, J., Stam, N., & Sleurink, N. (2018). How sustainable aRe euRope's tRopical timbeR impoRts? Estimating the market share of verified sustainable tropical timber on the European market. Retrieved from https://www.euandgvc.nl/documents/publications/2015/december/7/declarations-palm-oil

Kollert, W., Klein. M (2017). The Global Teak Study Analysis, Evaluation and Future Potential of Teak Resources.

Wood-database 2019 -Teak. (n.d.). Retrieved November 7, 2019, from http://www.wood-database.com/teak/

21.7.2Data sources used in the criticality assessment

European Commission. (2019). Negotiations and agreements - Trade. Retrieved July 7, 2019, from http://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/

FSC. (2019). Species. Retrieved November 4, 2019, from https://www.lesserknowntimberspecies.com/species

Houtvademecum. (2011). Centrum Hout Almere. Sdu uitgevers bv, den Haag. ISBN 978 90 125 82162, NUR 833/835.

Kollert, W., Klein. M (2017). The Global Teak Study Analysis, Evaluation and Future Potential of Teak Resources.

Midgley, S., Somaiya, R. T., Stevens, P. R., Brown, A., Kien, N. D., & Laity, R. (2015). Planted teak: global production and markets, with reference to Solomon Islands. Australian Centre for International Agricultural Research (ACIAR), 92.

OECD. (2019). Export restrictions on Industrial Raw Materials. Retrieved July 5, 2019, from https://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

TNO. (2019). Expert judgement Jan de Jonge.

Van Benthem, M., Kremers, J., Oldenburger, J., Stam, N., & Sleurink, N. (2018). How sustainable aRe euRope's tRopical timbeR impoRts? Estimating the market share of verified sustainable tropical timber on the European market. Retrieved from https://www.euandgvc.nl/documents/publications/2015/december/7/declarations-palm-oil

Warner, A. J., Monton Jamroenprucksa, Ladawan Puangchit, Development and evaluation of teak (Tectona grandis L.f.) taper equations in northern Thailand, Agriculture and Natural Resources, Volume 50, Issue 5, 2016, Pages 362-367, ISSN 2452-316X, https://doi.org/10.1016/j.anres.2016.04.005.

21.8Acknowledgments

This factsheet was prepared by the JRC in collaboration with TNO. The authors would like to thank the FSC association, Aleš Straže, and Silvia Melegari for their contribution.

22. NICKEL

22.1 Overview

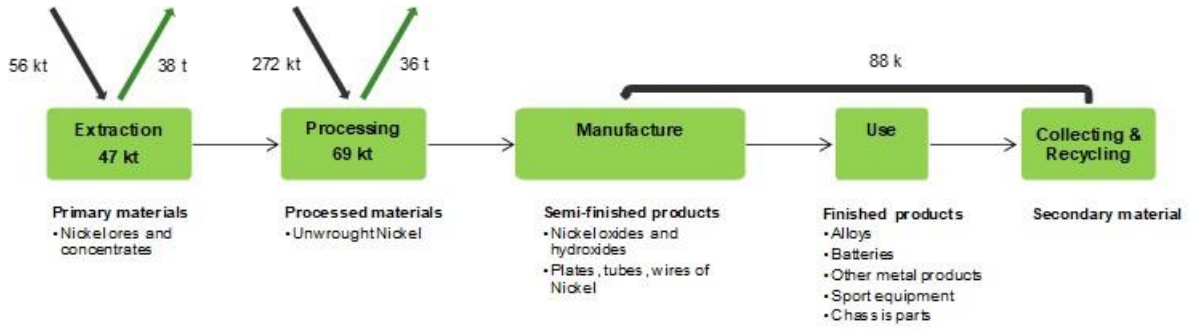
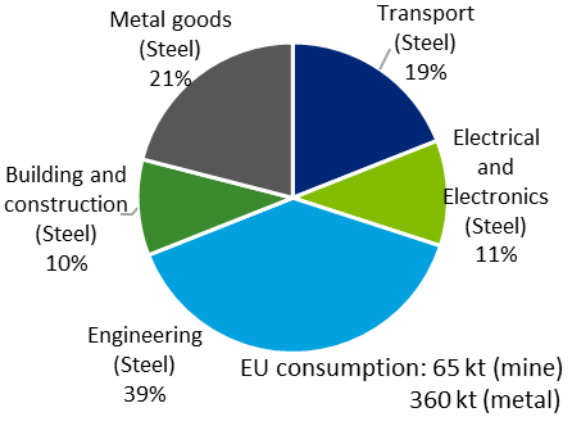


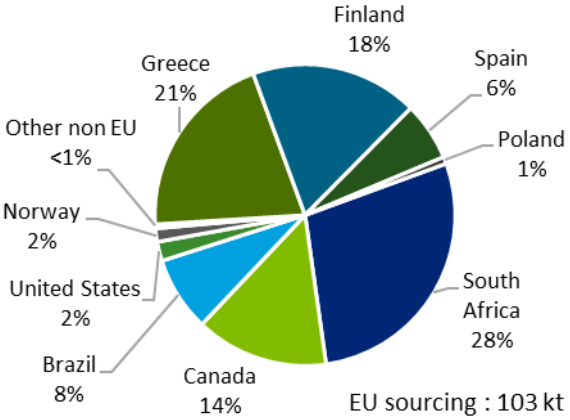
Figure 200: Simplified value chain for nickel for the EU, averaged over 2012-2016[137]

Nickel (chemical symbol Ni) is a shiny white metal with typical metallic properties. In nature, it mostly occurs in combined form, and mainly as isotopes of mass number 58 (68%) and 60 (26%). It has a relatively high melting point of 1,455°C and a density of 8.908 g/cm^3.

For the purpose of this assessment, nickel is analysed at both extraction and processing stages. At the mining stage, trade data is analysed using the CN code 2604 which is labelled "Nickel ores and concentrates" (20% Ni). At the processing stage, trade data include CN codes 75021000 "Nickel unwrought, not alloyed" (100% Ni), 75022000 "Unwrought nickel, alloyed" (50% Ni), 75040000 "Nickel powders and flakes" (100% Ni), 28254000 "Nickel oxides and hydroxides" (66.6% Ni), 28273500 "Nickel chloride" (24.7% Ni), 28332400 "Nickel sulphate" (5% Ni) and 72026000 "Ferro-nickel" (25% Ni). Production and trade data are yearly averages over the period 2012-2016 .

Global usage of refined nickel metal amounted to 1 835 kt in 2016 and is expected to rise in the next twenty years (year of reference 2018) (Nickel Institute, 2018). The LME trades a contract on ingots of nickel of at least 99.80% purity. Each contract represents 6 t of nickel and is quoted in US dollars.





[137] JRC elaboration on multiple sources. See next sections.

Figure 201: End uses and EU sourcing of Nickel (mine stage) (Nickel Institute, 2017 and EUROMETAUX, 2019).

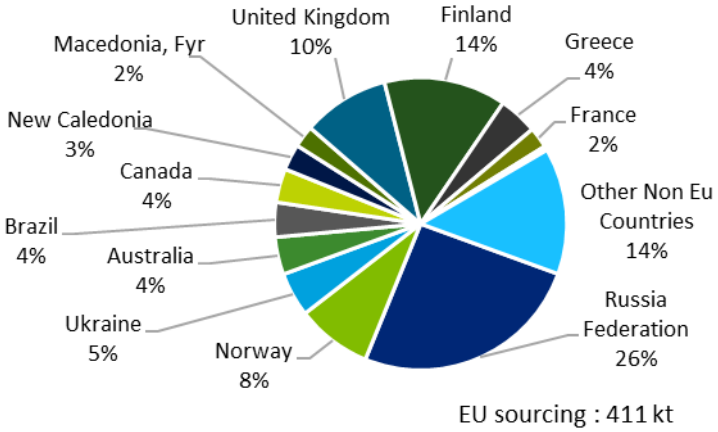


Figure 202: EU sourcing of Nickel (metal stage) (Nickel Institute, 2017 and EUROMETAUX, 2019).

According to DERA raw materials price monitor and the LME Bulletin, nickel price have decreased in the period 2011-2019; from January 2019 it increased from USD 10.710 per tonnes to USD 17.665 per tonnes.

Between 2012 and 2016, the EU consumption of nickel ore was almost 65 kt. 47 kt was produced domestically , mainly in Greece (45%; 21 kt) and Finland (40%; 19 kt). The EU consumption of refined nickel in the same period was 375 kt, most supplied by the Russian Federation (36%; 104 kt). Within the EU, refined nickel is supplied mainly by Greece (18 kt) and France (9 kt).

Main nickel use is for alloy production (stainless steel accounts for about 65% of nickel first-use). More than half of nickel consumption in the EU is used for manufacturing various machineries and equipment (35%) and basic metals (22%).

Given its use in. renewable energy technologies (e.g. solar panel) and batteries for e-mobility, Nickel can play a role in enabling low-carbon energy solutions in the EU economy, contributing to achieve the objectives of the European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy by 2050"[138]. Nickel is among the key raw materials for the decarbonization of the EU.

. World nickel resources amount around 89,000 kt (metal content) (USGS, 2019). Indonesia, Brazil, Australia have the world's largest nickel reserves, followed by the United States.

The world production of nickel concentrates was 2 270 kt per year on average between 2012 to 2016, with Indonesia accounting for 18% of the total production, followed by Philippines (17%), Australia (11%), the Russian Federation (11%) and Canada (10%) (WMD, 2019). Europe produced 47 kt or 2% of the global production. Almost 85% of the EU production took place in Greece (21 kt) and Finland (19 kt)(UN, 2017).

World refined nickel metal production amounted to 1,887 kt (WBMS, 2018) per year between 2012 to 2016. China and the Russian Federation were the world leading suppliers with 29%

[138] COM(2018) 773 final A Clean Planet for all. A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy

(540 kt per year) and 12% (233 kt per year) of the global production. The EU produced on average 85 kt/year of refined nickel, i.e. 4% of the global production, with Finland accounting for 66% (56 kt) of the production (UN, 2017) between 2012 to 2016.

China apply export tax of 15% on nickel concentrates. Indonesia has an export prohibition also for ores and concentrates. The Russian Federation applies export tax of 25% on refined nikel.

22.2Market analysis, trade and prices

22.2.1Global market analysis and outlook

Between 1994 and 2011, world production doubled from900 kt to almost 1,800 kt. The world production remained more or less stable in recent years (last reference year was 2017) (INSG, 2018). The global production of nickel ore between 2012 and 2016 was annually 2 271 kt on average. The largest world producer of nickel ore is Indonesia (more than 17% of the global production capacity), followed by Philippines, Australia, Russian Federation and Canada (together 49% of the global production capacity). China, Russian Federation and Japan are also the larger producers of refined nickel: their production capacities are 29%, 12% and 10%, respectively.

China was the major producer of Nickel in both 2016 and 2017 (600 kt), followed by Indonesia, Japan, Russian federation and Canada (more than 150 kt per country) (INSG, 2018).

The world primary nickel usage grew since 2010 and exceeded 2 100 kt in 2018 (INSG, 2018). Nickel is mainly used in stainless steel industry. In 2017 it was estimated to consume about 75% of the primary nickel and also nearly 900 kt of scrap nickel. In the last years (last year of reference was 2017), the demand of nickel also increased due to growing usage of batteries, especially for e-mobility. 55 kt were estimated to be used for batteries in the period 2007-2017. Estimates show an increase up to 440 kt in the next ten years (last year of reference was 2017) (Bohlsen , 2018; Stutt A., 2019).

Nickel demand is expected to increase mainly due to growing market for electric vehicles. Roskill forecasts that global the share of nickel used in batteries will grow from around 3–4% of the total nickel consumptionto 15–20% .

Table 108: Qualitative forecast of supply and demand of nickel

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Nickel		X	++	++	++	++	+	+

22.2.2EU trade

Between 2012 and 2016, the EU imported 56 kt of nickel ore on a yearly average.. More than half was imported from South Africa (29 kt). The two other main suppliers were Canada and Brazil, representing together 41% of the nickel ores imported in EU (15 kt and 8 kt, respectively).

Between 2010 and 2012, the imports of nickel metal to the EU significantly increased. This rise can be attributed especially to the rebound of the EU manufacturing sectors, base metal, metal

products and electrical equipment manufacturing. Between 2012 and 2016, the EU imports stabilized on the average of 287 kt per year. The largest importer of refined nickel to the EU was the Russian Federation (104 kt), followed by Norway (34 kt).

The EU yearly exported 38 kt of nickel ores and 36 kt of refined nickel. The EU import reliance was 28% for nickel ores and 77% for refined nickel, between 2012 to 2016.

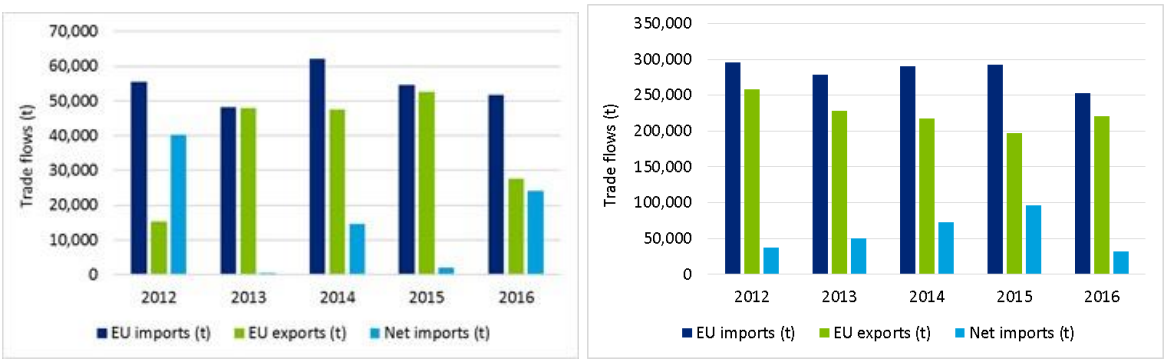


Figure 203: EU trade flows for nickel ores (left) and refined nickel (right) (UN, 2017)

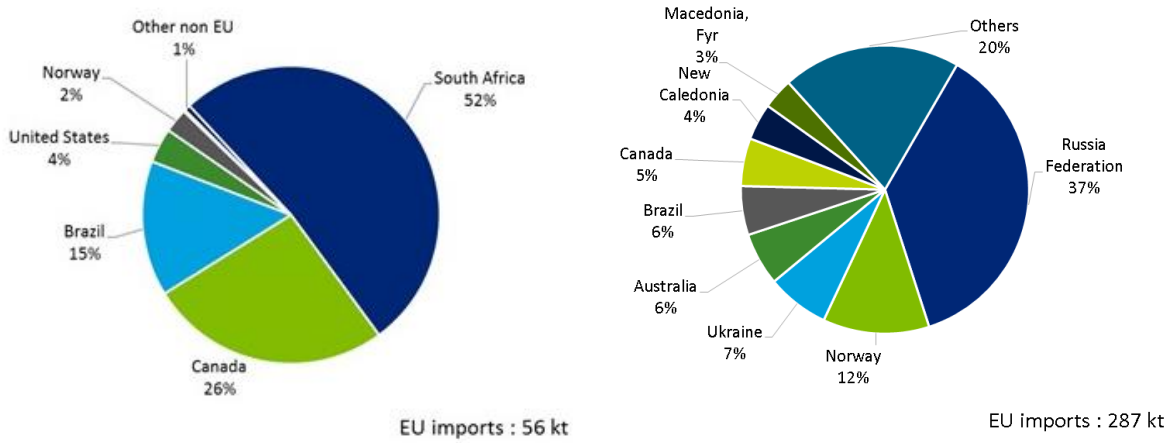


Figure 204: EU imports of nickel ores (left) and refined nickel (right) (UN, 2017)

Some countries have restrictions concerning trade with nickel. According to the OECD´s inventory on export restrictions, China uses export taxes on unwrought nickel and nickel alloys as well as on nickel waste and scrap. The status of the export tax instituted by Russia is unclear in recent years, but was present in the period before 2012. There is also a wide range of other countries (the Philippines, Argentina, Nigeria, Morocco, Indonesia and Brazil) imposing trade restrictions on nickel related products. These apply to ores or concentrates, or downstream products such as plates, wires etc. However, none of these restrictions applies on nickel unwrought metal. Early 2014, Indonesia has been enforcing an export ban on nickel ore. Although the ban was relaxed in early 2017, with some export quotas being granted conditionally to a limited number of companies, it is still largely being enforced. The "relaxed" ban is, moreover, complemented with a substantial level of export taxes applying to the allowed export quotas. The EU launched a complaint at WTO on 22 of November 2019.

22.2.3Prices and price volatility

Since 1960s, prices had been rising. Price peaks had been induced or increased several times by strikes in Canada. The average price of primary nickel (>99.8%) on the London Metal Exchange between 2011 and 2015 was USD 16,827.82 per tonnes (DERA, 2016). In 2016, the

price of nickel reached its lowest level since 2016, then it stabilized and started to increase (higher than USD 17,000 per tonnes).



Figure 205: Prices of nickel (USD per tonne) from 2007 to 2019 (LME, 2019)

22.3EU demand

After the global financial crisis, the world nickel consumption accelerated since 2010 to exceed 2,200 kt 2017 (INSG, 2018).

22.3.1EU demand and consumption

The annual average EU consumption of nickel metal between 2015 and 2018 was stable, around 300 kt (INSG, 2018; Glencore, 2018) (329 kt based on Statista, 2018).

22.3.2Uses and end-uses of nickel in the EU

Nickel is mainly used to produce different stainless and alloy steels that are later usedin building and construction materials, tubes, machinery and metal goods, transportation, electrical and electronic, engineering, and consumer and other products. stainless steel is the biggest user of primary and scrap nickel (alloys, special steel, plating, batteries and foundries are following) (INSG, 2018). A short explanation is provided hereinafter:

- Stainless steel: Nickel increases stainless steel's formability, weldability, ensures resistance against acids and enhances corrosion resistance. The addition of nickel (8-10%) results in the most important class of corrosion- and heat-resistant steels. Stainless steel accounts for about 65% of nickel first-use, either as metal construction material or other base metal.
- Other steel alloys: nickel is used in other steel alloys to improve the hardness, malleability and closeness of grain. Nickel based alloys also have very useful low expansion characteristics which make them well suited for applications where extreme temperatures are required.

- Non-ferrous alloys: nickel is used in non-ferrous alloys. The most common, cupronickel, is used extensively in coins to improve corrosion resistance. Its adjustable electrode potential enables seawater resistance, most important in the marine industry and for desalination plants. Other non-ferrous alloys are nickel-titanium memory alloys which can revert back to their original shape without undergoing plastic deformation under stress and super-alloys for power generation, aerospace and military applications.
- Plating: Thin layers of nickel are used in plating to increase corrosion and wear resistance, especially in medical equipment, construction materials and cosmetic applications such as cutlery and domestic fittings. Nickel plating is also used in the manufacture of computer hard discs and optical storage media.
- Foundry: Foundry products include nickel castings for pumps, valves and fittings.
- Beside its application in batteries, nickel is used in a wide range of chemical processes, including hydrogenation of vegetable oils, reforming hydrocarbons and production of fertilisers, pesticides and fungicides.

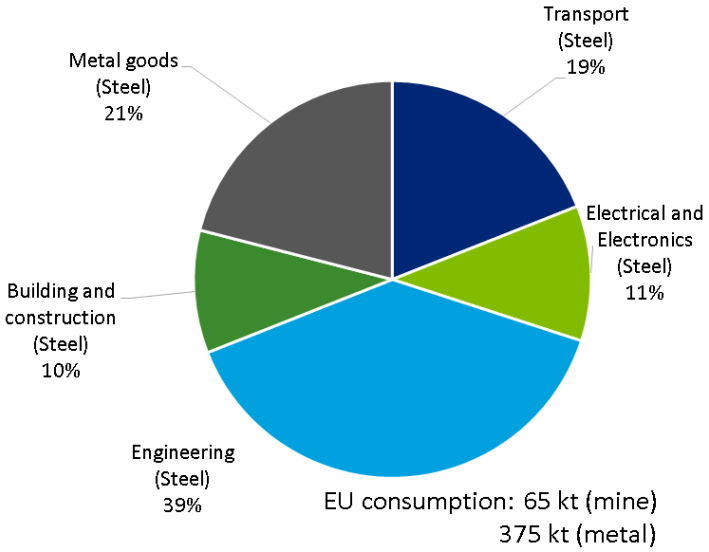


Figure 206: EU end uses of nickel. Average figures for 2012-2016 (Nickel Institute, 2017 and EUROMETAUX, 2017)

Relevant industry sectors are described using the NACE sector codes (Eurostat, 2016).

Table 109: Nickel applications, 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2016)

Applications	2-digit NACE sector	Value added of NACE 2 sector (M€)	4-digit NACE sectors
Transport (Steel)	C30 - Manufacture of other transport equipment	44,304	C30.1.1 - Building of ships and floating structures; C30.2.0 - Manufacture of railway locomotives and rolling stock; C30.3.0 - Manufacture of air and spacecraft and related machinery; C30.9 - Manufacture of transport equipment n.e.c.
Electrical and	C27 - Manufacture of	80,745	C27.2.0 - Manufacture of

Applications	2-digit NACE sector	Value added of NACE 2 sector (M€)	4-digit NACE sectors
Electronics (Steel)	electrical equipment		batteries and accumulators; C27.5.1 - Manufacture of electric domestic appliances; C26.1.1 - Manufacture of electronic components
Engineering (Steel)	C28 - Manufacture of machinery and equipment n.e.c.	182,589	C28.1 - Manufacture of general-purpose machinery; C28.2 - Manufacture of other general-purpose machinery; C28.9.3 - Manufacture of machinery for food, beverage and tobacco processing ; C28.9.5 - Manufacture of machinery for paper and paperboard production; C25.9.2 - Manufacture of light metal packaging
Building and construction (Steel)	C25 - Manufacture of fabricated metal products, except machinery and equipment	148,351	C25.1.1 - Manufacture of metal structures and parts of structures; C25.1.2 - Manufacture of doors and windows of metal; C25.2.1 - Manufacture of central heating radiators and boilers; C25.2.9 - Manufacture of other tanks, reservoirs and containers of metal
Metal goods (Steel)	C24 - Manufacture of basic metals	55,426	

Nickel-based alloys and nickel–containing stainless have a key role in renewable energy technologies, e.g. thermal solar plants. Also, it is used in hydropower and geothermal energy plants, wave energy technologies. Nickel is needed to prevent degradation especially in systems with high operating temperatures (Nickel Institute, 2018).

Also, nickel use in the battery sector is already increasing and it is expected to increase even more rapidly in the next 20 years (reference year 2018). This is mainly related to the fast development of Li-ion batteries for the automotive sector and the improvement in electrical energy storage systems (Nickel Institute, 2018).

22.3.3Substitution

Substitutes are possible for nickel used in metal products such as plates, tubes, beams etc., other steel alloy materials such as titanium, chromium, manganease and cobalt are mentioned as substitutes for nickel as alloying element (Karhu et al., 2016) . This also holds true for applications processing these materials such as machinery, leisure goods, medical equipment and specific building materials (doors, windows etc.). However, those alternatives usually are

at higher cost or occur with adverse impacts on performance. The true market tendency is actually reverse due to prices. E.g. in batteries the trend is to decrease the amounts of cobalt and substitute it by nickel. There are increasing concerns regarding cobalt prices and availability (especially that of cobalt), which in thern leads to the production and development of low cobalt batteries and, as a result, high-nickel content. Future chemistries are envisage with even higher nickel content than the existing ones e.g. the newly proposed NMC 9.5.5 battery (with 9 parts of nickel, and 0.5 of cobalt and manganese) (Azevedo et al., 2018) (Zubi et al., 2018).

The material-for-material substitution for nickel in battery applications, mostly the Nickel Metal Hydride (NiMH) batteries are typically not performed mainly due to performance and costs (Terceiro et al., 2013) Lithium (Lithium-ion) batteries can serve as an alternative, but are essentially different products with different technical requirements. Moreover, many Li-ion based battery technologies contain up to 15% nickel. Several Li-ion chemistries contain nickel such as NMC (Lithium Nickel Manganese Cobalt Oxide) which is growing in automotive and energy storage applications, or the NCA (Lithium Nickel Cobalt Aluminium Oxide). In batteries for electric vehicles, these types of batteries use respectively 33% and 80% of nickel, and in NMC chemistries, higher percentages are expected in the next future (Nickel Institute. 2019).

22.4Supply

22.4.1EU supply chain

Nickel ore is extracted and processed in the EU. The EU extracted 47 kt per year of nickel in concentrates over the period 2012-2016. Greece (21 kt) and Finland (19 kt) accounted for 85% of EU production. The EU was dependent on nickel ore foreign imports, with an import reliance of 28%.

Domestic production of refined nickel amounted to 124 kt per year between 2012 to 2016. With the biggest share belonging to Finland which accounted with 55 kt. The EU was dependant on foreign imports of refined nickel, with an import reliance of 77%.

Terrafame Oy (Finland) is constructing a new battery chemicals plant on site that will change the current target production of 30 kt of NiCo-sulfide (at 66% of Ni content) completely to Ni-sulphate (170 kt). Production will start on January 2021, and the end use of the nickel product will be changed completely: from previous steel industry, to battery manufacturing for electric vehicles.

Figure 207 shows the nickel material flows in the EU economy from the nickel MSA performed in 2019 (MSA, 2019 under publication).

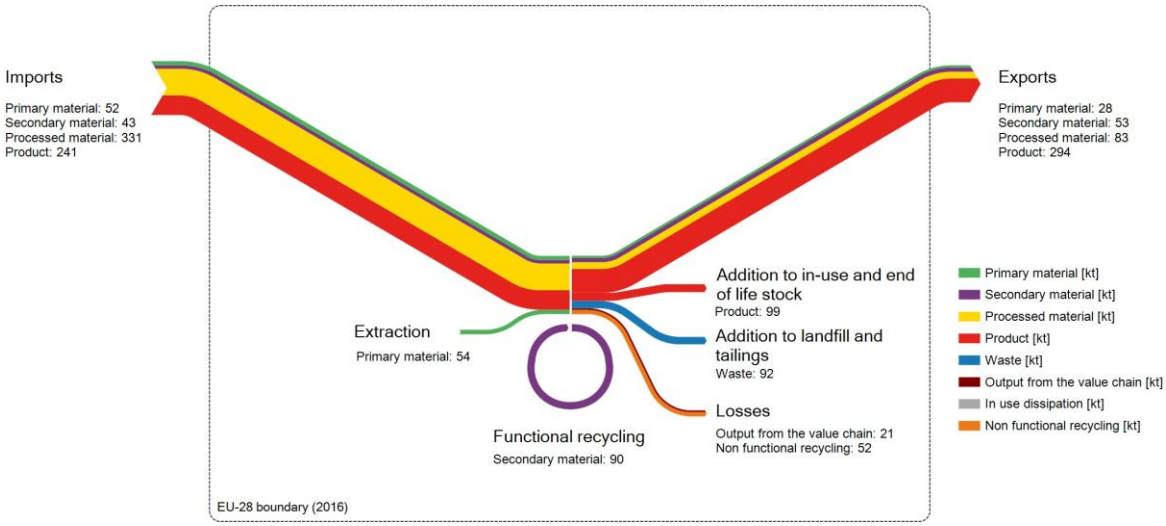


Figure 207 Sankey diagram showing the material flows of nickel in the EU economy in 2016 (Draft nickel MSA 2019).

22.4.2Supply from primary materials

22.4.2.1 Geology, resources and reserves of nickel

Geological occurrence: The presence of nickel in the earth's crust is middling, with 47 parts per million upper crustal abundance (Rudnick & Gao, 2003). Most nickel deposits of economic importance occur in geological environments of magmatic sulphides and in laterites. Nickel concentrations of sulphide ores, which are the primary source of mined nickel at present, range from 0.15% to around 8% nickel, but 93% of known deposits are in the range 0.2-2% nickel. The most important nickel sulphide mineral is pentlandite [$(Fe,Ni)_9S_8$], which occurs mainly in iron- and magnesium-rich igneous rocks in Russia, South Africa, Canada and Australia.

Lateritic ores, with an average nickel content of 1-1.6%, are formed by (sub)tropical surface weathering of ultramafic rocks. Their main nickel-bearing minerals are garnierite (general name for Ni-Mg hydrosilicates) and nickeliferous limonite [(Fe,Ni)O(OH)], occurring in New Caledonia (France), Indonesia, Columbia and Greece (Bide et al., 2008). There are 3 types of lateritic deposits: limonite type, silicate type and oxide type, corresponding to the different horizons (layers) of the deposits; the middle one (silicate) showing the highest Ni content (around 1.8-2.5%). Despite accounting for around 70% of global Ni deposits, lateritic ores constitute only 40% of the current world production (Jébrak and Marcoux, 2008).

According to the Minerals4EU website, some exploration for nickel was carried out in Greenland, the UK, Sweden, Sapin, Portugal, Poland, Ukraine and Kosovo (Minerals4EU, 2019). Currently, an extensive exploration of nickel is taking place in Finland (GTK, 2019).

Global resources and reserves*:* According to USGS, identified land-based resources averaging 1% nickel or greater contain at least 130 million tonnes of nickel, with about 60% in laterites and 40% in sulphide deposits (USGS, 2019). Extensive nickel resources also are found in manganese crusts and nodules on the ocean floor. The decline in discovery of new sulphide deposits in traditional mining districts has led to exploration in more challenging locations such as east-central Africa and the Subarctic. The USGS reports 89 million tonnes of world known

nickel reserves (USGS, 2019). The global reserves are largely reported in Indonesia, Brazil, Australia (Table 110).

Table 110: Estimated global reserves of nickel (USGS, 2019)

Country	Nickelreserves (million tonnes)
Finland	NA
New Caledonia	---
United States	110,000
Indonesia	21,000,000
Australia	19,000,000
Brazil	11,000,000
Russian Federation	7,600,000
Other Countries	6,500,000
Cuba	5,500,000
Philippines	4,800,000
South Africa	3,700,000
China	2,800,000
Canada	2,700,000
Guatemala	1,800,000
Madagascar	1,600,000
Colombia	440,000
World total (rounded)	*89,000,000*

EU resources and reserves*:* Resource data for some Countries in Europe are available in the Minerals4EU website (Minerals4EU, 2019) but cannot be summed as they are partial and they do not use the same reporting code.

Table 111: Reserve/resource data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2019)

Country	Reporting code	Quantity	Unit	Grade	Code Resource Type
Spain	NI43-101	1.132	kt	0.6%	Proven
Finland	NI43-101 JORC	0.1 1.5	Mt Mt	0.59% 0.32%	Proven Proved
Ukraine	Russian Classification	15.007	kt	-	RUS(A)
Macedonia	Ex-Yugoslavian	5,600	kt	0.96%	(RUS)B
Kosovo	Nat. rep. code	8,812.5	kt	1.22%	(RUS)A
Turkey	JORC	29.7	Mt	1.13%	Proved

22.4.2.2 World and EU mine production

The global production of nickel ores between 2012 and 2016 was annually 2,271 kt on average. Indonesia and Philippines are the leading producers of nickel ores, (respectively 18% and 17%, which means 400 kt and 377 kt). They are followed by Australia (11%; 258 kt), the Russian Federation (11%; 253 kt) and Canada (10%; 228 kt).

With an annual production of 47 kt (2012-2016), the EU accounted for 2% of the world production. Almost half of the EU production is to be attributed to Greece (45%; 21 kt), followed by Finland (40%; 19 kt), Spain (14%; 6 kt) and Poland (2%; 760 t).

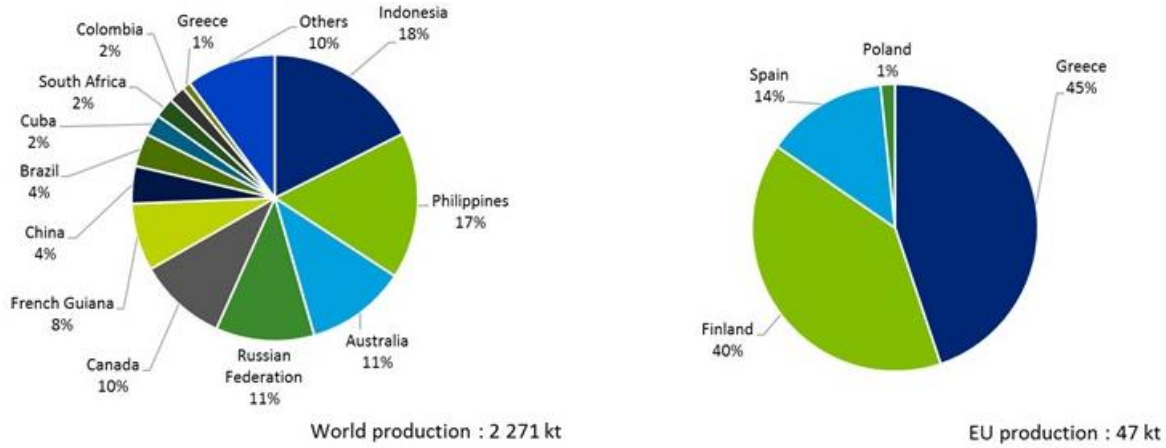


Figure 208: Global and EU mine production of Nickel ores in tonnes and percentage. Average for the years 2012-2016 (WMD, 2019)

22.4.3Supply from secondary materials/recycling

22.4.3.1 Post-consumer recycling (old scrap)

Nickel can be recycled without loss of quality and sourced as secondary raw material to be used in many of its applications; large tonnages of secondary or "scrap" nickel are currently used to supplement newly mined ores (INSG, 2018; Nickel Institute, 2018).

There are several enterprises in the EU for recycling of nickel. Major recycling activities of nickel, take place further downstream in the value chain, namely in the stainless steel mills, given that more than 80% of nickel first uses are related to the use as alloying element in stainless steel and other nickel containing alloys. The dominant use of nickel as alloying element in stainless steels as well as other non-ferrous alloys facilitates collection and recycling. The economic value of nickel metal provides a significant incentive for this. The recycling efficiencies are estimated to be around 68% (Nickel Institute, 2018). Production of stainless steel takes into account the use of recycled material, including stainless steels and other nickel alloys, mixed turnings, waste from primary nickel producers and re-melted ingot from processing nickel-containing slags, dusts, batteries etc. Although special alloys are recycled as mono-material wherever possible, in practice different alloys and products may get mixed and blending processes are used to maintain quality. For the US and EU a share of 43% and 45% in the total nickel consumption is reported for recovered nickel (Nickel Institute, 2016). In the 2017 criticality assessment, the UNEP methodology (UNEP, 2011) was applied resulting in a recycling input rate of 34%. In the current criticality assessment the EOL-RIR of 17% has been adopted[139].

22.4.4Processing of Nickel

Ore beneficiation comprises the metal concentration and refining of the nickel ores, to ultimately obtain nickel matte. The specific processes depend on whether the ore is a sulphide or a laterite.

[139] Based on ongoing MSA study of nickel (2019)

- Sulphide ores processing: After ore crushing, sulphide ores which typically contain several sulphur-bearing minerals such as chalcopyrite and pyrrhotite undergo magnetic separation in order to remove pyrrhotite-bearing particles. A two-step flotation is then performed on the non-magnetic concentrate. The first stage is designed to remove copper concentrate, and the second stage produces a Ni concentrate of approximately 10-20% Ni after dewatering and thickening processes. The magnetic concentrate is further grinded to liberate Ni-bearing particles and goes through another flotation process.
  Refining process is subsequently applied to the final Ni concentrate (containing up to 25% Ni), using a pyrometallurgical or hydrometallurgical route. Nickel hydrometallurgy is commonly performed using ammonia leach process. Other leaching processes use chlorine or acid leaching. The metal is then recovered in the solution by applying electrowinning. For the pyrometallurgical stages, the reaction of oxygen with iron and sulphur in the ore supplies a portion of the heat required for smelting (Brittanica, 2009). The choice of the refining route is dependent on several factors such as the maximum amount of impurities allowed in the matte, the energy efficiency ratio, etc.
- Lateritic ores processing: Lateritic (oxide) ores have fewer options for treatment, and are mostly dried and smelted in furnaces. Hydrometallurgy can also be applied to the limonitic lateritic ores using the Caron Process (selective reduction combined with ammonia leaching) or the Pressure Acid Leaching (heating of slurried ore)

Various processes are used to refine nickel matte, depending on the type of the ore the matte came from. These processes include hydrogen reduction (ammonia pressure leach), roasting to produce high-grade nickel oxides that are then pressure leached before electrowinning or refining through the carbonyl process. The carbonyl process can be used to produce high-purity nickel pellets. In this process, copper and precious metals remain as a pyrophoric residue that requires separate treatment. Electro-winning, in which nickel is removed from solution in cells equipped with inert anodes, is the more common refining process. Sulphuric acid solutions or, less commonly, chloride electrolytes are used (WBG, 1998).

Primary nickel is produced and used in the form of ferronickel, nickel oxides and other chemicals, and as nickel metal with a concentration of over 90% (Class I if Ni content higher than 99%. This is used in batteries). Ferronickel (15-45% of nickel content) predominantly originates from lateritic ores which is converted into an impure product. In the recent years, production of a low grade ferronickel grade called Nickel Pig Iron (NPI) has boomed almost exclusively in China (2-17% of nickel content). NPI is made of low-grade lateritic nickel ore, coking coal, and a mixture of gravel and sand as an aggregate (Eurofer, 2016).

Between 2012 and 2016, the world production of refined nickel was higher than 1,887 kt per year, mainly supplied by China (29%; 540 kt), the Russian federation (12%; 233 kt) and Japan (10%; 183 kt). The EU produced less than 4% of the world production. The leading supplier in the EU is Finland (55 kt), followed by Greece (18 kt) and France (9 kt) (WBMS, 2018).

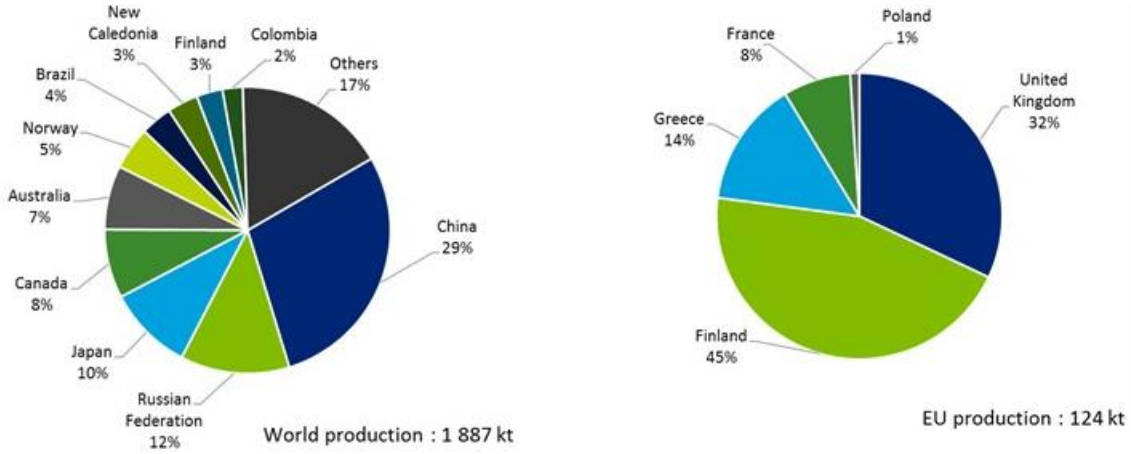


Figure 209: Global and EU refined nickel yearly production. Average for the years 2012-2016 (WBMS, 2018)

22.5Other considerations

22.5.1Environmental and health and safety issues

Nickel production is energy intensive. However, nickel finds its way into a wide range of applications where it significantly reduces the generation of greenhouse gases during use. an overview of the environmental impacts of nickel products is provided by Mistry et al. (2015), concluding that the most relevant contribution in terms of environmental impacts is attributed to the primary extraction and refining processes (about 60% - 70% of the GWP). Also, it is to be noticed that nickel is already recovered as secondary raw materials to be used in different applications.

Nickel cannot be used in post assemblies inserted into pierced ears and other parts of the human body unless the rate of nickel release from them is less than 0,2 micrograms/cm²/week. Nickel cannot be used in articles intended to come into direct and prolonged contact with the skin if the rate of nickel release from the parts of these articles coming into direct and prolonged contact with the skin is greater than 0,5 micrograms/cm²/week or if these articles have a non-nickel coating unless the coating is sufficient to ensure that the rate of nickel release from those parts of these articles coming into direct and prolonged contact with the skin will not exceed 0,5 micrograms/cm²/week for a period of at least 2 years of normal use of the articles. Articles which are the subject of any of the aforementioned cannot be placed on the market unless the conform to the stipulated requirements (REACH, 2006).

22.5.2Socio-economic issues

The extraction of nickel is associated to socio-economic issues in different countries e.g. Guatemala (IISD, 2018). In the Philippines, nickel is characterised by high risk of internal conflicts and high water risk. In Finland a major leak in the Talvivaara Mine occored in 2012 discharging nickel, uranium and other toxic metals into the nearby surroundings and lakes (EJOLT 2015). 12 conflicts related to nickel are reported in the Environmental Justice Atlas since 1993, and environmental degradation together with land competition and disputes over the use of ancestral lands and conflicts with indigenous communities are pointed as the main cause of conflicts. Also, South Africa is characterised by a high risk for the two environmental indicators, but also high risk of internal conflicts, even tough conflicts are mainly related to other materials (e.g. platinum, sand and asbestos).

22.6Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. Supply risk has been analysed at both mine and processing stages. The higher supply risk is for the mine stage. The results of this and earlier assessments are shown in Table 112.

Table 112: Economic importance and supply risk results for nickel in the assessments of 2011, 2014, 2017, 2020 (European Commission, 2011; European Commission, 2014; European Commission, 2017)

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Nickel	9.54	0.27	8.83	0.24	4.8	0.3	4.9	0.49

22.7Data sources

22.7.1Data sources used in the factsheet

Azevedo, M., Campagno N., Hagenbruch, T., Hoffman, K., Lala, A., Ramsbottom, O., (2018). Lithium and cobalt –a tale of two commodities, McKinsey&Company

Bohlsen M. (2018). Nickel Monthly News For The Month Of November 2018. https://seekingalpha.com/article/4225730-nickel-monthly-news-month-november-2018

Draft nickel MSA (2019). Results of the nickel MSA study. Internal document – not published. Reference date: 10 January 2020.

DERA (2016). Pricelist of raw materials. http://www.bgr.bund.de/DE/Themen/Min_rohstoffe/Produkte/Preisliste/cpl_16_11.pdf?__blob=publicationFile

EJOLT (2015). http://www.ejolt.org/2015/07/talvivaara-mine-environmental-disaster/

Eurofer (2016). Expert consultation M. Rigamonti

European Commission (2011). Critical raw materials for the EU. [online] Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission (2014) Report on critical raw materials for the EU – Non Critical raw materials profiles.

European Commission (2017). Study on the review of the list of Critical Raw Materials - Critical Raw Materials Factsheets & Non-critical Raw Materials Factsheets.

Eurostat (2016). International Trade Easy Comext Database https://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do

International Nickel Study Group - INSG (2018). The world nickel factbook 2018. https://insg.org/wp-content/uploads/2019/03/publist_The-World-Nickel-Factbook-2018.pdf

GTK (2019). Exploration projects in Finland. http://en.gtk.fi/export/sites/en/informationservices/maps/exploration_projects.pdf

International Institute dor Sustainable Development – IISD. Green Conflict Minerals. https://www.iisd.org/story/green-conflict-minerals/

Jébrak, M., Marcoux, E., Géologie des ressources minérales - Soc. Industrie Minérale, Paris, 2008

Karhu, M., Bachér, J., Yli-Rantala, E., Huttunen Saarivirta, E., Nieves Cordones, P., Martel Martin, S., del Corte Sanz, M. (2016). Report on the economic assessment of substitution trajectories. D5.3 SCRREEN report

London Metal Exchange – LME (2019). Nickel pricing. https://www.lme.com/Metals/Non-ferrous/Nickel#tabIndex=2

Minerals4EU (2019). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

Nickel Institute (2016). Nickel in the European Union. Available at: https://www.nickelinstitute.org/MediaCentre/Publications/NickelIntheEuropeanUnion.aspx

Nickel Institute (2018). Nickel and sustainability: Towards a circular economy. NICKEL, VOL. 33, NO. 2, 2018. https://www.nickelinstitute.org/media/2698/nickelvol33no2summer2018_fb_eng.pdf

Nickel Institute (2019). Nickel in batteries. https://www.nickelinstitute.org/about-nickel/nickel-in-batteries/

OECD. (2016) Export restrictions on Industrial Raw Materials database [online]. http://qdd.oecd.org/table.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

REACH (2006) Annex XVII entry 27 of Regulation (EC) 1907/2006 (REACH).

Rudnick, R.L. and Gao. S. (2003). Composition of the Continental Crust. In: Treatise on Geochemistry, Volume 3. Editor: Roberta L. Rudnick. Executive Editors: Heinrich D. Holland and Karl K. Turekian. pp. 659. ISBN 0-08-043751-6. Elsevier, p.1-64.

Statista (2018). Demand for nickel worldwide in 2018, by region (in 1,000 tons). https://www.statista.com/statistics/260809/global-consumption-of-nickel-by-region/

Stutt A. (2019). Megafactories buildout could up nickel demand in batteries 19 fold—Benchmark. http://www.mining.com/battery-megafactories-buildout-nickel-demand-19-fold-benchmark/

Tercero Espinoza, L., Hummen, T., Brunot, A., Hovestad, A., Pena Garay, I., Velte, D., Smuk, L., Todorovic, J., van der Eijk, C. and Joce, C. (2015). Critical Raw Materials Substitution Profiles. September 2013 Revised May 2015. CRM_InnoNet.

UNEP (2011). Recycling rate of metals. Available at: http://www.unep.org/resourcepanel/portals/24102/pdfs/metals_recycling_rates_110412-1.pdf

United Nations (2017). UN Commodity Trade Statistics Database. https://comtrade.un.org/

USGS (2019). Mineral Commodity Summaries. http://prd-wret.s3-us-west-2.amazonaws.com/assets/palladium/production/atoms/files/mcs2019_all.pdf

WBG (1998). World Bank Group Environment, Health and Safety Guidelines. https://www.ifc.org/wps/wcm/connect/469da18048855b7f891cdb6a6515bb18/nickel_PPAH.pdf?MOD=AJPERES

World Bureau of Metal Statistics – WBMS (2018). World metal statistics year book. http://www.world-bureau.com/services-more.asp?owner=2#

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

Zubi, G., Dufo-López, R., Carvalho, M., Pasaoglu, G. (2018). The lithium-ion battery: State of the art and future perspectives. Renewable and Sustainable Energy Reviews 89, 292–308

22.7.2Data sources used in the criticality assessment

Crundwell, F. et al. (2011). Extractive Metallurgy of Nickel, Cobalt and Platinum Group Metals. ISBN: 9780080974781. Elsevier

Deloitte Sustainability, British Geological Survey, Bureau de Recherches Geologiques et Minieres, Netherlands Organisation for Applied Scientific Research (2017). Study on the review of the list of Critical Raw Materials - Criticality Assessment. https://publications.europa.eu/en/publication-detail/-/publication/08fdab5f-9766-11e7-b92d-01aa75ed71a1/language-en

OECD. (2019). Export restrictions on Industrial Raw Materials. Retrieved July 5, 2019, https://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

Graedel T.E. (2019). Assessment according to Nickel Institute comments. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4443350/

Draft MSA on Nickel. Results of the Nickel MSA Study. Internal document – not published. Reference date: 10 January 2020.

Nickel institute (2017). MSA work on Nickel based on Nickel Institute data

United Nations (UN) (2017). UN Commodity Trade Statistics Database. https://comtrade.un.org/db/

World Bureau of Metal Statistics (WBMS) (2018). World metal statistics year book

USGS (2019). USGS Mineral Commodity Summaries 2019 – Nickel. https://pubs.er.usgs.gov/publication/70202434

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

22.8Acknowledgments

This factsheet was prepared by the JRC. The authors would like to thank XXX, the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this Factsheet.

23. PERLITE

23.1 Overview

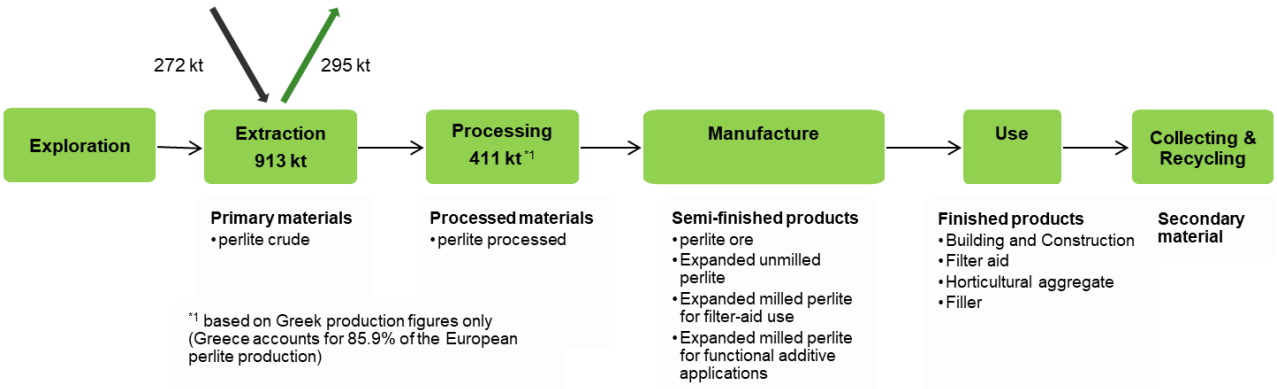


Figure 210: Simplified value chain for perlite for the EU[140], average 2012-2016

Perlite is a generic term for naturally occurring siliceous rock. It is a volcanic glass with sufficient water content to cause it to expand, or froth up, when heated, forming a lightweight granular aggregate. Perlite is commonly used in its expanded form. Perlite's low density and porous texture (expanded form), low thermal conductivity, high sound absorption and chemical stability makes it a suitable material for a diverse range of applications including construction, horticulture, insulation, filtration and industrial uses.

The CN code used for perlite is (Eurostat Comext, 2019): 253010 "vermiculite, perlite and chlorites, unexpanded", 25301010 "perlite, unexpanded".

The EU is an important supplier of perlite, with approximately 30% of the global production. EU is a net exporter of perlite hence the sector is a positive contributor to the European economy. China, Greece and Turkey appear to be the World largest exporters of perlite. Exports from Greece are mainly to the United States (USGS, 2019). Turkey exports perlite to the EU and the Russian Federation (Eurostat, 2019).

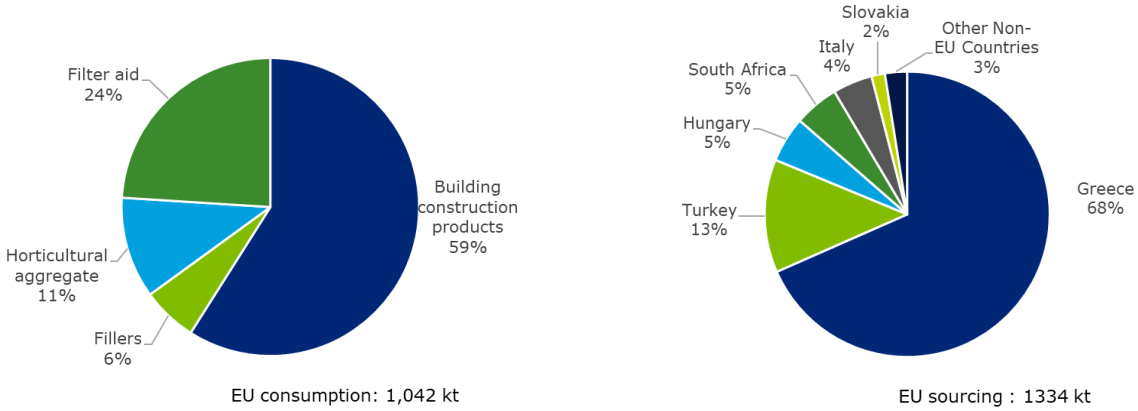


Figure 211: End uses (Perlite Institute, 2019) and EU sourcing (BGS, 2019; Eurostat, 2019) of Perlite (2012-2016).

[140] JRC elaboration on multiple sources (see next sections)

The global future of perlite is closely connected to the future of the construction industry. Building and infrastructure construction related projects are expected to increase in the future and as such the consumption of perlite is likely to increase as well.

The f.o.b mine price for the period 2014-2017 ranges between EUR 50 and 66 per tonne (USGS, 2019). The average annual value of processed crude perlite sold to expanders in 2015 was EUR 54 per tonne. Perlite consumed by expanding plants operated by mining companies was valued at EUR 58 per tonne. The average annual value of expanded perlite in 2015 was EUR 295per tonne. Expanded perlite unit values ranged from 617 € per metric ton for low-temperature insulation to EUR 180 per tonne for formed products. This broad range is a function of the end use and quality of the perlite needed for varying products (USGS, 2019).

The European annual consumption in the period 2012-2016 (5-year average figure) is estimated at 1,050 kt, of which 1,070 kt were domestic production, 273 kilotonnes were imports to the EU from non-EU countries and 295 kt were exports from the EU to non-EU countries.

The major end uses of perlite include: building construction products (59%), filter aid (24%) and horticultural aggregates (11%). Substitutes for perlite used in building construction products include expanded clay, vermiculite and pumice. Perlite may be substituted by pumice, vermiculite, slag, diatomite, expanded clay and shale and numerous other industrial minerals in filler applications. In horticultural applications, perlite may be substituted primarily by pumice and vermiculite, but also by expanded clay and numerous other products, such as rockwool, stonewool, coco-coir, sawdust, sphagnum peat moss, rice hulls and many more. In filter aid applications, the primary substitute of perlite is diatomite.

Perlite contribution to a clean planet can be e.g. linked to products used as insulators that contribute to energy savings in buildings.

Reserve and resource data are changing continuously as exploration and mining proceed and are influenced by market conditions. Perlite reserves are estimated at 50,000 kt for the US, 120,000 kt for Greece, 49,000 kt for Hungary and 57,000 kt for Turkey (USGS, 2019).

World mine production of perlite is about 4,090 kt per year in average between 2012 and 2016 (BGS, 2019). Greece, Turkey, China, Iran and US are the major producing countries. Greece and Turkey together account for 44 % of the global production, with each country accounting for 900 kt per year on average for the period 2012 to 2016. Other European countries excepting Greece which produce perlite include, Hungary with a production share of 1.7%, Italy with a share of 1.5%, Slovakia with a share of 0.5% and Bulgaria with a share of less than 0.1%.

Information on export restrictions is accessed by the OECD Export restrictions on Industrial Raw Materials database (OECD, 2019). There are no export restrictions, quotas or prohibitions identified that may impact on the availability of perlite.

23.2Market analysis, trade and prices

23.2.1Global market analysis and outlook

At global level, the United States is the world's largest importer of perlite accounting for almost 13% of the world imports per annum for the period 2012 to 2016. The net import reliance of the US as a percentage of its apparent consumption varies between 19 and 28% for the period

2014-2017 (USGS, 2019). China, Greece and Turkey appear to be the World largest exporters. Perlite is exported from China primarily to the Republic of Korea and Japan. Exports from Greece are mainly to the United States, in fact the United States imports perlite almost exclusively from Greece (USGS, 2019). Turkey exports perlite to Europe and the Russian Federation.

There is no specific information about the future demand and supply for the EU.

The global future of perlite is closely connected to the future of the construction industry. Building and infrastructure construction related projects are expected to increase in the future and as such the consumption of perlite is likely to increase. Expanded perlite plants in the United States rely on imports of perlite from Europe and this trend is expected to continue. Throughout 2017 and 2018, a new perlite deposit in Nevada was being actively explored and developed as a potential supplier of crude perlite ore for industrial and household applications. The estimated amount of processed crude perlite sold or used from U.S. mines increased to the highest level since 2005 (USGS, 2019).

Table 113: Qualitative forecast of supply and demand of perlite

Material	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Perlite		x	+	+	?	+	+	?

23.2.2EU trade

Europe is a net exporter of perlite with an average net export figure in the period 2012-2016 of 23.4 kt. In the same five-year period, it is recorded an average import figure per annum of 271.6 kt from extra-EU27 countries. Considering that Europe produced between 2012 and 2016 approximately 1,060 kt of crude perlite ore per annum suggests that imports of perlite to Europe represent a small flow.

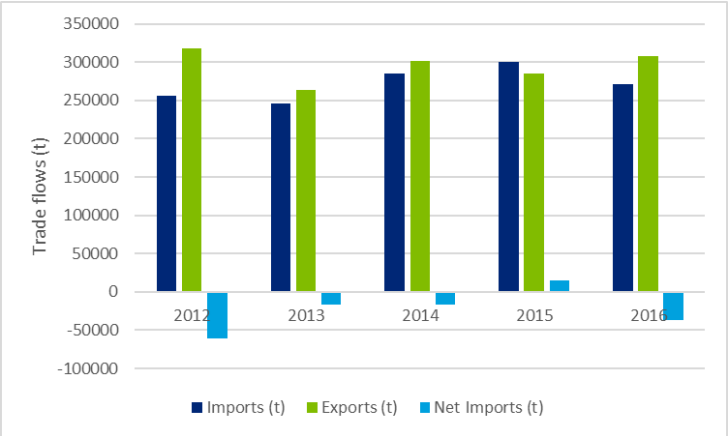


Figure 212: EU trade flows for perlite (Eurostat, 2019a)

Europe imports perlite primarily from South Africa (25%) and small quantities from China, Mozambique and the United States. Several other countries provide perlite to EU, but in smaller quantities. EU exports perlite primarily to the United States, Israel and Canada.

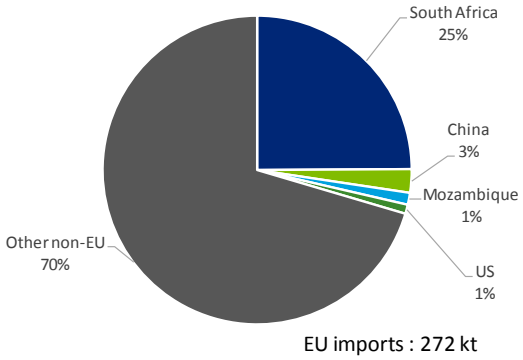


Figure 213: EU imports of perlite, average 2012-2016 (Eurostat, 2019a)

23.2.3Prices and price volatility

The f.o.b mine price for the period 2014-2017 ranges between EUR 50 and EUR 66 per tonne (USGS, 2019). The average annual value of processed crude perlite sold to expanders in 2015 was EUR 54 per tonne. Perlite consumed by expanding plants operated by mining companies was valued at EUR 58 per tonne. The average annual value of expanded perlite in 2015 was EUR 295 per tonne. Expanded perlite unit values ranged from EUR 617 per tonne for low-temperature insulation to EUR 180 per tonne for formed products. This broad range is a function of the end use and quality of the perlite needed for varying products (USGS, 2019, Minerals Yearbook, Perlite).

23.3EU demand

23.3.1EU demand and consumption

The European apparent consumption in the period 2012-2016 (5-year average figure) is estimated at 1,050 kt per year, of which 1,070 kt per year was the domestic production. 273 kt per year was the imports to the EU from extra EU countries and 295 kt per year is the exports from the EU to extra EU countries in the same period (5-year average figures). The above figures suggest that the majority of the domestic production is consumed within the European area and can sufficiently satisfy the EU industry demand for perlite, without import reliance issues. At global level, the United States is the leading consumer of crude and expanded perlite. Europe is a substantial contributor to the United States perlite flows as most EU perlite exports are to the United States (USGS, 2019).

23.3.2Uses and end-uses of Perlite in the EU

Perlite is used in building construction products, as filler in several applications, as horticultural aggregate and in filter aid applications. The EU market shares of the above mentioned applications are presented in Figure 214.

Relevant industry sectors are described using the NACE sector codes provided in Table 114.

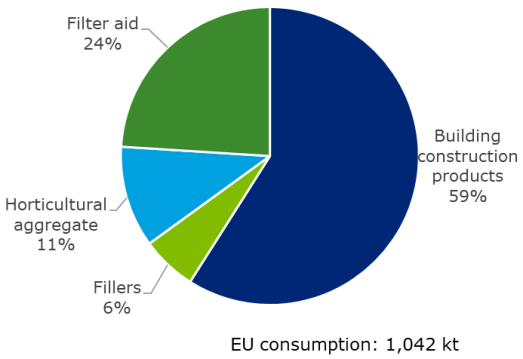


Figure 214: EU end uses of perlite(Perlite Institute, 2019). Average 2012-2016

Table 114: Perlite applications (Perlite Institute, 2019), 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2019).

Applications	2-digit NACE sector	Value added of NACE 2 sector (millions €)	4-digit NACE sectors
Building construction products	C23 - Manufacture of other non-metallic mineral products	57,255.0	C2361 Manufacture of concrete products for construction purposes; C2364 Manufacture of mortars; 23.65 Manufacture of fibre cement 23.70 Cutting, shaping and finishing of stone C2332 Manufacture of bricks, tiles and construction products, in baked clay.
Fillers	C23 - Manufacture of other non-metallic mineral products	57,255.0	C2920 - Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semi-trailers
Horticultural aggregate	C23 - Manufacture of other non-metallic mineral products	57,255.0	C2811 - Manufacture of engines and turbines, except aircraft, vehicle and cycle engines
Filter aid	C11 - Manufacture of beverages	32,505.0	C2571 - Manufacture of cutlery

Perlite in building construction products is used in lightweight aggregate construction, insulation, plasters, mortars, ceiling tiles and so on. Essential properties such as lightweight, fireproofing, acoustic insulation, temperature insulation are provided by perlite in a range of different products (Perlite Institute, 2019).

Perlite is used in horticulture as soil amendment due to its high permeability and low water retention properties. Plant rooting, seed starting medium and growing medium, soil conditioner, hydroponic and green roofs are some of the applications in which perlite is used (Perlite Institute, 2019; Patel and Torrisi, 2014).

Perlite finds use as a filler in explosives, caulking media, paints, plastics and packing for shipping products (Perlite Institute, 2019).

Perlite is used in liquid filtration in a range of products including beer, wine, edible oils, citric acid, sugars, oils, pharmaceuticals, water filtrations and many more. In air filtration perlite is used as a pre-coat for baghouses. Perlite has lower density than diatomite therefore less filter media (by weight) is required. Perlite, like diatomite, is a functional filtration component of depth filter sheets and pads (Sulpizio, 1999).

23.3.3Substitution

Substitutes for perlite have been identified in building construction products, fillers, horticultural aggregate and filter media. Substitutes are assigned a 'sub-share within' a specified application and considerations of the cost and performance of the substitute, as well as the level of production, whether the substitute has a 'critical' status and produced as a co-product/by-product.

Substitutes for perlite used in building construction products include expanded clay, vermiculite, diatomite and pumice. Several other materials could be used as lightweight aggregate depending on the end product and material availability, including, diatomite, expanded shale, pulverized fly ash, slag, glass and so on. Expanded clay may substitute perlite in masonry and mortal products primarily, but its use reduces the performance of the end product. Cost wise, expanded clay is a cheaper material than perlite. Vermiculite may substitute perlite in flame retardant products as it provides similar performance but is more expensive than perlite and. Pumice may also substitute perlite in some cases at a lower cost than perlite, but reduces the performance of the end product.

Perlite may be substituted by pumice, vermiculite, slag, diatomite, expanded clay and shale and numerous other industrial minerals in filler applications. The degree of substitution by any of these materials is governed by the end product specification, material availability and material cost.

In horticultural applications, perlite may be substituted primarily by pumice and vermiculite, but also by zeolite, expanded clay and numerous other products, such as rockwool, stonewool, coco-coir, sawdust, sphagnum peat moss, rice hulls and many more. The use of zeolite may enhance productivity in agricultural applications.

Filter aid is used in solid-liquid separation. In filter aid applications, the primary substitute of perlite is diatomite, which comprises a popular filter media. Cellulose and rice husk ash are also often used, including explanded clay and pumice. Perlite is more suitable for the separation of coarse microparticulates from liquids having high solids loading. Perlite is lower in density than diatomite, hence less filter media (by weight) is required for the process. Perlite is a functional component of depth filter sheets and pads. Rice husk ash is used for coarse and fine filtration applications. Cellulose is used for coarse filtration applications and where silica cannot be tolerated. Finally, zeolite may be a potential substitute in filters (SCRREEN Workshop, 2019).

There are no quantified 'market sub-shares' for the identified substitutes of perlite and the ones uses are based on hypotheses made through expert consultation and literature findings (USGS, 2019). It is underlined that a major factor that defines sunstitution is cost and local availability of the potential substitute.

23.4Supply

23.4.1EU supply chain

The 5 years average European production of perlite between 2012 and 2016 was 1,060 kt per year, which accounts for almost 26% of the global production. Producing countries include Greece, Hungary, Italy, Slovakia and Bulgaria (BGS, 2014 and 2019).

Europe is a net exporter of perlite and the primary destinations of the European perlite is the United States, Israel and Canada. The majority of perlite is consumed within Europe. The quantity of perlite exported from Europe is only marginally higher than the quantity of perlite imported to Europe. The EU sourcing (domestic production + imports) of perlite is 1,334 kt. There are no export restrictions, quotas or prohibitions identified that may impact on the availability of perlite.

23.4.2Supply from primary materials

23.4.2.1 Geology, resources and reserves of perlite

Geological occurrence: Perlite is hydrated volcanic glass formed by the chemical weathering of obsidian at or near the earth's surface. Commercial deposits are mainly related with Tertiary and Quaternary volcanism. Perlite occurs as lava flows, dykes, sills and circular or elongated domes, with the domes representing the largest and commonest deposits. However, the best resources is the glassy top of a permeable high-silica lava flow. Large domes tend to yield less perlite due to complex multi-event cooling histories, which form interleaved mixtures of glass and rhyolite (Kogel et al, 2016; Evans, 1993).

Overall, the formation of perlite deposits is complex requiring several essential consecutive events to take place and it is determined by the eruptive history of the parent volcano. Perlite is often classified by industry according to its texture as pumiceous (least dense), granular and onion skin (most dense). Pumiceous perlite is characterized by a frothy open vesicles texture. Granular perlite has a sugary and blocky fracture and onionskin perlite has a well-defined curved perlitic fracture and a pearly to resinous luster. Most commercial perlite is granular, or pumiceous (Kogel et al, 2016).

Global resources and reserves[141]*:* Selective reserve figures of perlite for 2018 are shown in Table 115. A global reserve figure cannot be estimated as data from several important producing countries are missing.

[141] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of perlite in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template (www.crirsco.com), which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

Table 115: Global reserves of perlite in 2018 (USGS, 2019)

Country	Perlite Reserves (kt)
United States	50,000
Greece	120,000
Hungary	49,000
Turkey	57,000

Reserve data for Ukraine are also available at Minerals4EU (2019) but cannot be summed as they are partial and they do not use the same reporting code.

Table 116: Reserve data for Ukraine compiled in the European Minerals Yearbook at Minerals4EU (2019)

Country	Reporting code	Quantity	Unit	Grade	Code reserve type
Ukraine	Russian Classification	2980.8	Thousand m^3	-	A

EU resources and reserves[142]*:* Resource data for some EU countries and Turkey are available at Minerals4EU (2019) but cannot be summed as they are partial and they do not use the same reporting code.

Table 117: Resource data for the EU compiled in the European Minerals Yearbook at Minerals4EU (2019)

Country	Reporting code	Quantity	Unit	Grade	Code resource type
UK	None	1	Mt	-	Estimate
Turkey	None	4.5	Bt	-	Total
Slovakia	None	4.43	Mt	economic	Verified Z1
Greece	USGS	160	Mt	-	Indicated
Hungary	Russian Classification	11.6	Million m^3	2.08 t/m^3	A+B

23.4.2.2 World and EU mine production

Crude perlite is extracted by open pit mining methods and transported to the processing plant for further beneficiation. Perlite mines use ripping or/and blasting to extract perlite. Ripping is effective when perlite is soft and friable. Depending on the deposit being extracted, selective mining may be undertaken to avoid the inclusion of rhyolite or obsidian (Kogel et al, 2016).

[142] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for perlite. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for perlite, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU (2019) by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for perlite at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system. Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However, a very solid estimation can be done by experts.

The first steps of processing include comminution (primary and secondary crushing) to reduce its size and drying in a rotary dryer. Following that tertiary crushing is undertaken using a variety of grinding mills and classifiers. Blending may also take place to meet market specifications (United States Environmental Protection Agency, 1995; Kogel et al, 2016).

Crude perlite in various size grades is produced at the end of this process. Crude perlite may find use as is, but often it provides the feed to expansion plants to produce expanded perlite.

At the expansion plant, crude perlite is either preheated or fed directly to the furnace. Perlite in this stage can expand as much as 40 times its original volume. Expansion takes place in temperatures between 600 and 900°C in a stationary vertical expander or a rotary horizontal expander. Expanded perlite (foam form) comprises a frothy, low-density product. Expanded perlite in microspheres is another form produced from fine ground perlite (United States Environmental Protection Agency, 1995; Kogel et al, 2016).

World mine production of perlite is about 4,090 kt per year in average between 2012 and 2016. Greece, Turkey, China, Iran and US are the major producing countries, but production of perlite takes place in several other countries at much smaller scale. Greece and Turkey together account for 44 % of the global production, with each country accounting for 900 kt per annum on average for the period 2012 to 2016. In Greece major perlite production comes from the island of Milos and in Turkey perlite is produced from the Western part of the country. Imerys S.A. is the most important supplier of perlite and the company owns important deposits both in Greece and Turkey (BGS, 2019).

Other European countries except from Greece producing perlite include, Hungary with a production share of 1.7%, Italy with a share of 1.5%, Slovakia with a share of 0.5% and Bulgaria with a share of less than 0.1%.

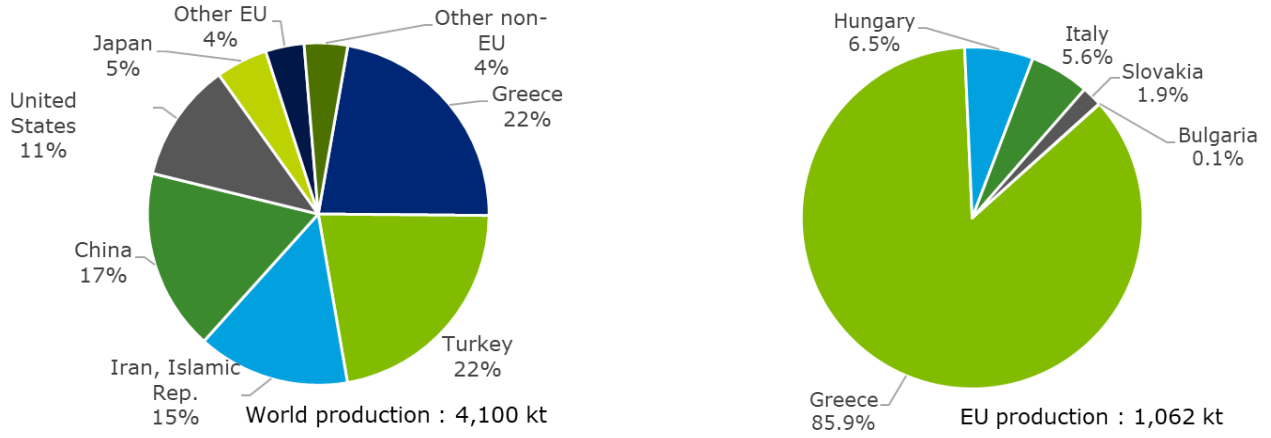


Figure 215: Global and EU mine production of perlite, average 2012–2016 (BGS, 2019)

23.4.3Supply from secondary materials/recycling

Perlite is not commonly recovered from waste and therefore there is no availability of perlite from secondary sources. However, construction and demolition waste, which represents the most important application for perlite, is widely recycled across the EU. The recycling of mineral-based waste in EU, based on Eurostat data, is estimated at 42%. This rate applies to all different categories of mineral-based waste, including perlite for products that finds use but not solely on perlite. There is limited literature on perlite recycling therefore the estimation of a recycling rate is not possible.

23.5Other considerations

23.5.1Environmental and health and safety issues

No major environmental concerns are anticipated during perlite mining and processing, provided that proper mining techniques are followed, the legislation is respected and appropriate post mining actions (e.g rehabilitation of mining sites) are implemented.

Based on several available toxicology and epidemiology data, the risk pertinent to occupational exposure to perlite is comparable to exposure to other inert insoluble ("nuisance") dusts (Maxim et al., 2014; Perlite Institute 2019; Polatli et al., 2001; Sampatakakis et al., 2013). Animal studies have indicated that the lethal dose LD_{50} (for oral ingestion) is more than 10 g/kg and, from a chronic inhalation study in guinea pigs and rats, that the no-observed-adverse-effect level (NOAEL) for the inhalation pathway is 226 mg/m^3.

However, it is mentioned that companies should always use all apropriate means (personal protective equipment, workplace practices, engineering controls, continuous medical surveillance etc) to ensure that workplace exposure complies with applicable occupational exposure limits (OELs). Special emphasis should be paid on monitoring and controlling exposure to respirable crystalline silica associated with all mined minerals, since this make cause autoimmune disorders, chronic renal disease, and other adverse health effects (NIOSH, 2002).

23.5.2Socio-economic issues

Socio-economic issues are very important for the areas where perlite is mined or processed since such activities contribute to social welfare and economic growth. On the othe hand in order to meet the criteria of sutainable growth and environmental protection, sustainable development indicators (SDIs) need be considered at all stages, including exploration, mining, processing and post-mining so that social, economic and environmental improvement is achieved (Tzeferis et al., 2013; Blengini et al., 2013; Komnitsas et al., 2013).

23.6Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list.

Table 118: Economic importance and supply risk results for perlite in the assessments of 2011, 2014 and 2017 (European Commission, 2011, 2014 and 2017)

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Perlite	4.20	0.31	4.55	0.28	2.1	0.4	2.31	0.42

23.7Data sources

Market shares are based on the statistical data provided by IMA-Europe and the Perlite Institute (IMA-Europe, 2019; Perlite Institute, 2019). Production data for perlite are from World Mineral Statistics dataset published by the British Geological Survey (BGS, 2019). Trade data was extracted from the Eurostat Easy Comext database (Eurostat, 2019). Data on trade agreements are taken from the DG Trade webpages, which include information on trade agreements between the EU and other countries (European Commission, 2019). Information

on export restrictions are accessed by the OECD Export restrictions on Industrial Raw Materials database (OECD, 2019).

For trade data the Combined Nomenclature (CN) code 253010 - VERMICULITE, PERLITE AND CHLORITES, UNEXPANDED 'has been used. There is a CN code for perlite only (25301010 - PERLITE, UNEXPANDED), but no trade data is available for this code. Due to trade data being available for a group of mineral products, rather than just perlite and in order to present trade flows for perlite only the following hypotheses and calculations were undertaken:

- It was assumed that trade flows are a reflection of each country's production.
- Chlorite production data is not available and chlorite trade is assumed to be small, therefore for the purposes of this calculation it is considered negligible.
- For countries that are producers of both perlite and vermiculite, the ratio of perlite production versus vermiculite production in a single country was calculated and used to 'normalise' the trade data to reflect perlite imports only; This ratio was applied to all trade data and not just to producing countries of perlite, as other countries may also trade this commodity.

All data were averaged over the five-year period 2012 to 2016. Several assumptions are made in the assessment of substitutes, especially regarding the allocation of sub-shares. Hence the data used to calculate the substitution indexes are often of poor quality.

23.7.1 Data sources used in the factsheet

BGS (2014). World Mineral Production 2008-2012, [online] Keyworth, Nottingham British Geological Survey, Available at: https://www.bgs.ac.uk/mineralsuk/statistics/worldStatistics.html

BGS (2019). World Mineral Production 2014-2017, [online] Keyworth, Nottingham British Geological Survey, Available at: https://www.bgs.ac.uk/mineralsuk/statistics/worldStatistics.html

Blengini, G.A., Moltrer, A., Valbusa, M., Komnitsas, K., Agioutantis, Z., Garbarino, E., (2013). Data and methodologies for a resource-efficient planning of primary and secondary aggregates in South East Europe (SEE) countries, Proceedings 6th International Conference "Sustainable Deveoplemt in the Minerals Industry (SDIMI)", 30 June - 3 July 2013, Milos, Greece, http://sdimi2013.conferences.gr/sdimi2013-home.html

European Commission (2011). Critical raw materials for the EU. [online] Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission (2014) Report on critical raw materials for the EU – Non Critical raw materials profiles.

European Commission (2016). DG Trade. Agreements [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/

European Commission (2019). DG Trade. Agreements [online] Available at: https://ec.europa.eu/trade/policy/countries-and-regions/

Eurostat (2019a). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2019b). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2 (last update 19/08/19)

Evans, A. M. (1993). Ore Geology and Industrial Minerals. An Introduction. Third Edition Oxford and Northampton Blackwell Science

Eurostat (2019a). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2019b). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: https://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

Industrial Minerals Association (IMA-Europe) (2019). Data and information on perlite provided by IMA-Europe during stakeholder workshops and expert consultation.

Industrial Minerals (2016). Industrial Minerals Pricing Database. [online] Available at: http://www.indmin.com/

Kogel, J. E., Trivedi, N.C., Barker, J.M., Krukowski, S.T. (2006). Industrial Minerals & Rocks. Commodities, Markets, and Uses. 7th Edition. SME.

Komnitsas, K., Agioutantis, Z., Shields, D., Blengini, G.A., Tzeferis, P.G. (2013). Stakeholder identification in the planning phase of aggregate and quarrying projects, Proceedings 6th International Conference "Sustainable Deveoplemt in the Minerals Industry (SDIMI)", 30 June - 3 July 2013, Milos, Greece, pp. 294-301, http://sdimi2013.conferences.gr/sdimi2013-home.html

Maxim, LD., Niebo, R., McConnell, E.E. (2014). Perlite toxicology and epidemiology, a review, Inhal. Toxicol. 26(5), 259-270.

Minerals4EU (2019). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

National Institute for Occupational Safety and Health (NIOSH). (2002). Health effects of occupational exposure to respirable crystalline silica. Department of Health and Human Services, Centers for Disease Control Prevention, National Institute for Occupational Safety and Health, Atlanta, Georgia, 145 p, https://www.cdc.gov/niosh/docs/2002-129/pdfs/2002-129.pdf?id=10.26616/NIOSHPUB2002129.

OECD (2019). OECD Export restrictions on Industrial Raw Materials database. [online] Available https://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

Patel, K. and A. Torrisi (2014). A growing market: vermiculite and perlite in horticulture. Industrial Minerals

Perlite Institute (2019). Applications of perlite [online] Available at: https://www.perlite.org/

Perlite Institute (2011). Health effects of perlite, https://www.perlite.org/wp-content/uploads/2018/03/health-effects-perlite.pdf, accessed June 29, 2019

Polatli, M., Erdinç, M., Erdinç, E., Okyay, E. (2001). Perlite exposure and 4-year change in lung function. Environ Res. 86, 238–43.

Sampatakakis, S., Linos, A., Papadimitriou, E., Petralias, A., Dalma, A., Papasaranti, E.S., Christoforidou, E., Stoltidis, M. (2013). Respiratory disease related mortality and morbidity on an island of Greece exposed to perlite and bentonite mining dust. Int. J. Environ. Res. Public Health 10, 4982–95.

Sulpizio, T. E. (1999). Advances in filter aid and precoat filtration technology. American Filtration & Separation Society Annual Technical Conference.

Tzeferis, P., Kavalopoulos, Komnitsas, K., (2013). Production data and Sustainable Development Indicators (SDIs) for the Greek Mining/Metallurgical Industry in the period 2007-2011, Proceedings 6th International Conference "Sustainable Deveoplemt in the Minerals Industry (SDIMI)", 30 June - 3 July 2013, Milos, Greece, pp. 269-276, http://sdimi2013.conferences.gr/sdimi2013-home.html

United States Environmental Protection Agency (1995). AP 42, Fifth Edition, Volume I Chapter 11: Mineral Products Industry - Perlite. [online] Available at: https://www3.epa.gov/ttn/chief/ap42/ch11/index.html

USGS (2019). U.S. Geological Survey, Mineral Commodity Summaries, February 2019

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

23.7.2 Data sources used in the criticality assessment

Sulpizio, T. E. (1999). Advances in filter aid and precoat filtration technology. American Filtration & Separation Society Annual Technical Conference.

European Commission (2014). Report on Critical Raw Materials for the EU. [online] Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission (2016). DG Trade. Agreements [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/

Eurostat (2019a). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2019b). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2 (last update 19/08/19)

Industrial Minerals Association (IMA-Europe) (2016). Data and information on perlite provided by IMA-Europe during stakeholder workshops and expert consultation within the 'Study on the review of the list of critical raw materials'.

Industrial Minerals (2016). Industrial Minerals Pricing Database. [online] Available at: http://www.indmin.com/

Kogel, J. E., Trivedi, N.C., Barker, J.M., Krukowski, S.T. (2006). Industrial Minerals & Rocks. Commodities, Markets, and Uses. 7th Edition. SME.

OECD (2019). OECD Export restrictions on Industrial Raw Materials database. [online] Available https://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

SCRREEN CRM validation workhop (2019). Expert's comment, Brussels, 11 Sep. 2019.

USGS (2019). U.S. Geological Survey, Mineral Commodity Summaries, February 2019, https://prd-wret.s3-us-west-2.amazonaws.com/assets/palladium/production/atoms/files/mcs2019_all.pdf

23.8Acknowledgments

This factsheet was prepared by the JRC in collaboration with Prof. Konstantinos Komnitsas (Technical University Crete). The authors would like to thank the Ad Hoc Working Group on Critical Raw Materials, in particular Ms. Aurela Shtiza and Ms. Francesca Girardi of IMA-Europe, as well as experts participating in SCRREEN workshops for their valuable contribution and feedback.

24. POTASH

24.1 Overview

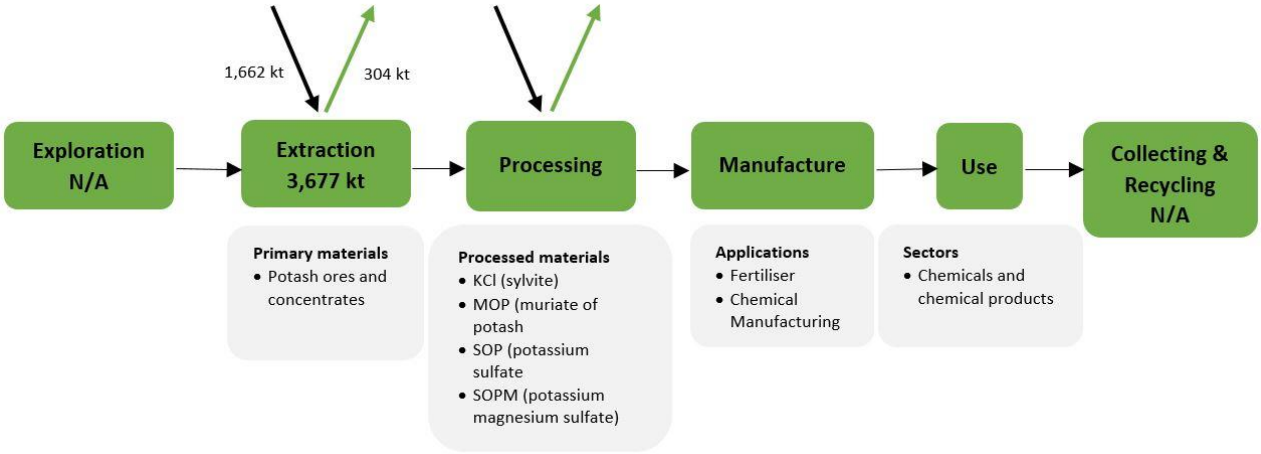


Figure 216: Simplified value chain for Potash (K_2O content)[143],. Average 2012-2016.

Potash is a type of salt rich in potassium, an essential nutrient for human, animal and plant life. The term potash stems from its former production from wood ashes by evaporating it in large iron pots. Potash refers to a group of potassium (K) bearing minerals and chemicals. Sylvine (potassium chloride, KCl) is the most important source for potash. It is present in the main industrial minerals sylvinite (KCL+NaCl) and carnallite ($KCl+MgCl_2+NaCl$) but other sources of K are sulphate of potash (SOP-K_2SO_4) and nitrate of potash (NOP-KNO_3 - this form does not have mining production) (Kerogen, 2019). In this assessment production data according to WMD (2019), stating the amount of produced potassium oxide (K_2O) is considered. Potassium oxide cannot be found in nature, but it is the basis for comparing all potassium compounds. Marketable potassium chloride contains about 60% of potassium oxide. (CropNutrition, 2019; Western Potash, 2019; BGS, 2011)

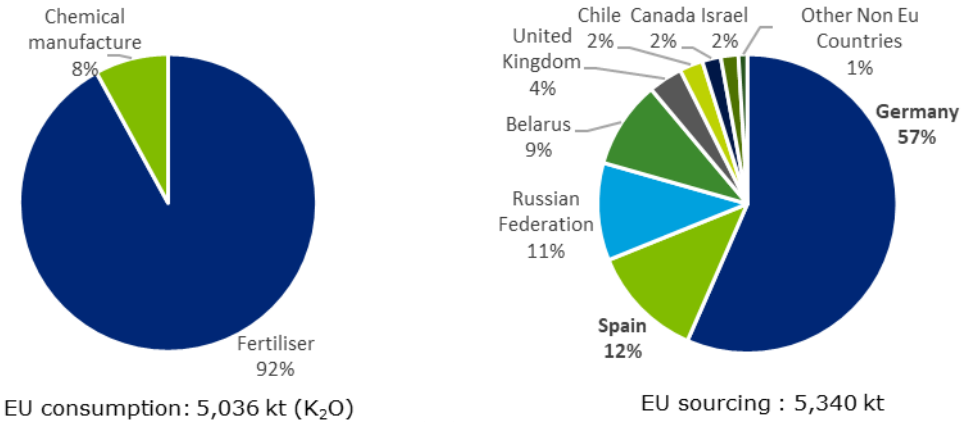


Figure 217: End uses and EU sourcing of Potash (Eurostat, 2019a; WMD, 2019)

[143] JRC elaboration on multiple sources (see next sections)

For trade figures, records by Eurostat were evaluated using HS code 310420 "Potassium chloride for use in fertiliser". In order to allow comparability, potassium chloride is converted into potassium oxide as in the 2017 criticality assessment.

Between 2012 and 2016, the average yearly market value amounted to 14.9 billion US dollars. Canada was the largest exporter with a market share of over 30%, followed by Russia and Belarus, approx. 18% each. The biggest importers were the United States (20%), Brazil (17%), and China (14%)(OEC, 2019).

Worldwide, 92% of potassium chloride are used for fertiliser production, whilst the remaining 8% are used for secondary aluminium refining, potassium hydroxide production, electroplating, oil-well drilling mud, snow and ice melting, steel heat-treatment and water treatment (USGS, 2017a).
The EU sourced an average of 5.34 Mt from domestic and external sources per year in the period of 2012-2016. Germany is the major supplier, providing 57%, followed by Spain and Russia (12% and 11%). The EU is a net importer of potash. Annually an average of 1.66 Mt were imported and 0.30 Mt were exported. The largest suppliers are Russia (34%) and Belarus (30%) (Eurostat, 2019a; WMD, 2019).

Potassium is an essential nutrient for humans, animals and plants and cannot be substituted (USGS, 2019).

Production of crops to produce ethanol and other biofuels that will give substitutive to fossil fuels with zero CO_2 balance, will require big amounts of potash. The increasing of the EU crops production by the use of potash (among other fertilizers) will reduce the import of those crops and reduce the CO_2 footprint of their transport (Kerogen, 2019).

According to USGS there are global reserves of 5,800 Mt K_2O equivalent. The largest reserves are located in Russia and Canada, in the EU Germany and Spain have reserves of 190 Mt. World resources are estimated at 250 billion t. (USGS, 2019).

The main producers of potash are Canada (28%), Russia (17%), Belarus (15%), and China (13%). There are also two large suppliers within the EU – Germany and Spain, producing 8% and 2% of world supply. The average annual production of potash between 2012 and 2016 was 37.52 Mt (WMD, 2019). Given the type of applications and potash being highly water soluble, it is not recyclable (USGS, 2019).

24.2Market analysis, trade and prices

24.2.1Global market analysis and outlook

Between 2012 and 2016, the average annual market value amounted to 14.9 billion US dollars. Canada is the largest exporter with a market share of over 30%, followed by Russia and Belarus, approx. 18% each. The biggest importers were the United States (20%), Brazil (17%), and China (14%) (OEC, 2019).

It is likely that the potash consumption and production will increase further. Due to the growing population, food consumption increases continuously and that requires higher amounts of potash for fertiliser. Moreover, cultivation of corn and other crops for ethanol production will increase again requiring potassium fertiliser. Potash consumption is expected to increase to 46.2 Mt by 2022 (USGS 2019).

New mines in Belarus, China, Laos, and Spain are expected to start production between 2019 and 2022, as well as the expansion of existing potash mines will increase world production capacity (USGS 2017a; USGS 2019).

Potash Outlook Ongoing capacity growth, with an additional 8 Mt K2O expected to be brought on stream between 2018 and 2023 Global potassium capacity is forecast to increase by an overall 13%, from 59.9 Mt K2O in 2018 to 67.8 Mt K2O in 2023. This equates to a net increment of 8 Mt K2O, most of which is represented by new projects expected to be commissioned in Russia and Belarus, as well as an increase in North America and West Asia. In product terms, global potassium capacity in 2023 would reach 122.6 Mt products, expanding by a net 21.5 Mt (Kerogen, 2019).

EECA and North America will account for 92% of potential potash supply growth in 2018-2023. In terms of MOP equivalent, global potash supply would reach 92 Mt in 2023.The EECA and North America would account for around 36% and 34% of potential supply, respectively, in 2023 (Kerogen, 2019).

New large-scale capacity additions, coupled with modest potash demand growth, will lead to a growing potential surplus Global demand for potassium for all uses would grow at 1.2% p.a., from 43.0 Mt K2O in 2018 to 45.7 Mt K2O in 2023. Potential global potash supply/demand conditions show a considerable widening of the estimated annual surplus between 2018 and 2023, then reaching 9.4 Mt K2O (Kerogen, 2019).

Expansion of regional deficits would support an 8% increase in potash trade by 2023. The near-term projected increase in demand will occur in Latin America and some key consumers across Southeast Asia, suggesting large import growth potential in Brazil, Southeast Asian countries (including Indonesia and Malaysia) and Africa (Kerogen, 2019).

Table 119: Qualitative forecast of supply and demand of Potash

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Potash		X	+	+	+	+	+	?

24.2.2EU trade

The EU is a net importer of potash. In the period of 2012-2016 imports, with 1.66 Mt, were about 5.5 times higher than exports, with 0.30 Mt on average (Eurostat, 2019a).

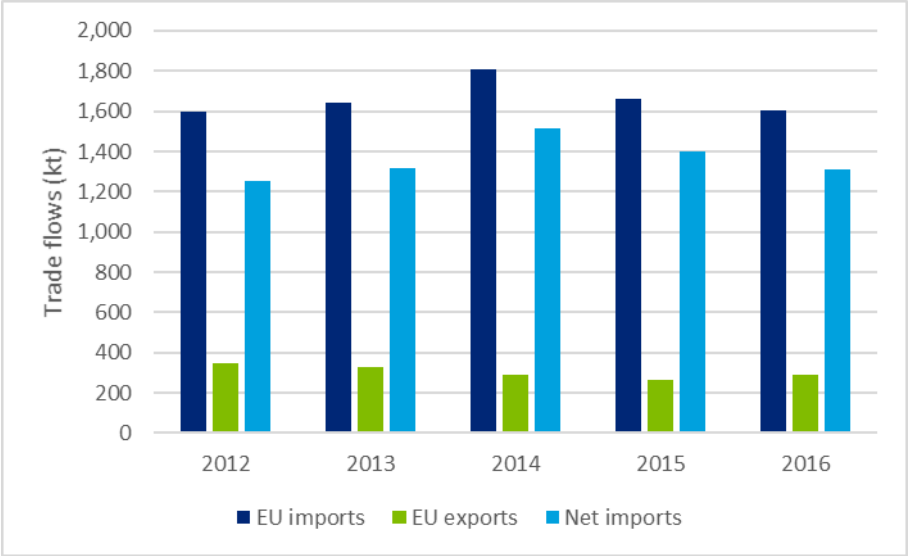


Figure 218: EU trade flows for Potash (K2O equivalent) (Eurostat, 2019a)

These figures remain fairly constant also in the following years. 2017 imports amount to 1.71 Mt and exports to 0.25 Mt. Both show a slight increase in 2018 with 1.78 Mt of potash being imported and 0.26 Mt exported (Eurostat, 2019a).

The main suppliers for the EU are Russia and Belarus, providing together about 64% of EU demand. There are currently no free trade agreements in place with these two countries (Eurostat, 2019a; European Commission, 2019) .

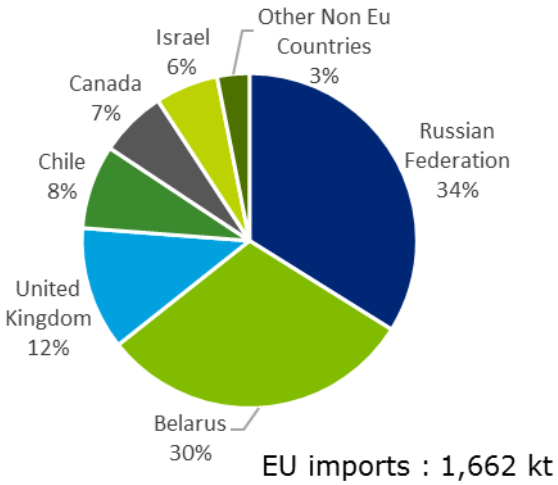


Figure 219: EU imports of Potash (K_2O equivalent) (Eurostat, 2019a)

According to the OECD there are currently no export quotas placed on potash exported to the EU; however, potash exports from Belarus, China and Jordan entering the EU are subject to an export tax of up to 25 %. The EU has trade agreements with Chile, Canada, and Israel in place. (OECD, 2019; European Commission, 2019).

24.2.3Prices and price volatility

USGS reports potash prices since 1900. As Figure 220 shows potash prices have been fairly constant since 1922. Between 2012 and 2016 prices were declining reaching USD 350 pert in 2016. In 2017 potash prices started to recover with USD 410 per t, and this trend continued in 2018 with USD 415 pert. Trades are conducted via companies involved in mining and refining of potash, these include Potash Corporation of Saskatchewan, Agrium, and Mosaic. All of which trade on the New York Stock Exchange and futures are available for potash chloride (Investopedia, 2019).

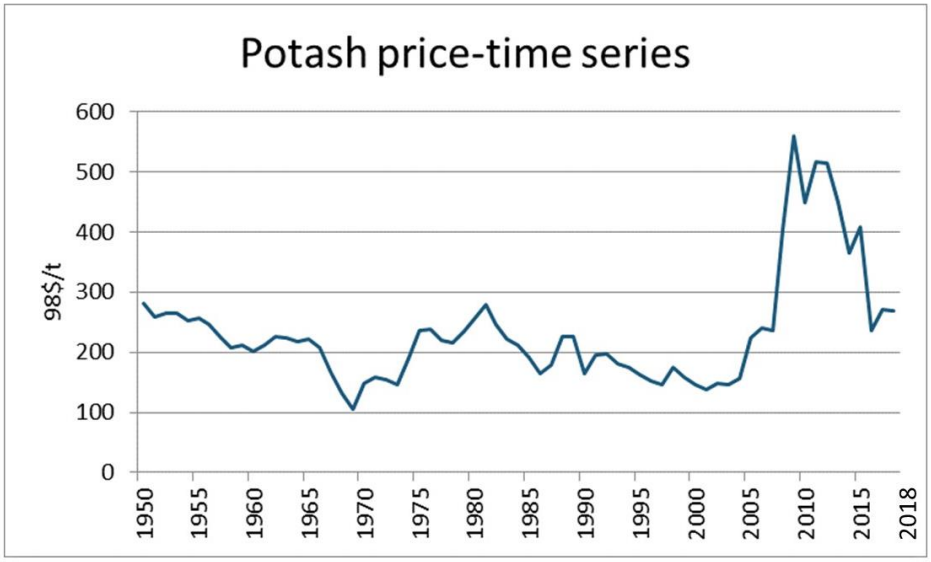


Figure 220: Prices of Potash (98USD per tonne, prices converted to 1998 consumer price index) from 1950 to 2018 (USGS, 2017b; USGS, 2019)

24.3EU demand

The global production of potash is on average 37,516 kt per year and the market value amounts to 14.9 billion dollars in the period of 2012-2016. In 2018 production increased to 42.87 Mt. Prices remained fairly constant at 775 USD per tonne in 2017 and 740 USD per tonne in 2018 (WMD, 2019; OEC, 2019; USGS, 2019).

24.3.1EU demand and consumption

The average apparent consumption of the EU between 2012 and 2016 amounted to 5,036 kt of potash (K_2O). This demand is mainly met by production from Germany (57%).

About half of EU imports are consumed by just six countries, namely Belgium, France, Germany, Ireland, the Netherlands, and Spain. These countries account for a significant amount (approx. 70%) of European agricultural output, and hence drive European demand for potassium chloride as a fertiliser (Eurostat 2019a; WMD, 2019).

24.3.2Uses and end-uses of Potash in the EU

According to USGS 92% of the global potash consumption are fertiliser products. (Unfortunately, no data specific for the EU is available.)

However, there are various other uses for potash (FEECO International Inc., 2019):

- Animal feed: potash has the same purpose in animal feed as in fertiliser, it increases the amount of nutrients and promotes healthy growth (use of potassium carbonate).
- Food products: source of food seasoning, for brewing beer, etc.; also dietary supplements provide potassium (use of potassium carbonate).
- Soaps, detergents, dyes: potassium soaps are not as common as sodium hydroxide-derived soaps, because they are softer. However, potassium soaps offer greater solubility and require less water than sodium soaps (use of potassium hydroxide).
- Water softener: potash can be used to treat hard water as an environmentally friendly alternative, it is more efficient than sodium chloride (use of potassium chloride).
- Snow and ice melting: Potash is essential for the production of de-icing products for treating roads for example, at the same time providing fertiliser for adjacent vegetation (use of potassium chloride).
- Glass: by using potash in glass manufacturing the melting temperature of the mixture can be lowered; as it also confers clarity to glass, potash is often used in spectacles, glassware, computer and TV monitors (use of potassium carbonate).
- Energy Storage: molten salts (typically a mixture of 60% sodium nitrate and 40% potassium nitrate) can be used to store thermal energy, for example from solar panels, until electricity is needed, allowing thermal power plants to operate just like a conventional fossil fuel, or nuclear power plant. This technology might lead to an increase of potassium consumption in the future, as the thermal energy industry expands (SolarReserve, 2018; Johnson, et al., 2019).
- Other: aluminium recycling, explosives, pharmaceuticals.

As the percentage of the above mentioned applications could not be determined, they are combined as chemical manufacture in Figure 221.

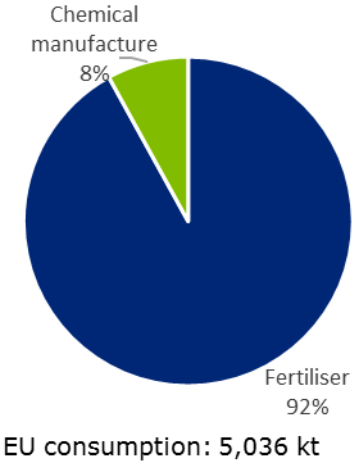


Figure 221: Global end uses of Potash. Average figures for 2012-2016 (USGS, 2017a)

Relevant industry sectors are described using the NACE sector codes (Eurostat, 2019b).

Table 120: Potash applications, 2-digit and associated 4-digit NACE sectors, and value added per sector

Applications	2-digit NACE sector	Value added of NACE 2 sector (M€)	4-digit NACE sectors
Fertiliser production	C20 - Manufacture of chemicals and chemical products	105.514	C2015 – Manufacture of fertilisers and nitrogen compounds
Chemical manufacture (incl. animal feed, glass, de-icing products, etc.)	C20 - Manufacture of chemicals and chemical products	105.514	C2013 – Manufacture of other inorganic basic chemicals

24.3.3Substitution

There are no substitutes for potash, as potassium is one of the three vital nutrients for plant growth (next to nitrogen and phosphorous). There have been trials with unconventional potassium sources, such as glauconitic sands, potassium feldspars and some slags, but without success. Animal manure, guano, bone meal, compost, etc. as low-nutrient-content alternatives are not feasible due to high transportation costs (USGS, 2017a; BGS, 2011).

24.4Supply

24.4.1EU supply chain

There are two countries in the EU producing potash – Germany and Spain. This equals about 10% of global supply and 68% of EU demands can be covered. The EU has many trade partners (38 countries) covering the remaining demand. The main suppliers are Russia (11%), followed by Belarus (9%) and the United Kingdom (4%). Annually, about 1,662 kt of potash (K_2O) are imported.

The main consumer of EU exports is by far Brazil, importing approx. 257 kt per year. Further important consumers of EU potash exports are Morocco, the UK, and Malaysia. In total, 395 kt of potassium chloride (that equals 245 kt K_2O) were exported. (All values are an average of 2012-2016.) These numbers result in an import reliance of 27% (Eurostat, 2019a; WMD, 2019).

24.4.2Supply from primary materials

Potash is primarily extracted from deep underground deposits by conventional mining methods similar to those used for extracting coal (i.e. mechanised longwall mining) or those used in some metallic or industrial mineral mines (i.e. rooms & pillars) (Kerogen, 2019).
Potash may also be extracted by injecting a heated brine into the mine workings to dissolve the potash in-situ, the resulting solution is then pumped to the surface and the potash recrystallized by evaporation (Potash Corp, 2016). This process is known as solution mining (European Commission, 2017).

24.4.2.1 Geology, resources and reserves of potash

Geological occurrence: Potash mineral deposits are chemical sedimentary rocks that formed by the evaporation of saline waters (e.g. seawater) resulting in the precipitation of salt

minerals. Salt deposits may be broadly split into two groups: (1) present day, or geologically young shallow-water salt deposits and (2) ancient deep-water salt deposits.

Shallow water deposits typically occur in semi-arid to arid coastal environments and are characterised by their limited thickness and restricted lateral extent. The low magnesium sulphate content of shallow water deposits indicates precipitation from non-marine, or mixed marine - non-marine waters. Whereas deep water deposits form thick, laterally extensive deposits enriched in magnesium sulphate; this enrichment in magnesium sulphate is indicative of formation by precipitation of seawater in a restricted marine basin. Deep water deposits are typically bedded, with carbonate minerals occurring at the base of the sequence followed by calcium sulphates, halite, magnesium sulphates and then magnesium and potassium chlorides. Mineable potash deposits are generally associated with thick halite deposits, where the potash occurs as thin seams near to the top of the halite beds.

European potash production is primarily from the Zechstein Formation, a large (ca. 200,000 km3) Permian evaporite sequence that outcrops in Germany, the United Kingdom, the Netherlands and Poland. A large proportion of the Zechstein formation is found beneath the North Sea, where it plays an important role as cap rock for the North Sea oilfield. (European Commission, 2017)
In Spain, potash mines are in the Catalan Potash Basin and projects are in the Centre Zone of the Sub-Pirenaic Eocene –Oligocene –Sannoisiense (ICL-Iberia/Geoalcali)

Global resources and reserves[144]: Worldwide reserves of 5,800 Mt K_2O equivalent have been explored. The largest reserves are located in Russia (2,000 Mt) and Canada (1,200 Mt). For further figures see Table 121.

According to USGS world resources of potash are estimated at about 250 billion t.

Table 121: Global reserves of Potash in year 2018 (USGS, 2019)

Country	Potash Reserves K_2O equivalent (million t)
United States	220
Belarus	750
Brazil	24
Canada	1,200
Chile	100
China	350
Germany	150
Israel	270
Jordan	270

[144] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of potash in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template.[144], which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

Country	Potash Reserves K_2O equivalent (million t)
Russia	2,000
Spain	41
United Kingdom	170
Other countries	280
World Total	**5,800**

EU resources and reserves[145]*:* According to Minerals4EU resource data for Europe, there are resources located in Spain and the United Kingdom (See Table 122)

Table 122: Resource data for Europe compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2019)

Country	Reporting code	Quantity	Unit	Grade	Code Resource Type
Spain	-	117,500,000	T (Potash)	-	Historic Resource Estimates
United Kingdom	-	3,142	Million t (Polyhalite)	-	JORC (indicated & inferred)
United Kingdom	-	266,200	Million t (Polyhalite)	-	Estimate
United Kingdom	-	11,5	Million t (K_2O content)	-	JORC (indicated & inferred)
United Kingdom	-	10,610	Million t (K_2O content)	-	Estimate

[145] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for potash. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for potash, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for potash the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019).Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However a very solid estimation can be done by experts.

There is also some data available on reserves in the EU:

Table 123: Reserve data for EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2019)

Country	Reporting code	Quantity	Unit	Grade	Code Resource Type
Italy	-	500	Million t (Potash salt)	-	Estimated
Spain	Other	2,600,000	t (Potash)	-	Proven reserves
Spain	Other	11,600,000	t (Potash)	-	Probable reserves
Spain	Other	53,900,000	t (Potash)	-	Possible reserves

For Europe in general various other reserves were reported at the time of the Minerals4EU assessment. There were also a number of exploration licences active, mainly in Spain (5 licences), and the UK.

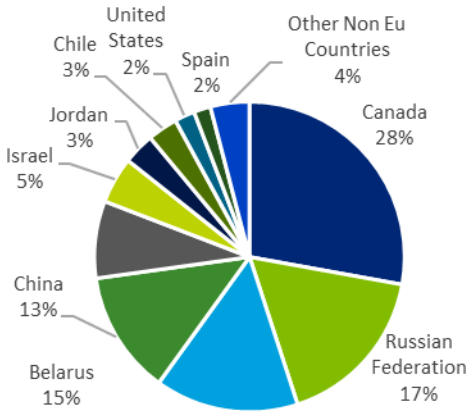
24.4.2.2 World and EU mine production

Fifteen countries worldwide produce potash with a total amount of 37,516 kt per year. The largest producer is Canada, providing 28% of global supply. It is followed by Russia (17%), Belarus (15%), and China (13%). Germany and Spain are the two EU countries producing 10% of global potash supply. They produced an average of 3,677 kt per year in the period 2012-2016, Germany supplying 82% of EU production.

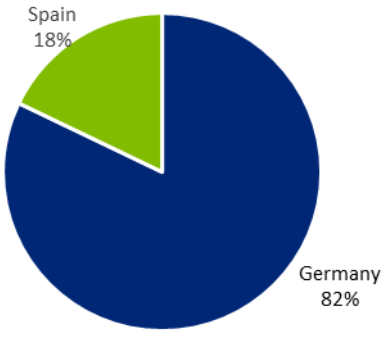
In 2017 production numbers increased further to 42,860 kt of K_2O (WMD, 2019).

Leading producer in Europe is K+S KALI GmbH operating six mines in Germany.

In Spain one new mine (Muga – Vipasca) run by Geoalcali is currently in development and is waiting for final approvals. Geoalcali also pursue three more exploration projects in adjacent areas (Geoalcali, 2019).



Global production : 37,516 kt



EU production : 3,677 kt

Figure 222: Global and EU mine production of Potash in t and percentage, 2012-2016 (WMD, 2019).

24.4.3Supply from secondary materials/recycling

Potash minerals are highly-water soluble, which results in them becoming widely dispersed in the natural environment and as fertilizer are being taken up by plants and organisms; they are therefore biologically recycled (European Commission, 2017).

24.4.4Processing of Potash

The processing of potash ores comprises four stages: (1) potash ore is crushed and ground to release the potash minerals from the ore, at this stage clay minerals are also removed from the ore (i.e. desliming); (2) potash minerals are separated from unwanted salt minerals (e.g. halite) by froth-floatation; (3) the potash minerals are dried and size-graded; and finally (4) further purification takes places by dissolving the potash minerals in hot-brine to remove impurities. Upon cooling a high-purity precipitate is formed (crystallization), which may be used in the production of fertilisers and potassium-chemicals. In the case of solution mining, the concentration of potash is only the step 4 (Potash Corp 2016).

24.5Other considerations

24.5.1Environmental and health and safety issues

Annex VII of EU Regulation (EC) No 889/2008 lists caustic potash as authorised to be used in organic production for cleaning and disinfection of buildings and installations for animal production to prevent cross-infection and diseases. Potassium nitrate is a registered substance under REACH, with no current Authorisations or Restrictions.

Typically, environmental effects of potash production are quite localized, and in most cases, confined to the mine site. Large volumes of water are typically required by mining and beneficiation activities. Water quality can be affected by the release of slurry brines and/or erosion of spoil piles and waste disposal facilities unless appropriate mitigation measures are in place.

EU OSH requirements exist to protect workers' health and safety, employers need to identify which hazardous substances they use at the workplace, carry out a risk assessment and introduce appropriate, proportionate and effective risk management measures to eliminate or control exposure, to consult with the workers who should receive training and, as appropriate, health surveillance[146].

24.5.2Socio-economic issues

The Environmental Justice Atlas (2019) reports examples of mines and refining with social issues related to potash production, either during operations or in the production of potassium ferilizers. Among these, Potasas del Llobregat in Catalonia (Spain) and Sakhon Nakhon Potash mine (Thailand).

[146] https://ec.europa.eu/social/main.jsp?catId=148

24.6Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. As trade data for potash minerals is still unavailable it was again only possible to calculate supply risk for potash ores and concentrates.

Table 124: Economic importance and supply risk results for Potash in the assessments of 2014, 2017, 2020 (European Commission, 2014; European Commission, 2017)

Assessment	2011			2014			2017			2020	
Indicator	EI	SR		EI	SR		EI	SR		EI	SR
Potash	-	-		8.61	0.21		4.8	0.7		5.4	0.79

The value added used in the 2017 and 2020 criticality assessment corresponds to a 2-digit NACE sector rather than a 'megasector' used in the previous assessments and the economic importance figure is therefore reduced. The supply risk indicator is higher than in the previous years, which is due to the methodological modification and the way the supply risk is calculated. Hence differences between the assessment results are largely due to changes in methodology (as outlined above).

24.7Data sources

Data for EU consumption is not available at the time of the assessment. Moreover, Eurostat does not record trade data for potash minerals.

24.7.1Data sources used in the factsheet

BGS (2011). Mineral Planning Factsheet – Potash. Available at: https://www.bgs.ac.uk/downloads/search.cfm?SECTION_ID=0&MIME_TYPE=0&SEARCH_TXT=potash&dlBtn=go

Crop Nutrition (2019). What is Potash? [Online]. Available at: https://www.cropnutrition.com/what-is-potash (Accessed: 09.09.2019)

European Commission (2014) Report on critical raw materials for the EU – Non Critical raw materials profiles [Online]. Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission (2017). Study on the review of the list of Critical Raw Materials – Non-critical Raw Materials Factsheets. Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission (2019). Negotiations and agreements [Online]. Available at: https://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/ (Accessed 12.09.2019)

Eurostat (2019a). Comext – International Trade [Online]. Available at: http://epp.eurostat.ec.europa.eu/newxtweb/ (Accessed: 07.09.2019)

Eurostat (2019b). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E) [Online]. Available at: https://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2 (Accessed: 07.09.2019)

FEECO International, Inc. (2019). 7 Uses For Granulated Potash [Online]. Available at: https://feeco.com/7-granulated-potash/ (Accessed: 13.09.2019)

Geoalcali (2019). Projects [Online]. Available at: https://www.geoalcali.com/en/muga/ (Accessed: 13.09.2019)

Kerogen (2019). Expert feedback, Mr. Gonzalo Mayoral.

ICL (2019). Polysulphate [Online]. Available at: http://www.icl-uk.uk/product/polysulphate/ http://www.icl-uk.uk/product/iclpotashplus/ (Accessed: 07.11.2019)

Investopedia (2019). Potash [Online]. Available at: https://www.investopedia.com/terms/p/potash.asp (Accessed: 13.09.2019)

Johnson, Samuel C., Davidson, F. Todd, et al. (2019). Storage and Hybridisation of Nuclear Energy. Techno-economic Integration of Renewable and Nuclear Energy. Available at: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/molten-salts

Minerals4EU (2019). European Minerals Yearbook – Data for Potash [Online]. Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/pages/bycommodity.jsp?commodity=Potash (Accessed: 11.09.2019)

OEC (2019) Observatory of Economic Complexity. Available at: https://oec.world/en/profile/hs92/280490/.

OECD (2019). Export restrictions on Industrial Raw Materials [Online]. Available at: https://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/ (Accessed: 12.09.2019)

Potash Corp. (2016). The Potash Journey – Potash Profile. Available at: www.potashcorp.com/media/POT_Journey_Brochure.pdf

SolarReserve, LLC. (2018). Molten Salt Energy Storage [Online]. Available at: https://www.solarreserve.com/en/technology/molten-salt-energy-storage.html (Accessed: 13.09.2019)

USGS (2017a). 2015 Minerals Yearbook – Potash [Advance Release]. Available at: https://www.usgs.gov/centers/nmic/potash-statistics-and-information

USGS (2017b). Historical Statistics for Mineral and Material Commodities in the United States – Potash. Available at: https://www.usgs.gov/centers/nmic/historical-statistics-mineral-and-material-commodities-united-states

USGS (2019). Mineral Commodity Summaries – Potash. Available at: https://www.usgs.gov/centers/nmic/potash-statistics-and-information

Western Potash (2019). What is Potash? [Online]. Available at: https://www.westernpotash.com/about-potash/what-is-potash (Accessed: 09.09.2019)

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

24.7.2Data sources used in the criticality assessment

European Commission (2014) Report on critical raw materials for the EU – Non Critical raw materials profiles [Online]. Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission (2017). Study on the review of the list of Critical Raw Materials – Non-critical Raw Materials Factsheets. Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission (2019). Negotiations and agreements [Online]. Available at: https://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/ (Accessed 12.09.2019)

Eurostat (2019a). Comext – International Trade [Online]. Available at: http://epp.eurostat.ec.europa.eu/newxtweb/ (Accessed: 07.09.2019)

OECD (2019). Export restrictions on Industrial Raw Materials [Online]. Available at: https://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/ (Accessed: 12.09.2019)

USGS (2019). Mineral Commodity Summaries – Potash. Available at: https://www.usgs.gov/centers/nmic/potash-statistics-and-information

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

24.8Acknowledgments

This factsheet was prepared by the JRC in collaboration with Ms. Marie-Theres Kügerl (Resources Innovation Center Leoben). The authors would like to thank the Ad Hoc Working Group on Critical Raw Materials, in particular Euromines, as well as experts participating in SCRREEN workshops for their valuable contribution and feedback.

25. RHENIUM

25.1 Overview

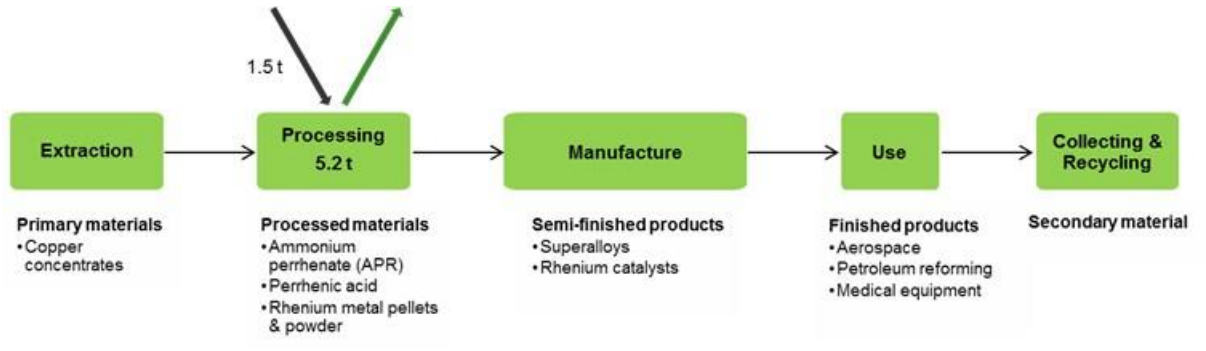


Figure 223: Simplified value chain for rhenium[147] for the EU, averaged over 2012-2016

Rhenium (Re) is a silvery-white metal refractory metal. It has a very high melting point (3,185°C) and a heat-stable crystalline structure. It is ductile, dense (21.04 g/cm3) and highly resistant to corrosion. It is mostly found as trace impurities in copper and molybdenum sulphide ores.

For the purpose of this assessment, rhenium is analysed at the processing stage only, as rhenium is recovered as a by-product of copper mining. Refined production is expressed in terms of metal content. There is no trade data specific to rhenium in Eurostat's Comext database because the import tariff code for rhenium (metal) also covers niobium (CN 8112923100).

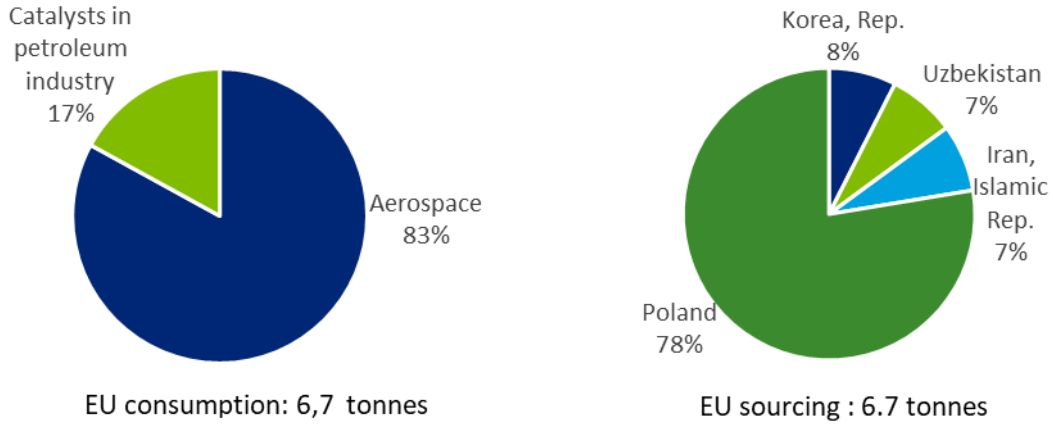


Figure 224: End uses and EU sourcing of rhenium (average 2012-2016) (Lipmann, 2016; WMD, 2017&2018)

[147] Elaboration on multiple sources (see next sections)

The market of rhenium is mostly driven by the demand for superalloys in the aerospace industry. Demand is forecasted to increase with the growth of the global passenger air traffic. Recycling and engine will satisfy most of this demand growth. Rhenium is mostly sold on long-term contracts between producers, consumers and traders. Between 2012 and 2016, catalytic-grade ammonium perrhenate price averaged USD 3,080 per kilogram and rhenium metal pellet average price was USD 2,780 per kilogram. Since then, the prices have falled to USD 1300-1500 per kg (Eurometaux, 2020).

World demand for rhenium was estimated at about 60-65 tonnes in 2015. The EU rhenium consumption was in the order of a few tonnes which were sourced through domestic production in Poland, some imports and recycling such as revert alloys.

Rhenium is mainly used in superalloys for the aerospace and in platinum-rhenium catalysts for the production of high-octane unleaded gasoline. Substitution of rhenium in current major's applications is low as alternatives are associated to a loss in performance.

The higher performance of rhenium-bearing superalloys have resulted in longer-lasting components and higher fuel efficiencies.

Rhenium is a by-product of copper mining. World known reserves of rhenium are estimated at around 2,400 tonnes (USGS, 2019). Chile has the world's largest reserves (48%). Porphyry copper deposits are the world's most important source of rhenium.

The world production of rhenium from primary sources was 43.6 tonnes per year on average, with Chile accounting for 48% of the total production. Molymetfollowed by the United States were the second largest producer (18%) and Poland (12%). Rhenium production from recycled and revert materials was estimated to about 20 tonnes in 2015.

Environmental, social and economic issues associated to copper mining such as acid drainage, water usage and social unrest in South-America have a potential impact on rhenium primary supply.

25.2Market analysis, trade and prices

25.2.1Global market analysis and outlook

World estimated consumption of rhenium was estimated at about 70 tonnes in 2017 (Pratt & Whitney, 2018). The refractory metal is mainly used in the manufacture of super alloys for gas turbine engines and therefore demand for the refractory metal grows with the demand for engines in commercial and defence aircrafts. According to Roskill (2015), demand from the superalloy sector has grown at a compound annual growth rate of 7% between 2005 and 2014. In 2018, Airbus estimated that the global passenger fleet will more than double between 2018 and 2037 driving a need for 37,390 new aircrafts (Airbus, 2018).

On the primary supply side there are no major rhenium projects in the pipeline. The demand growth will mostly be met through recycling and engine revert alloys.

The industry is highly concentrated in terms of production, with Chile, USA and Poland as the major suppliers. Key rhenium producers include Molymet, Freeport MCMoRan, KGHM and LS-Nikko. The main change since 2016 is the entrance of Codelco as a major primary producer.

Table 125: Qualitative forecast of supply and demand of rhenium

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Rhenium		x	+	+	+	+	+	+

25.2.2EU trade

There is no reliable statistics on rhenium products trade because the import tariff code for rhenium (metal) also covers niobium (Trade code 8112923100). Rhenium is also imported into EU as NH_4ReO_4 (rhenium ammonium perrhenate - APR) under the tariff code number 2841908590 which is described under the classification list of 'salts of oxometallic or peroxometallic acids'. Experts estimate 1.5 to 2 tonnes of import into EU and the UK per year, on average over 2012 to 2016. Possible sources of imports are South Korea, Japan, Kazakhstan, Russia, Armenia, Uzbekhistan, Iran and Chile (expert communication, 2016).

25.2.3Prices and price volatility

Rhenium is sold on long-term contracts between producers, consumers and traders. Prices are generally not publicly available. In 2014, rhenium producer Molymet and the aircraft engine manufacturer Pratt & Whitney entered largest ever long-term agreements valued at USD 690 million. References prices based on past transactions are published by some commercial providers (e.g. Asian Metal, Metal Pages). Rhenium is traded as ammonium perrhenate (APR) and as metallic rhenium.

Rhenium is an expensive metal. Its average price between 2000 and 2010 has been USD 3,000 per kilogram. Demand for rhenium grew in the mid-2000s with the appearance of a new generation of super alloys for turbine blades containing up to 6% rhenium and the development of Gas-to-Liquids (GTL) processes. As a result, rhenium price rose rapidly starting in 2006 to reach an all-time high of about USD 12,000 per kilogram (rhenium metal) in August 2008, before decreasing with the onset of the global economic recession. The price has returned to its long trend level of about USD 1,500 per kilogram (Figure 225). Between 2012 and 2016, catalytic-grade ammonium perrhenate price averaged USD 3,080 per kilogram and rhenium metal pellet average price was USD 2,780 per kilogram (BRGM database, 2019).

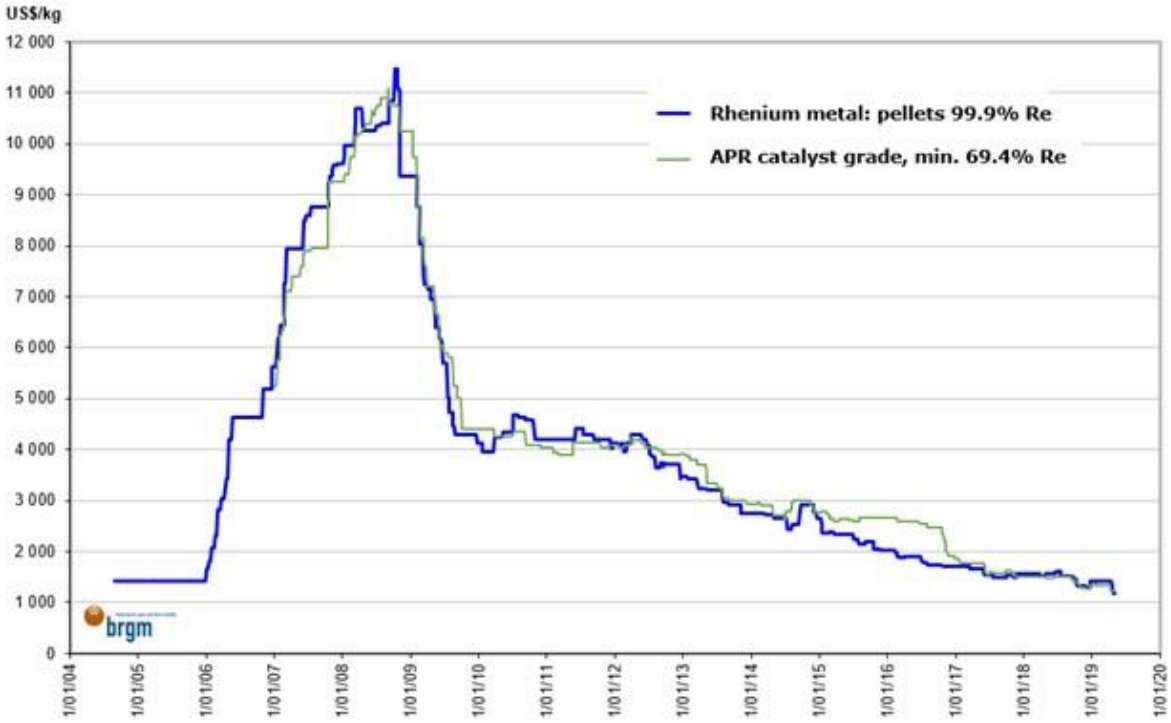


Figure 225: Rhenium prices (USD/kg) from 2004 to 2018 (BRGM database, 2019)

25.3EU demand

25.3.1EU demand and consumption

The EU apparent consumption (production + imports- exports) of rhenium during the period 2012 to 2016 cannot be calculated because of the lack of reliable trade data, but according to experts is likely to be of the order of a few tonnes. The aerospace and defence industry is the major end-user of rhenium in the EU.

25.3.2Uses of rhenium in the EU

Rhenium is mainly used in the aerospace and petrochemical industries.

About 80% of the world annual consumption of rhenium is used in high-temperature superalloys for the manufacture of turbine blades for aircraft and industrial gas turbine (jet) engines (Lipmann, 2016). Small addition of rhenium increases creep strength of superalloys, enabling them to withstand higher temperatures. These superalloys are commonly grouped into generations based on their rhenium content: first-generation rhenium-free alloys gave way to second generation alloys in the 1990s, containing 2–3 % rhenium have seen the greatest market utilization. Third-generation alloys contains 6% rhenium and the fourth generation is characterised by high rhenium (6%) and ruthenium (3-6%) contents (Mottura & Reed, 2014). It is also used along with platinum as a catalyst (bi-metallic catalyst with 0.3% Re and 0.3% Pt) in the production of high-octane unleaded gasoline. Other uses include thin filaments in a wide array of bulbs and mass spectrometers, in thermocouples, and in heating elements and X-ray targets for medical equipment..

Table 126 presents the main uses of rhenium in the EU… :. Relevant industry sectors are described using the NACE sector codes (Eurostat, 2019b).

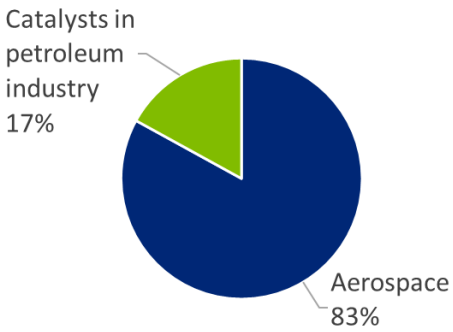


Figure 226: EU end uses of rhenium in 2012-2016 (Lipmann, 2016).

Table 126: Rhenium applications, 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2019b)

Applications	2-digit NACE sector	4-digit NACE sectors	Value added of NACE 2 sector (M€)
Aerospace	C30 - Manufacture of other transport equipment	C3030- Manufacture of air and spacecraft and related machinery	44,304
Catalysts in petroleum industry	C19 - Manufacture of coke and refined petroleum products	C1920- Manufacture of refined petroleum products	17,289

25.3.3Substitution

Since the advent of third-generation superalloys which contains more rhenium, engine manufacturers have opted to reduce their rhenium consumption, primarily due to cost concerns. A number of rhenium-free alloys or alloys with a reduced rhenium content have been developed over the last 20 years (General Electric, Onera, Pratt & Whitney etc.). Ceramic matrix composites (CMCs) parts are used in some types of commercial aircraft engine (CFM LEAP engine). However there is currently very little substitution potential for rhenium in superalloys used in the hottest parts of large gas turbine engines (up to 1,600ºC).

Catalysts consisting of platinum only are less efficient in most applications and more expensive. Substitutes in other applications are cobalt and tungsten for coatings on X-ray tubes, rhodium and rhodium-iridium for high-temperature thermocouples, tungsten and platinum-ruthenium for coatings on electrical contacts, tungsten and tantalum for electron emitters (Millensifer et al., Polyak, 2019).

25.3.4EU supply chain

25.3.4.1 Geology, resources and reserves of rhenium

Geological occurrence:

Rhenium has an estimated average concentration of 0.2 ppb in the Earth continental upper crust (Rudnick & Gao, 2003). It is dominantly hosted in the mineral molybdenite, where it isomorphically substitutes for molybdenum. Rhenium is not mined as concentrated ore but is recovered as a by-product of copper ore processing.

Porphyry copper-molybdenum deposits supply about 80% of the rhenium produced by mining. The metal is produced from molybdenum concentrates from several deposits in Chile and Peru (El Teniente, Toquepala), Western United States, Armenia, Kazakhstan, Uzbekistan and Iran (Sar Cheshmeh deposit).

Sediment-hosted strata-bound copper deposits are the other major primary source of rhenium, both the sandstone-types in Kazakhstan (Dzhezkazgan deposits) and the Kupferschiefer[148] types in Poland (Lubin-Sieroszowice mining district). The nature of the rhenium mineral host in these type of deposits is still poorly understood. (John et al., 2017).

Rhenium is also found in some sandstone uranium deposits in Kazakhstan and Uzbekistan and at the Merlin high-grade molybdenum-rhenium deposit in Australia (Babo, 2017).

Global resources and reserves[149]*:*

Global reserves of rhenium at the end of 2018 were estimated at around 2,400 tonnes (USGS, 2019), with Chile accounting for about half of the total (55%), followed by the United States (17%) and Russia (13%) (Table 127). However this figure does not include reserves in Poland, Uzbekistan, China and in Australia where a high grade molybdenum and rhenium deposit has been newly discovered. Published probable reserves at the Merlin deposit in Queensland are estimated at 129 tonnes of rhenium (7.1 million tonnes with 18.1 g/t rhenium, JORC) (Queensland Government, 2017).

The lack of grade and tonnage data for most deposits, prevents a thorough assessment of world rhenium resources.

[148] Copper-, polymetallic-, hydrocarbon-bearing black shale of the lowermost Zechstein Group of Permo-Triassic age (252 Ma) in Germany and Poland (Keith, S. B., Spieth, V., & Rasmussen, J. C., 2018).

[149] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of rhenium in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template.[149], which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

Table 127: Global reserves of rhenium in year 2019 (USGS, 2019)

Country	Rhenium Reserves (tonnes, metal content)
Chile	1,300
United States	400
Russia	310
Kazakhstan	190
Armenia	95
Peru	45
Canada	32
China	N.A.
Poland	N.A.
Uzbekistan	N.A.
World total (rounded)	*2,400*

EU resources and reserves[150]*:*

Information on rhenium resources in the EU is not available. Poland reserves data are not published.

25.3.4.2 World and EU mine production

There are no producers of primary rhenium, and almost all rhenium is produced as a by-product of copper and molybdenum concentrates processing. Production data are therefore presented in the "Processing of rhenium" section.

25.3.5Supply from secondary materials/recycling

Recycling has become an important source of rhenium. The rate of recovery of rhenium from end-of-life products is superior to 50% (EoL-RIR) (UNEP, 2011). The rhenium recycling industry experienced considerable capacity growth when rhenium metal and APR spot prices were high (Roskill, 2015). Rhenium is recycled from end-of-life turbine blades, mill scraps and spent petrochemical catalysts.

The rhenium price spike between 2008 and 2012 led to a surge in the processing and use of 'engine revert', a high-quality post-consumer scrap produced from end-of-life gas turbine parts. Once scrapped engine parts have been checked for chemical uniformity, cleaned of their zirconia- or alumina-based heat-resistant coating and shot-blasted, one is left with pieces of 100% homogenous superalloy metal ready to be remelted. Estimates vary, but industry sources claim that in 2015 engine revert supplied around 20% of all superalloy feedstock (Tantalum-Niobium International Study Center -T.I.C., 2016).

[150] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for rhenium. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for rhenium, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for rhenium the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019). Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However a very solid estimation can be done by experts.

The catalysts industry has an 80% recovery efficiency, reducing the virgin rhenium needs to replace spent catalysts (MMTA, 2016). About 15 tonnes of rhenium are thought to be recovered as ammonium perrhenate from petroleum-reforming catalysts containing rhenium and platinum (Anderson et al., 2013; MSP-Refram, 2016). The main incentive for recycling is the value of platinum. Catalyst regeneration is a closed loop process.

In Europe, rhenium was recycled in Germany (Buss & Buss Spezialmetalle, H.C. Starck and Heraeus Precious Metals)(Lefebvre et al., 2016). Toma Group in Estonia had the capability to recover rhenium from alloys and rhenium scrap into high purity ammonium perrhenate (Catalyst Grade purity), according to their website (Toma Group, 2012).

25.3.6 Processing of rhenium

Rhenium is mainly recovered from the gases and dusts produced during the processing of molybdenite concentrates (porphyry copper-molybdenum deposits) or of copper concentrates (sedimentary copper deposits) (Anderson et al., 2013, John et al., 2017).

Copper concentrates and molybdenum concentrates are separated using differential flotation. During roasting of the molybdenite concentrates to produce molybdenum oxide MoO_3, the rhenium is oxidised to rhenium heptoxide Re_2O_7 which is extremely volatile and exits the furnace with the flue gas. Re_2O_7 is then recovered from the gas phase by a wet scrubbing process and rhenium is precipitated as ammonium perrhenate (NH_4ReO_4) using solvent extraction or ion-exchange processes.

When molybdenum is not recovered during the ores processing, as it is the case with Polish ore, rhenium is recovered from copper concentrate smelter flue gases.

Recovery of rhenium from flue gases has increased to approximatively 80%. Ammonium perrhenate (APR) can be used directly in the production of platinum-rhenium catalysts or serves as a precursor material in the manufacture of rhenium metal powder and pellets. Rhenium metal is generally produced by hydrogen reduction of ammonium perrhenate (APR). Rhenium pellets and high-purity rhenium powder are used in the superalloy industry. Perrhenic acid is used in the manufacture of Pt-Re reforming catalysts.

Global production of rhenium was estimated at about 43.6 tonnes per year on average during the period 2012-2016, of which 27.1 tonnes (48%) was produced in Chile by Molymet (Molibdenosy Metales) from domestic and imported concentrates. The United States ranks second with 8 tonnes (18%) produced at Freeport-McMoran Copper & Gold's Sierrita processing facilities in Arizona from molybdenite concentrates (USGS, 2017). Rhenium was also recovered in South Korea (around 3 tonnes) by L S Nikko Copper Inc from imported concentrates and in Armenia, Kazakhstan, Mexico, Peru, and Uzbekistan.

In the EU, rhenium is recovered in Poland from copper concentrates produced from the Lubin mine, Polkowice-Sieroszowice mine and Rudna mine (Bartlett et al., 2013). The Polish company KGHM Polska Miedź (KGHM) also recovered rhenium from domestic copper concentrates for a total of 5.2 tonnes. Polish copper concentrates contains between 4 and 12 ppm of rhenium (Śmieszek et al., 2017). KGHM is producing APR and metallic rhenium at the Głogów smelting facility (Anderson et al., 2013).

There are a few aerospace approved producers of rhenium pellets in the EU, among them KGHM, Heraeus and Hoganas (previous HC. Starck). Hoganas are well known for the production of low micron powders of Re which are used in tungsten-rhenium alloys in Japan.

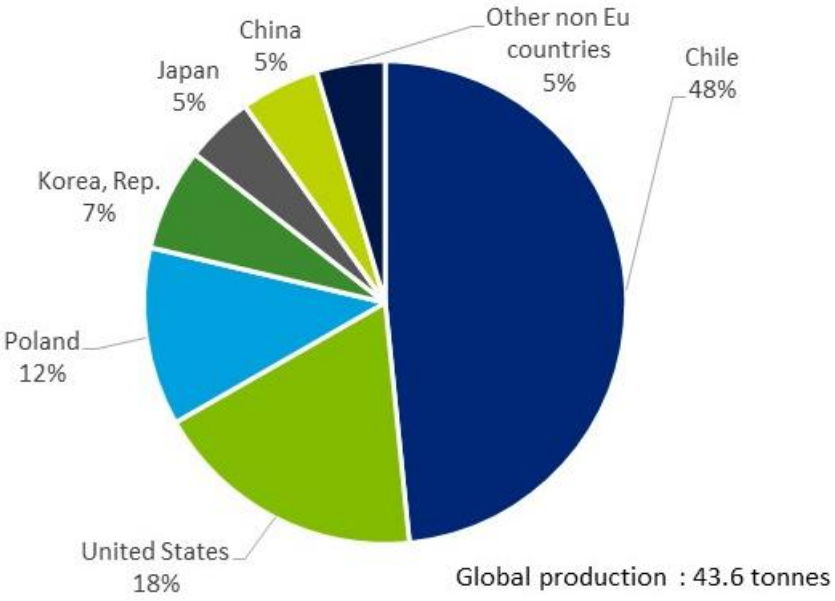


Figure 227: Global rhenium production (expressed in metal content). Average for the years 2012-2016. (WMD, 2018; Lipmann, 2016)

25.4Other considerations

25.4.1Environmental and health and safety issues

Five substances have been registered under REACH by the Precious Metals and Rhenium Consortium: Rhenium metal (Re), perrhenic acid (HO_4Re), ammonium perrhenate (H_4NO_4Re), Sodium rhenate (NaO_4Re) and potassium perrhenate (KO_4Re) (REACH,2017). Environmental issues associated with rhenium production are related to the mining of poprphyro-copper and sedimentary deposits and include acid-mine drainage, water usage, are the main risks.

25.4.2Socio-economic issues

Social and labour conflict often happened especially in the largest copper producing nations such as Chile.

25.5Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. The Economic Importance score remained relatively stable compared to the score in 2017 criticality assessment. The end-use application has not changed greatly; variation existed in the value added of the sectors for which the end use was relevant. The supply risk score is lower than the supply risk in criticality assessment 2017. The supply risk score in this assessment is a result of global supply risk, different from that of the criticality assessment 2017, which used the combination of global supply risk and EU supply risk. The EU supply risk was not considered because the figure for the quantity of EU import of rhenium was incomplete.

The results of this and earlier assessments are shown in Table 128.

Table 128: Economic importance and supply risk results for rhenium in the assessments of 2011, 2014, 2017, 2020 (European Commission, 2011; European Commission, 2014; European Commission, 2017)

Assessment	2011			2014			2017			2020	
Indicator	EI	SR		EI	SR		EI	SR		EI	SR
Rhenium	7.7	0.8		4.5	0.8		2.0	1.0		1.98	0.45

25.6Data sources

There is no reliable statistics on rhenium products imports and exports. Estimates were supplied by the industry.

25.6.1Data sources used in the factsheet

Airbus (2018). Airbus Global Market Forecast 2018-2037. [online] Available at: https://www.airbus.com/aircraft/market/global-market-forecast.html

Audétat, A. , Li, W. (2017). Review The genesis of Climax-type porphyry Mo deposits: Insights from fluid inclusions and melt inclusions. Ore Geology Reviews, Vol. 88, pp. 436–460.

Audion A.S., Martel-Jantin B. (2011). Panorama mondial 2010 du marché du rhénium. Rapport final. BRGM/RP-60205-FR, 76 p.

Bartlett, S.C., Burgess, Harry, Damjanović, Bogdan, Gowans, R.M., and Lattanzi, C.R., (2013). Technical report on the copper-silver production operations of KGHM Polska Miedź S.A. in the Legnica-Glogów copper belt area of southwestern Poland, NI 43–101 technical report, prepared for KGHM Polska Miedź S.A.: Toronto, Ontario, Canada, Micon International Ltd., 159 p. [online] Available at: https://kghm.com/en/technical-report-copper-silver-production-operations-kghm-polska-miedz-sa-legnica-glogow-copper-belt

Babo, J., Spandler, C., Oliver, Nick H.S., Brown, M., Rubenach, M J., Creaser, R A. (2017) The high-grade Mo-Re Merlin deposit, Cloncurry District, Australia: paragenesis and geochronology of hydrothermal alteration and ore formation. Economic Geology, 112. pp. 397-422.

Eurometaux (2020). Personal communication during CRM review process.

European Commission (2019). Free trade agreements. [online] Available at: https://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/

Eurostat (2019). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2019b). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

Heraeus Precious Metals (undated). Rhenium – a valuable and rare element. [online] Available at: https://www.heraeus.com/en/hpm/hmp_products_solutions/rhenium/rhenium.html

John, D.A., Seal, R.R., II, and Polyak, D.E., 2017, Rhenium, chap. P of Schulz, K.J., DeYoung, J.H., Jr., Seal, R.R., II, and Bradley, D.C., eds., Critical mineral resources of the United States—Economic and environmental geology and prospects for future supply: U.S. Geological

Survey Professional Paper 1802, p. P1–P49, [online] Available at: https://doi.org/10.3133/pp1802P

Keith, S. B., Spieth, V., & Rasmussen, J. C. (2018). Zechstein-Kupferschiefer Mineralization Reconsidered as a Product of Ultra-Deep Hydrothermal, Mud-Brine Volcanism. In *Contributions to Mineralization*. InTech. https://doi.org/10.5772/intechopen.72560

Lefebvre, G., Cuesta-López, G.S., Barros García, R., Arragonés, M.M., González Moya, M., Monge, Q. and Maund, N. (2016). Report on balance between demand and supply of refractory metals in the EU. MSP-REFRAM, Ref. Ares(2016)7113944 - 21/12/2016. [online] Available at: https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5af1b6fc5&appId=PPGMS

Millensifer, T.A., Sinclair, D., Jonasson, I., Lipmann, A. (2014). Rhenium, pp. 579-614, in Gunn, G (Ed) (2014) Critical Metals Handbook John Wiley & Sons Ltd, Chichester, UK.

Minerals4EU (2019). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

MMTA (2016) Rhenium. [online] Available at: https://mmta.co.uk/metals/re/

Mottura, A. and Reed, R.C.(2014). What is the role of rhenium in single crystal superalloys? MATEC Web of Conferences, Vol. 14, Eurosuperalloys 2014 – 2nd European Symposium on Superalloys and their Applications. [online] Available at: https://doi.org/10.1051/matecconf/2014140100110.1051/matecconf/20141401001

Polyak, D. E. (2019). Mineral Commodity Summaries. Rhenium. [online] Available at: https://www.usgs.gov/centers/nmic/rhenium-statistics-and-information

Pratt & Whitney (2018). Rhenium-the last 10 years. [online] Available at: https://www.safeport-funds.com/Portal/UserFiles/files/Pratt_&_Whitney_PPT.pdf

Prometia (2017). Towards a strong and sustainable European refractory metals supply-chain. MSP-REFRAM final Report. [online] Available at: http://prometia.eu/wp-content/uploads/2014/02/MSP-REFRAM-FINAL-REPORT-WEB.pdf

OECD (2016). OECD Export restrictions on Industrial Raw Materials. [online] Available at: http://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

REACH Metals (2017). Rhenium [Re]. [online] Available at: https://www.reach-metals.eu/uploads/pdf/consortium/PMC%20inventory_Rhenium_150604_171207.pdf

Roskill (2015). Rhenium - Global Industry, Markets & Outlook. Report brochure. [online] Available at: https://roskill.com/market-report/rhenium/

Rudnick R. L. and Gao S., (2003). Composition of the Continental Crust. Treatise On Geochemistry. Heinrich D. Holland and Karl K. Turekian(ed), Vol. 3. pp. 1–64.

Śmieszek,Z., Czernecki, J., Sak, T., Madej, P. (2017) Metallurgy of non-ferrous metals in Poland. Journal of Chemical Technology and Metallurgy, Vol. 52, N°2. pp. 221-234. [online] Available at: https://dl.uctm.edu/journal/node/j2017-2/10-16_102_Smieszek_221_234.pdf

Sinclair, W.D., 2007, Porphyry deposits, in Goodfellow, W.D., ed., Mineral Deposits of Canada: A Synthesis of Major Deposit-Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods: Geological Association of Canada, Mineral Deposits Division, Special Publication No. 5, p. 223-243.

Tantalum-Niobium International Study Center (T.I.C). Bulletin No 167, October 2016. [online] Available at: https://www.tanb.org/images/T_I_C__Bulletin_no_167_(October_2016).pdf

Toma Group (2012). Tungsten-molybdenum-rhenium, complex special alloys. [online] Available at: http://toma-group.com/portfolio-view/tungsten-molybdenum-rhenium/

UNEP, 2011b. International Resource Panel, 2011, Recycling Rates of Metals, a Status Report.

USGS (2019). Mineral Commodity Summaries. [online] Available at: https://www.usgs.gov/centers/nmic/mineral-commodity-summaries

25.6.2 Data sources used in the criticality assessment

EC (2017). Study on the review of the list of Critical Raw Materials - Critical Raw Materials Factsheets & Non-critical Raw Materials Factsheets.

Eurostat (2019). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2019b). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

Eurostat (2019c). Contribution of recycled materials to raw materials demand- End-of-life recycling input rates (EOL-RIR). [online] Available at: https://ec.europa.eu/eurostat/databrowser/view/cei_srm010/default/table?lang=en

MMTA (2016) Rhenium https://mmta.co.uk/metals/re/

OECD (2016). OECD Export restrictions on Industrial Raw Materials. [online] Available at: http://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

??? Deliverable 1.5 MSP Refram European Funded Project, 2016

Queensland Government (2017). Emerging strategic minerals in Queensland (July 2017). [online] Available at: www.dnrm.qld.gov.au

World Mining Data (2018). [online] Available at: https://www.world-mining-data.info/wmd/downloads/PDF/WMD2018.pdf

Other : general knowledge etc., no source readily available

25.7Acknowledgments

This factsheet was prepared by the JRC in collaboration with the French Geological Survey (BRGM). The authors would like to thank the Ad Hoc Working Group on Critical Raw Materials, as well as experts participating in SCRREEN workshops for their valuable contribution and feedback.

26. SAPELE WOOD

26.1 Overview

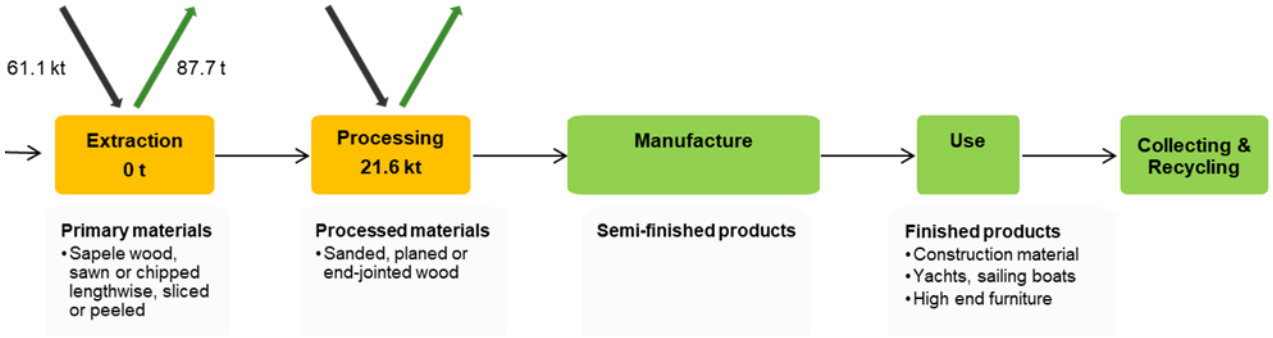


Figure 228: Simplified value chain for Sapele wood (2012-2016)(Eurostat, 2019)

The sapele is a long-lived and slow-growing tree, originally from the forests of west and central Africa ("Wood-database 2019 - Sapele"). Sapele wood was first assessed fro criticality in 2017. For the purpose of this assessment, sapele wood is considered to be represented by HS/CN trade codes 4407 2710, 4407 2791 and 4407 2799.

The average world market of sapele wood between 2013 and 2017 was estimated to be about 220t worth USD 200 to 300 million, . It is not traded on any centralised exchange, so prices come from publicly reported over-the-counter transactions.

As for most tropical wood applications, material substitutes exist, like utile, sipo or khaya. The material and/or related products are not explicitly mentioned in the document.

World resources, expressed in annual production capacity, are estimated at about 40 mega tonnes. There are no reserves of sapele wood in the EU as there is no geophysical space that would allow cultivation of sapele forest on an economic scale..

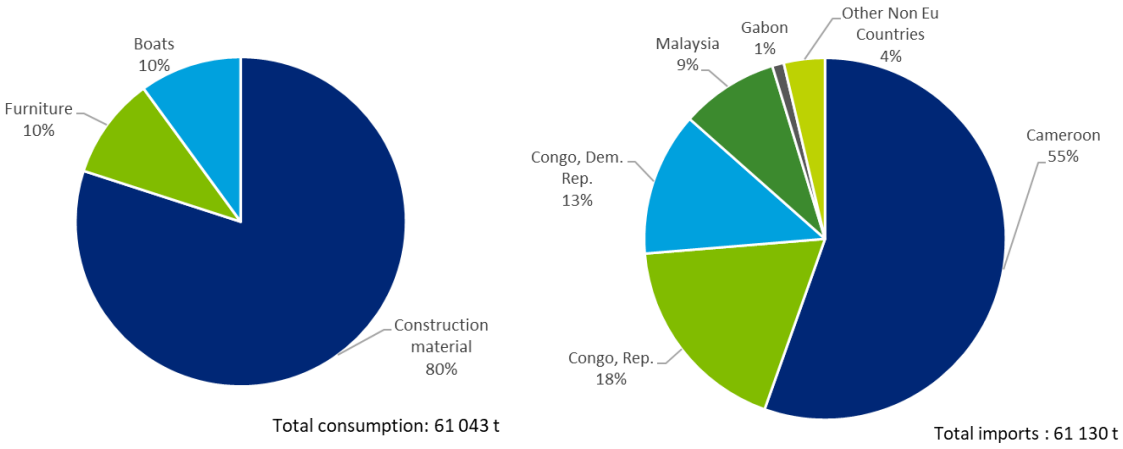


Figure 229: Main uses of sapele wood (left) and EU sourcing of Sapele wood, average 2012 to 2016(Eurostat, 2019)

The world annual production of sapele wood was estimated to be about 220 tonnes (between 2012 to 2017), based on international trade volumes and auxiliary data. According to metadata, the flows of wood are expressed in roundwood equivalent cubic meters (green) with a moisture content between 12 and 15%. The economic possible substitution rate of sapele wood is high, for all applications, several other woods are available that have similar properties, which greatly contributes to the fact that the material is not assessed as critical.

Sapele wood is not recycled from end finished products, but sapele wood components can be refurbished.

Sapele wood is commonly used in the EU in the shape of veneer or plywood, for applications such as flooring, boatbuilding and furniture.

26.2Market analysis, trade and prices

26.2.1Global market analysis and outlook

The market outlook forecast for world Sapele wood demand is assumed to be stable (FSC 2019). According to (Meier 2016) the demand for sapele wood product might on a longer term, increase for the next 10 years, as well as for the supply (seeTable 129). Forecast on 20 years could be based on a continuation of this trend.

Depressing markets in Japan are offset by emerging markets in other parts of Asia. It is therefore uncertain if supply and demand will rise or fall in the long term. Given persistent problems with sustainable supply of sapele wood, the trend in sapele use will be determined by the extent in which responsible sourcing is adopted and enforced by regulation.

Table 129: Qualitative forecast of supply and demand of sapele wood

Materials	Criticality of the material in 2017		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Sapele wood		x	+	+	+	+	+	+

26.2.2EU trade

Europe imports 100% of sapele wood (about 61,1 kt per year). The forms of sapele wood that are imported vary for instance between logs and other pieces of wood that are end-jointed, sliced, peeled, planed or sanded.

The trend since 2010 of EU imports of sapele wood is slowly but consistently downward. This is an illustration of the interchangeable use of tropical wood i.e. the economic substitution options at hand when considering tropical timber. The EU imports have reduced from 31 kt in 2013 to 17 kt in 2017.

The main suppliers of the EU are Cameroon (57%) and Congo (Brazzaville) (13%), see Figure 230, average between 2013 to 2017.

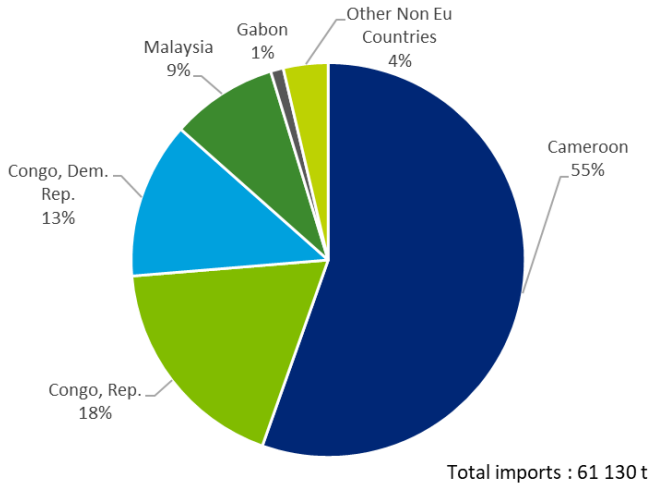


Figure 230: EU imports of sapele wood (Eurostat 2019b)

Highly reliable data sources on world production are not available. The origin of EU-28 imports and The International Tropical Timber Organization (ITTO) based information can however give: 1) information about trading partners, but also about sourcing countries, since extensive re-trading is not assumed to be significant (ITTO 2018).

No free trade agreements exist at this time between the EU or Cameroon or other sapele wood sourcing countries (European Commission 2019). There were no exports taxes, quotas or prohibition related to sapele wood (OECD 2019).

26.2.3Prices and price volatility

On average, prices of sapele seem to be between 400 and 2000 EUR per m^3 in the EU. Sapele wood is not traded on any centralised exchange, so reported prices come from publicly reported over-the-counter transactions.

Since 2013, European importers noted that reduced supplies and higher demand had led to rising export prices of several species of African wood, including: Framire, Iroko and Sipo until the second quarter of 2016. The prices of sapele and Wawa remained stable at relatively high levels (ITTO 2018).

The demand for tropical wood in general seems to be associated with a relatively high price elasticity. The gap between suppliers' export prices and depressed Asia's domestic market prices have limited Asian buyers' commitments to future purchasing, suggesting that imports from 2015 are likely to decline (ITTO 2018).

26.3EU demand

The world global market of sapele wood was estimated to be about 220 kt, worth USD 200 to 300 million, between 2013-2017.

26.3.1EU demand and consumption

The total EU consumption of sapele wood on average between 2013 and 2017 was 61 kt, corrected for around 0.1 kt worth of re-exports to destinations outside the EU. About 80% of the sapele wood used in the EU goes into construction activities.

26.3.2Uses and end-uses of sapele wood in the EU

Sapele wood comes from a tropical tree. The botanic name is Entandrophragma Cylindricum Sprague, from the Meliaceae family. Common synonyms and equivalents are sapele, sapelli or sapeli. It is reported that sapele wood is sometimes registered as Guinea Mahogany, Swietenia, Khaya (Meier 2016) (all from the Meliaceae family), or Sipo or Kosipo (Lourmas, 2007; CIRAD, 2019), which is another type of tropical wood entirely. The wood at the heart is a golden to dark reddish brown. Colour tends to darken with age. Besides the common ribbon pattern seen on quarter sawn boards, sapele is also known for a wide variety of other figured grain patterns, such as: pommele, quilted, mottled, wavy, beeswing, and fiddleback. An adult tree is about 30-45m tall with a trunk diameter of 1-1.5m (Wood-database 2019).

Sapele wood is in the EU mainly used for construction material, as well as for furniture and boats. It is also reported that specific objects such as music instruments benefit from the use of sapele. Figure 231 presents the main uses of sapele wood in the EU.

Sapele wood works fairly well with hand and machine tools, tends to tear interlocked grain in planning, saws easily, finishes well, good gluing and nailing properties, satisfactory peeling and slicing (USDA 2019).

The calculation of economic importance is based on the use of the NACE 2-digit codes and the value added at factor cost for the identified sectors (

Table 130). The value-added data correspond to 2012-2016 figures.

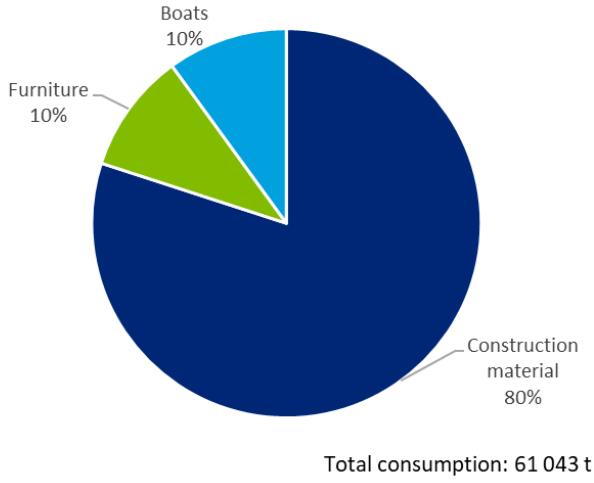


Figure 231: EU end uses of sapele wood (TNO 2019),(FSC 2019),(Lourmas et al. 2007).

The end-uses of sapele wood are mainly luxurious furniture and application related to yachting and construction materials like floors and windows.

Relevant industry sectors are described using the NACE sector codes (Eurostat 2019a).

Table 130: Sapele wood applications, 2-digit and associated 4-digit NACE sectors and value added per sector (Eurostat 2019a)

Applications	2-digit NACE sector	Value added of 2-digit NACE sector (M€)	4-digit NACE sectors
Construction material	C16 - Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	31600.8	C16.23 -Manufacture of other builders' carpentry and joinery
Yachts	C30 - Manufacture of other transport equipment	56768.5	C30.12 -Building of pleasure and sporting boats
High-end furniture	C31 - Manufacture of furniture	29806.2	C31.09 -Manufacture of other furniture

26.3.3Substitution

Tropical wood generally has interchangeable technical properties, and sapele is no exception (FSC 2019). For all applications, several other woods are available that have similar properties (FAO 2018; ITTO 2018; TNO 2019; "Wood-database 2019 - Sapele,"). Factors in deciding what wood to use are temporal availability and price of the wood, the technical performance of the alternatives for sapele wood will be virtually equal.

Alternate materials for the properties provided by sapele wood:

- Tropical timber like Framire, Iroko, Utile, Sipo or Khaya.

26.4Supply

26.4.1EU supply chain

The EU is rich with specialised businesses adding value to sapele wood. These are for instance furniture makers, artisanal wharfs building wooden sailboats. Wooden products for construction purposes are produced by larger enterprises (Eurostat 2019b). These enterprises normally take their supply from wholesale specialists in wood, a minority purchases its wood directly from an importer (Meier 2016). The EU relies 100% on imports for the supply of sapele wood.

Nigeria and Indonesia raised export prohibitions for sapele wood throughout 2013-2017. On top of that, Indonesia taxed some sapele products at 5%, and demanded a minimum export price for 2013 and 2014. Vietnam raised an export tax on sapele wood, which increased from 10 to 20% tax between 2011 and 2014, but refrained from similar measures since then.

26.4.2Supply from primary materials

26.4.2.1 Production locations of sapele wood

Geographical occurrence:

The sapele is a long-lived and slow-growing tree that plays an important ecological role in the forests of west and central Africa. It is distributed in Africa, as north western as Sierra Leone, east to Uganda and south to Angola (FAO, 2019). Sapele trees grow scattered in tropical evergreen and semi-deciduous forests. They can also be found in drier habitats, including abandoned fields (Lourmas et al. 2007). The growth rates are amongst the slowest in the genus (Hawthorne 1998), and estimated to be around 50 years.

Global resources and reserves

Reliable, public and updated information about acreage of sapele wood has not been found. It is stated that sapele trees grow in a density of 3 to 4 trees per hectare (Borota 2012).

EU resources and reserves

There are no relevant resources for sapele wood in the EU, given the absence of the economic viable geophysical conditions to grow the trees.

26.4.2.2 World and EU production

The world annual production of Sapele wood in average between 2013 and 2017 is estimated to be around 220 thousand tonnes. Although the bulk of sapele wood is likely to be grown in central west Africa, there is no source that can confirm the origin of the wood (TNO 2019). The referenced data sources are therefore assumed to be unfit to establish the size and the distribution of the world's production. The world production is estimated on an expert judgement that around 10% of the worlds sapele wood is used for final production in Europe (TNO 2019).

A proxy for major producing countries can be deduced from trade data. These indicates that major producers may be source countries such as Cameroon, Democratic Republic of Congo (Kinshasa), the Republic of Congo (Brazzaville), the Central African Republic, Ivory Coast and Gabon. It is unlikely that significant volumes of sapele wood are traded between these and neighbouring countries before officially documented in (Eurostat 2019b).

26.4.3Supply from secondary materials/recycling

26.4.3.1 Post-consumer recycling (old scrap)

The expected lifetime of sapele products is usually between 40 and 50 years. Recycling during the processing phases of wooden products is taking place on a small scale, by processing chips and sawdust into compressed wooden products that have similar properties. It is not out of the question that sapele products are re-used, both the functionality of that wood/product can never match that one of primary wood AND/OR can't replace the need for primary wood (TNO 2019).

26.4.3.2 Industrial recycling (new scrap)

Several pieces of sapele wood come available during processing, but these parts or traded as primary extracted wood, not recycled wood (TNO 2019).

26.5Other considerations

26.5.1Environmental and health and safety issues

Sapele wood is not related to any reported health problem.

This wood species is not listed in the CITES Appendices (CITES 2019), but is on the IUCN Red List (Hawthorne 1998). It is listed as vulnerable due to a population reduction of over 20% in the past three generations, caused by a decline in its natural range, and exploitation ("Wood-database 2019 - Sapele,"). Genetic erosion caused by the large-scale depletion of mature individuals from populations has taken place in some countries.

26.5.2Socio-economic issues

Sapele is commonly exported and it is considered as an economically important African wood species. It is sold both in limber and veneer forms.

While many European tropical sawn wood importers have reported uncertainty regarding the reliability of legality documentation issued by some African governments, African sawn hardwood exporters have been focusing their marketing efforts on the Middle Eastern and Asian markets where demand has been relatively steady, and buyers have had less stringent requirements than buyers in Europe (ITTO 2018).

It is important to highlight that there are infrastructure problems at African ports which reduces exports from Cameroon and other countries since 2015.

26.6Comparison with previous EU assessments

The assessment has been done using the same revised methodology as used in the assessment for the CRM list 2017. Sapele wood was being assessed for the first time in 2017 with the EI and SR results presented in the following table. Sapele wood was not assessed in 2011 or in 2014, therefore, it is only possible to make a comparison with the previous assessment.

The results of this and earlier assessments are shown inTable 131.

Table 131: Economic importance and supply risk results for sapele wood in the assessments of 2011, 2014, 2017 and 2020 (European Commission 2011, European Commission 2014, European Commission 2017)

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Natural rubber	N/A	N/A	N/A	N/A	1.3	1.4	1.41	2.27

The economic importance of Sapele wood has increased slightly in 2020 due to changes in the added value of the Nace 2 sectors compared to the 2017 assessment. The supply risk has

strongly increased to 2.27 in 2020, from 1.4 in 2017. This is due to the fact that Gabon and Ivory Coast seem to have stopped exports to Europe due to economic reasons.

26.7 Data sources

The first three out of four CN codes used for this assessment are 4407 2710, 4407 2791 and 4407 2799. They are all named "Sapelli" and are discerned in case the wood is end-jointed, planed or sanded or none of those. This offers a better assessment position compared to natural teak wood, that is put in a heterogeneous trade product group. Sapele products can still be regarded as non-processed goods (TNO 2019). The last product group 4403 4910, only lists wood in the rough.

Apart from the trade data, other sources of data were of poor quality in general. The data used is not from an official, independent source. The total production is based on expert judgement and not allocated to countries.

26.7.1 Data sources used in the factsheet

Borota, J. (2012). Tropical forests : some African and Asian case studies of composition and structure. Elsevier.

CIRAD. (n.d.). Tropix 7. Retrieved November 5, 2019, from 2019 website: https://tropix.cirad.fr/en

CITES. (2019). Appendices | CITES. Retrieved November 5, 2019, from https://www.cites.org/eng/app/appendices.php

European Commission. (2011). Critical raw materials. Retrieved July 8, 2019, from https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission. (2014). Report on critical raw materials for the EU - Critical raw materials profiles. Retrieved from https://ec.europa.eu/docsroom/documents/11911/attachments/1/translations/en/renditions/pdf

European Commission. (2017). Study on the review of the list of critical raw materials. Non-critical raw materials factsheets. https://doi.org/10.2873/876644

European Commission. (2019). Negotiations and agreements - Trade. Retrieved July 7, 2019, from http://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/

Eurostat. (2019a). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). Retrieved July 7, 2019, from https://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

Eurostat. (2019b). Easy Comext database. Retrieved from http://epp.eurostat.ec.europa.eu/newxtweb/

FAO. (2018). Guidelines and specifications FRA 2020. Retrieved from www.fao.org/forestry

Food and Agriculture Organization of the United Nations, F. (2019). FAOSTAT. Retrieved from http://www.fao.org/statistics/en/

FSC. (2019). Species. Retrieved November 4, 2019, from https://www.lesserknowntimberspecies.com/species

Hawthorne, W. (1998). Entandrophragma cylindricum. The IUCN Red List of Threatened Species, 1932(1), 40. https://doi.org/10.2307/4107728

ITTO. (2018). Review and Assessment of the World Timber Situation | ITTO | The International Tropical Timber Organization. Retrieved November 5, 2019, from https://www.itto.int/annual_review/

Lourmas, M., Kjellberg, F., Dessard, H., Joly, H. I., & Chevallier, M. H. (2007). Reduced density due to logging and its consequences on mating system and pollen flow in the African mahogany Entandrophragma cylindricum. Heredity, 99(2), 151–160. https://doi.org/10.1038/sj.hdy.6800976

Meier, E. (2016). Mahogany Mixups: the Lowdown | The Wood Database. Retrieved November 4, 2019, from http://www.wood-database.com/wood-articles/mahogany-mixups-the-lowdown/

OECD. (2019). Export restrictions on Industrial Raw Materials. Retrieved July 5, 2019, from https://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

TNO. (2019). Expert judgement Jan de Jonge.

USDA. (2019). Forest Products Laboratory - USDA Forest Service. Retrieved November 5, 2019, from https://www.fpl.fs.fed.us/research/centers/woodanatomy/techsheets_display.php?geo_category_id=4&genus_commonname_criteria=c&sorting_rule=1a

Wood-database 2019 - Sapele. (n.d.). Retrieved from https://www.wood-database.com/sapele

26.7.2Data sources used in the criticality assessment

European Commission, (2019). Free trade agreements. [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/[Accessed May 2019]

OECD (2019). Export restrictions on Industrial Raw Materials. [online] Available at: http://qdd.oecd.org/table.aspx?Subject=ExportRestrictions_IndustrialRawMaterials [Accessed May 2019]

FSC (2019) Expert judgement.

OECD (2019). Export restrictions on Industrial Raw Materials. [online] Available at: http://qdd.oecd.org/table.aspx?Subject=ExportRestrictions_IndustrialRawMaterials [Accessed May 2019]

TNO (2019) Expert judgement Jan de Jonge.

26.8Acknowledgments

This factsheet was prepared by the JRC, in collaboration with TNO. The authors would like to thank the FSC association, Aleš Straže, and Silvia Melegari for their contribution.

27. SELENIUM

27.1 Overview

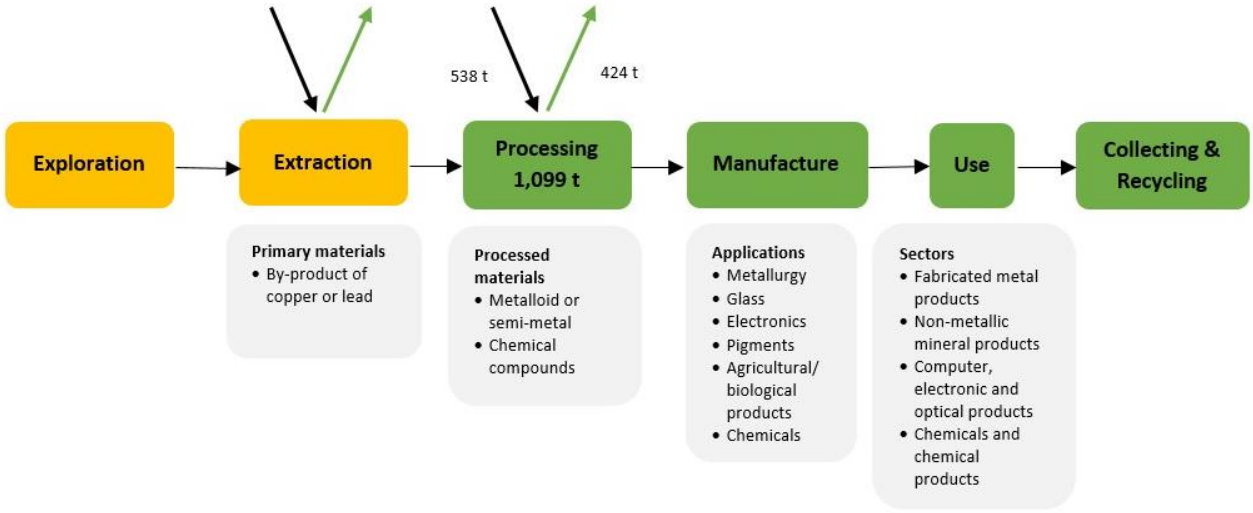
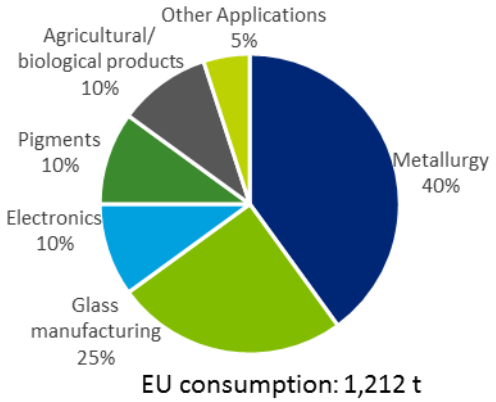
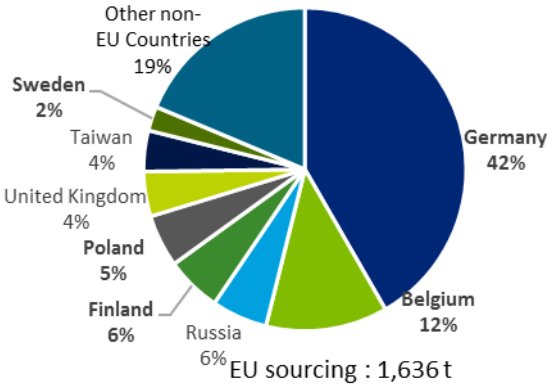


Figure 232: Simplified value chain for Selenium for the EU, average 2012-2016[151]

Selenium (chemical symbol Se) is a metalloid or semi-metal that can exist either in grey crystalline form or as a red-black powder. It has a hardness of 2.0 on Mohs scale and a melting point of 220.8°C (494 K). Selenium is photoconductive, meaning that its electrical conductivity increases when exposed to light, and photovoltaic, which means it converts light into electricity. It is rare in the Earth's crust, with an abundance of 30-90 parts per billion and inthe upper crust, its abundance is 90 parts per billion (R. ~L. Rudnick and Gao 2003). Although selenium does occasionally occur in native form, it is more commonly found in compounds that also contain base or precious metals. Approximately 90% of selenium produced in the world is obtained from the anode muds resulting from the electrolytic refining of copper, with the remainder obtained from the processing of lead ores.





[151] JRC elaboration on multiple sources (see next sections)

Figure 233: End uses (STDA 2010) (SCRREEN workshops 2019) and EU sourcing of Selenium (2012-16) (Eurostat, 2019b; WMD 2019)

For this evaluation production data by World Mining Data 2019 (WMD 2019) and Eurostat Comext data (Eurostat 2019b) were used.

WMD reports selenium production in terms of selenium content. For trade data CN8 code 28049000 "Selenium" was used. There is no differentiation regarding selenium content, or form of traded selenium, therefore, for the purpose of this assessment it has been assumed, that this code represents 100% selenium as already adopted in the previous criticality assessment.

Selenium is mainly traded in powder form with 99.9% selenium content. The average market value of the total traded selenium between 2012 and 2016 was USD 311 million per year. However, there was a significant drop during this period from USD 560 million in 2012 to USD 110 million in 2016, due to a decrease in selenium prices.
According to USGS selenium prices in 2012 were at USD 120 per kilogram and decreased by 52% to USD 48.7 per kilogram in 2015. In 2016 the prices only slightly recovered to USD 57.3 per kilogram. (OEC, 2019; USGS, 2017). According to DERA presimonitor (2020) selenium prices (average over January 2019 to December 2019) was USD 21.4 per kilogram.
The largest selenium importer was China with an average import of 30% of traded selenium (44% in 2015) followed by Hong Kong (14%) and the USA (8%). In 2016 imports by Hong Kong increased significantly from 11% in 2015 to 28% replacing China as number one importer.
There are many exporting countries with similar market shares, apart from 2016 when China became by far the largest exporter with 26%, followed by Hong Kong (13%), and Japan (10%). (OEC 2019)
The EU sources selenium mainly from domestic sources. Germany is the main supplier (42%), followed by Belgium (12%), Finland, and Poland (6% and 5%). Imports originate from Russia (6%), United Kingdom, and Taiwan (4% each) and various other countries. The average amount sourced between 2012 and 2016 was 1,636 t per year.

According to Selenium and Tellurium Developing Association (STDA) selenium is mainly used for metallurgical purposes but it is also used in glass manufacturing, electronics, pigments, agricultural/biological products and for other applications. In metallurgy selenium is used in the production of electrolytic manganese; as addition to carbon steel, stainless steel, and copper; with bismuth as a substitute for lead in brass plumbing fixtures, and as a grain refiner in the grids of lead-acid batteries. Other applications are mainly chemical manufactures.

Selenium can be substituted by silicon in low- and medium-voltage rectifiers. In order to replace cadmium sulphoselenide pigments organic pigments have been developed, moreover tellurium can replace selenium both in pigments and in rubber. In glass production selenium can be replaced by cerium oxide for example. For the production of electrolytic manganese metal sulphur dioxide can be used as well, but, it requires more energy. Bismuth, lead, and tellurium are possible substitutes in free-machining alloys. (USGS 2019)

Five EU countries produce selenium – Germany, Belgium, Finland, Poland, and Sweden. There are no reported resources in the EU. However, 19 European countries have reported copper resources and as selenium is usually produced as a by-product of copper it can be assumed that some of these resources contain selenium.
Globally the largest reserves are located in China, Russia, Peru, and the USA. In 2016 selenium reserves of about 100,000 t have been identified. (USGS 2017d)

The average world annual production of selenium in the period 2012-2016 was around 3,355 t per year, with 23% produced in China and 22,7% in Japan. The EU production of selenium was about 1,099 t per year (33% of global production) with 62% produced in Germany. (WMD 2019).

Selenium is used for the production of CIGS/CIS (copper indium gallium di-selenide) thin-film photovoltaic cells. Compared to other solar cells the production of CIGS/CIS cells consumes less semi-conducting materials and energy and therefore has a better environmental balance. (RETORTE GmbH 2019), However, thin film photovoltaic cells only account for about 4% of solar cell production. (USGS 2018a)

Selenium is vital for the human organism. Its uptake occurs mainly through food and water consumption, but also via contact with selenium containing soil or air. Despite selenium being an essential micronutrient it becomes highly toxic if the dose is too large. Exposure to high amounts is likely in areas close to hazardous waste-sites, or for people working in metal industries, selenium recovering industries, and paint industries using selenium. It can be released by coal and oil combustion and is then inhaled. Health effects include brittle hair and deformed nails, rashes, swelling and severe pains. Depending on the severity of the poisoning it can even cause death (Lenntech 2019).

27.2Market analysis, trade and prices

27.2.1Global market analysis and outlook

Between 2012 and 2016 the global selenium market value plummeted from USD 560 million to USD 110 million. This also corresponds to price development in this period. In 2017 there was a slight recovery to USD 159 million (OEC 2019).

The leading importer in this period was China with an average of 36% market share. Other large selenium consumers are Hong Kong (18%), which is increasingly gaining market shares in 2016 and 2017, and the USA (8%).

The main exporters on global level are Hong Kong (14%), Japan (12%), and China (10%). Belgium is the fifth largest exporter (OEC 2019).

The future demand and supply for selenium is presented in Table 132. Selenium demand, strongly depending on electrolytic manganese production, will likely fluctuate in the future, even though other selenium consumers, such as solar and agricultural industry, will grow, as their selenium demand is rather low compared to the manganese producing industry (USGS 2018b).

Table 132: Qualitative forecast of supply and demand of Selenium

Material	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Selenium		x	?	?	?	?	?	?

27.2.2EU trade

The trade code used for selenium in the criticality assessment was CN 2804 9000 ‘Selenium’. This code does not distinguish the particular form of selenium traded and therefore it has been

assumed that this represents 100% selenium and no adjustment has been made for selenium content of the trade flows.

The quantities of selenium imported to and exported from the EU during 2012–2016 are shown in Figure 234 (Eurostat, 2019b):

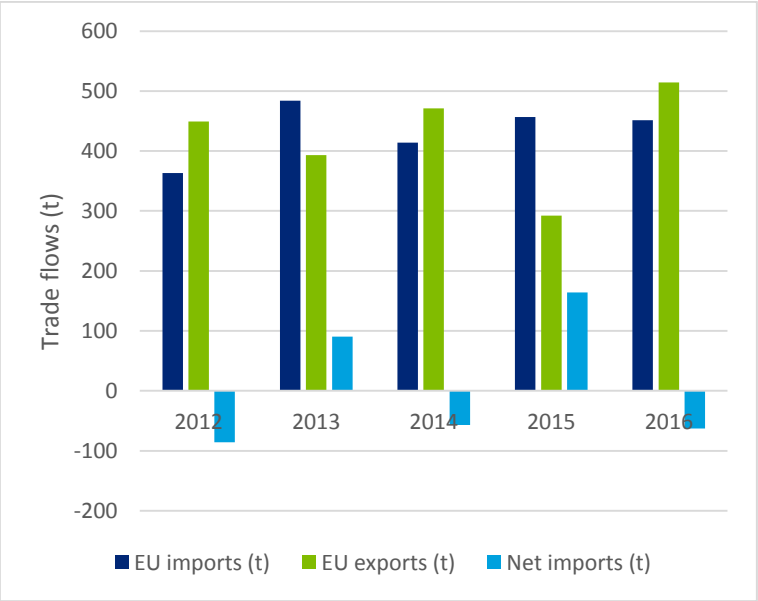


Figure 234: EU trade flows for Selenium (Eurostat, 2019b)

In the period 2012–2016, exports from the EU were similar to imports. On average 538 t of selenium were imported per year and 424 t were exported. The main suppliers for the EU are the Russian Federation (17%), United Kingdom (13%), Taiwan (12%), China (8%), Japan (8%), and Norway (8%). In 2017 there was a significant change in import and export numbers. Imports increased to 638 t whereas exports decreased to 398 t. Import numbers remained high in 2018 at 672 t and exported amounts increased again to previous levels at 578 t (Eurostat, 2019b).

No trade restrictions were reported over the 2012-2016 period (OECD 2019). Some EU free trade agreements are in place with suppliers such as Peru, Chile, Mexico, and South Korea (European Commission 2019).

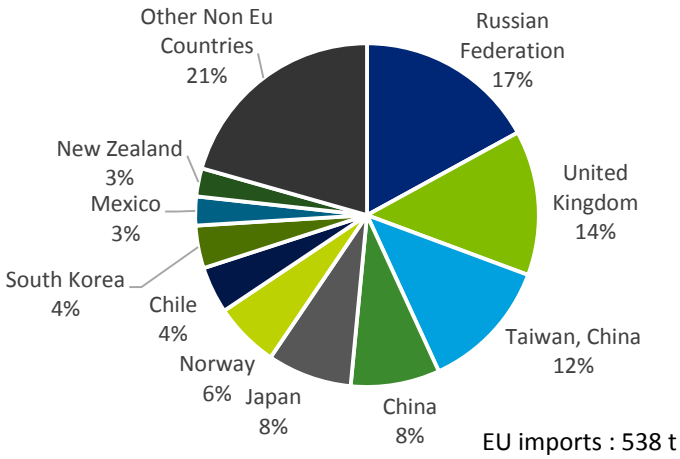


Figure 235: EU imports of Selenium, averaged 2012-2016 (Eurostat, 2019b)

27.2.3Prices and price volatility

USGS records selenium prices since 1908. The unit values for 1908-2018 converted to 1998 consumer price index are shown in Figure 236.

In 2016 prices reached USD 57.32 per kilogram on average, which represents a 7% recovery compared to 2015. This is a significantly lower level of prices than in 2012 (USD 120 per kilogram).

At the beginning of 2016, the selenium price was stable at around USD 44.09 per kilogram until midyear. In the second half of the year prices first rose to a monthly average of USD 74.96 per kilogram, and then decreased to USD 30.86 per kilogram in November and fell further to USD 18.74 per kilogram in December (USGS 2018a).

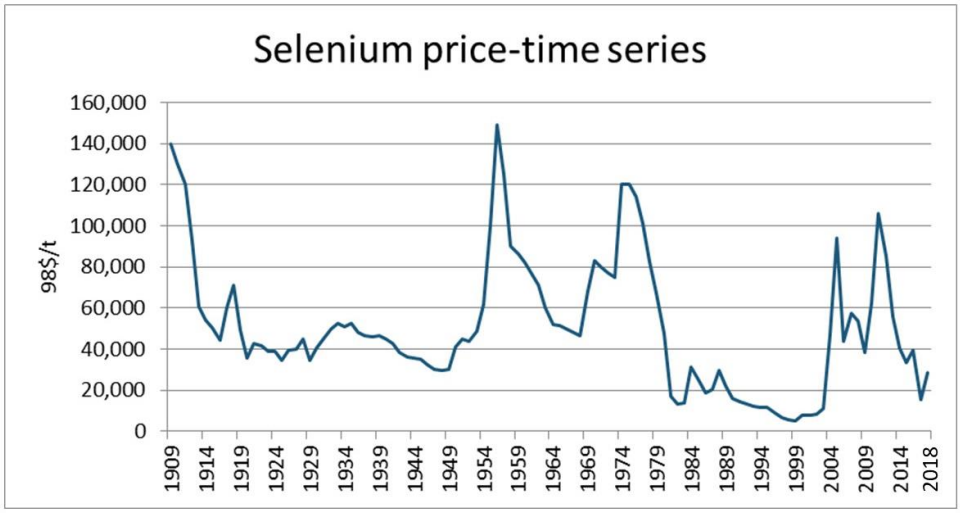


Figure 236: Price trend for Selenium based on yearly averages in USD per tonne (converted to 1998 consumer price index) from 1909-2018 (Data sourced from USGS, 2017; USGS, 2019)

In 2017 there was a significant drop of selenium prices to a yearly average of USD 23.76 per kilogram. The following year prices recovered again to USD 44.09 per kilogram (USGS 2019.

In general selenium prices show very high fluctuations. Selenium prices are also affected by market supply of copper because selenium is obtained as a by-product of copper refining. An increase in the supply of copper tends to reduce prices for selenium while a restriction in the supply of copper will generally result in increasing selenium prices.

27.3EU demand

An average of 3,355 t of selenium per year was produced by 18 countries worldwide between 2012 and 2016. This amount remained fairly constant in 2017 with 3,326 t. Selenium prices are subject to high fluctuations (see chapter 27.2.3). The overall market value decreased from USD 560 million in 2012 to USD 110 million in 2016, slightly recovering in 2017 to USD 159 million (WMD, 2019; OEC, 2019).

27.3.1EU demand and consumption

During the criticality assessment, EU consumption of selenium was calculated at 1,212 t per year, this is slightly lower than in the previous assessment with 1,366 t. Of this 675 t per year came from within the EU (calculated as EU production – exports to non-EU countries) with the remaining 537 t imported from outside the EU. Based on these figures the import reliance was calculated as 9%.

27.3.2Uses and end-uses of Selenium

Figure 237 presents the main end-uses of selenium.

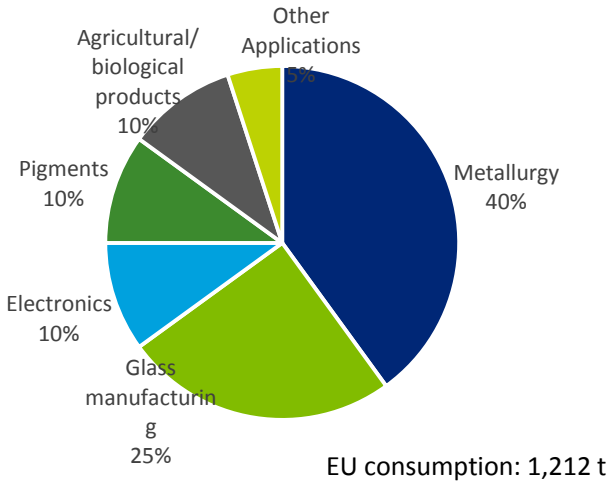


Figure 237: Global end uses of Selenium. (STDA, 2010)(SCRREEN workshops 2019)

This main end-uses of selenium can be summarised as follows (Data from Selenium Tellurium Development Association (STDA 2010):

- Metallurgy: production of electrolytic manganese (high purity manganese metal) where the addition of selenium dioxide improves energy efficiency; the addition of selenium to carbon steel, stainless steel and copper to improve their machinability; the use of selenium with bismuth as a substitute for lead in brass plumbing fixtures; and the use of selenium as a grain refiner in the grids of lead-acid batteries

- Glass manufacture: selenium is used as a decolouriser, to remove the green tint caused by iron impurities, and to produce a red colour; it also reduces solar heat transmission through glass
- Electronics: selenium is used in rectifiers (devices that convert alternating current (AC) into direct current (DC)); in voltage surge protection devices; high purity selenium and selenium alloys as the photoreceptor in photocopiers and laser printers; and in photovoltaic (solar) cells particularly the thin-film CIGS cells (copper indium gallium selenide)
- Pigments: selenium-containing pigments have good heat stability and are resistant to ultraviolet light or chemical exposure; they are used to impart red, orange or maroon colours to plastics, ceramics, glazes and paints
- Agricultural/biological products: Because selenium is an essential nutrient for animal and human health, it is also used as a food additive or applied with fertiliser to grassland for grazing animals if the soil is selenium-poor. Selenium is also available as a dietary supplement, and can be used as a fungicide to control dermatitis
- Other applications: selenium used as a catalyst for selective oxidation; in plastic caps; as a plating alloy to improve appearance and durability; gun bluing; and in a compound used to improve the abrasion resistance in vulcanised rubbers

STDA data is from 2010; however, USGS still reports the same global consumption patterns in their Mineral Commodity Summaries 2019. Unfortunately, no data on consumption patterns for the EU is available.

Relevant industry sectors are described in Table 133.

Table 133: Selenium applications, 2-digit and examples of associated 4-digit NACE sectors, and the value added of those sectors (Eurostat 2019a)

Applications	2-digit NACE sector	Value added of NACE 2 sector (millions €)	Examples of 4-digit NACE sector(s)
Metallurgy	C25 – Manufacture of fabricated metal products, except machinery and equipment	148,351	C2511 – Manufacture of metal structures and parts of structures; C2599 – Manufacture of other fabricated metal products n.e.c.
Glass manufacturing	C23 – Manufacture of other non-metallic mineral products	57,255	C2311 – Manufacture of flat glass; C2313 – Manufacture of hollow glass; C2319 – Manufacture and processing of other glass, including technical glassware
Electronics	C26 – Manufacture of computer, electronic and optical products	65,703	C2611 – Manufacture of electronic components; C2660 – Manufacture of irradiation, electromedical and electrotherapeutic equipment; C2670 – Manufacture of optical instruments and photographic equipment
Pigments	C20 – Manufacture of chemicals and chemical products	105,514	C2012 – Manufacture of dyes and pigments
Agricultural / biological products	C20 – Manufacture of chemicals and chemical products	105,514	C2015 – Manufacture of fertilisers and nitrogen compounds; C2110 Manufacture of basic pharmaceutical

Applications	2-digit NACE sector	Value added of NACE 2 sector (millions €)	Examples of 4-digit NACE sector(s)
			products
Chemical manufacture	C20 – Manufacture of chemicals and chemical products	105,514	C2059 – Manufacture of other chemical products n.e.c.

27.3.3Substitution

For the metallurgy category, bismuth, lead, and tellurium can substitute selenium to improve the machinability of alloys, and sulphur dioxide can be used in the electrolytic production of manganese. Costs and performance are considered to be similar with the exception of tellurium, which is more expensive.

There is a very large number of possible additives that can be used in glass manufacture. Cerium oxide and manganese have been identified as possible alternatives for decolourising glass, while gold chloride and copper-in will add red colouration to glass. All will provide similar performance to selenium but gold chloride is considerably more expensive.

In electronics, organic photoreceptors in photocopies and printers are frequently substituting selenium and the latter are in significant decline. Silicon is a major alternative to selenium in many electronic applications, especially solar cells and in rectifiers. Cadmium telluride is a potential substitute for CIGS in thin film photovoltaic solar cells.

With regards to pigments, mercury was once a suitable substitute for selenium but has largely been phased out in recent years for environmental protection reasons. Organic pigments are a potential substitute for selenium in pigments but the performance is reduced.

There are no substitutes for selenium in the agricultural or biological applications because selenium is an essential nutrient. No substitutes were considered for the chemical applications because less than 10% of selenium production is used in this category (USGS 2019) (SCRREEN workshops 2019).

27.4Supply

27.4.1EU supply chain

Reported EU selenium production over 2012–2016 is around 1,100 t per year (WMD, 2019), or 33% of the average annual global production. Imports to the EU from the rest of the world were about 538 t per year, while total exports (i.e. from both producing and non-producing countries) were approx. 424 t per year (again both averaged over the 2012–2016 period).

The United States Geological Survey (USGS 2018b) reported a total worldwide refinery selenium production, averaged over 2012 and 2016, of 2,305 t per year. Within the EU, average refined production of 1,068 t per year is reported in Belgium, Finland, Germany, Poland and Sweden, for a total of 47% of the worldwide refined production.

Selenium is also produced as a by-product in copper refineries of Boliden at Rönnskär in Sweden, Harjavalta in Finland (Boliden 2019) and in Poland. The black powder is used in pharmaceuticals, for soil improvement, paint manufacturing, staining and detaining, and in the steel industry. The source material for the copper refineries is partly from Boliden's own mines in Scandinavia and partly from non-EU sources.

Aurubis operates three copper smelters/refineries in Europe: Hamburg, Germany; Olen, Belgium; and Pirdop, Bulgaria. Aurubis reports that they recover by-product metals, including selenium, from copper smelting operations but it is not stated whether this occurs at all three smelters. The copper concentrates for these operations are sourced primarily outside the EU. Retorte, a subsidiary of Aurubis located in Rothenbach a.d. Pegnitz, Germany, specialises in refining selenium into a wide range of products including high purity selenium and alloys, powder and pellets, chemicals, animal feed additives and pharmaceuticals.

KGHM recover selenium with a purity of 99.40% from refining copper at its Głogów Copper Smelter/Refinery in Poland. KGHM operates three copper mines in Poland, one in Canada, two in the USA and one in Chile. After processing, the selenium is used in the glass, fodder, pharmaceutical, and cosmetics industries.

27.4.2Supply from primary materials

27.4.2.1 Geology, resources and reserves of Selenium

Geological occurrence: Selenium is relatively rare in the earth's crust with an average abundance of only 30–90 parts per billion (ppb) in the uppercrust (R. L. Rudnick and Gao 2003). It is also widely distributed meaning it is unlikely to be sufficiently concentrated to allow economic extraction in its own right and consequently selenium is only extracted as a by-product, usually of copper, but also of lead or occasionally nickel. Although it does rarely occur as a native material, it is most commonly found in compounds with base or precious metals which are classified as selenides or sulphoselenides (a number of other compounds also exist). Selenium tends to replace the element sulphur in its compounds and can occur in a relatively large number of the sulphur mineral albeit in very small quantities.

Selenium is a chalcophile element, meaning it preferentially combines with sulphur rather than oxygen, but it can be readily separated from sulphur because it has a lower oxidation potential. It can occur in a wide range of different deposit types including (based on Luttrell, 1959):

- Hydrothermal base metal sulphide deposits
- Disseminated porphyry copper deposits
- Vein and replacement copper deposits
- Volcanic-hosted massive sulphide deposits
- Copper-lead sulphide veins
- Epithermal silver-gold veins
- Mercury-antimony deposits
- Sandstone-type uranium-vanadium deposits
- Sedimentary deposits, including coals, volcanic tuffs, phosphates and some shales

Selenium derived from these deposits can also be concentrated in soils or vegetation.

Global resources and reserves[152]*:* Reserves for selenium are based on identified copper deposits and average selenium content. Coal generally contains between 500 and 1,200 ppb of

[152] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of selenium in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible

selenium, or about 80 to 90 times the average of copper deposits. The recovery of selenium from coal fly ash, although technically feasible, does not appear likely to be economical in the foreseeable future. (USGS 2018b)

Table 134: Global reserves of Selenium in year 2016 (USGS, 2018b)

Country	Selenium Reserves (t)	Selenium Reserves (%)
China	26,000	26
Russia	20,000	20
Peru	13,000	13
United States	10,000	10
Canada	6,000	6
Poland	3,000	3
Other Countries*	21,000	21
World total (rounded)	99,000	

*Other countries includes India, Serbia and Sweden

Considering reserves reported in 2018 there were no changes to the numbers and reserves are still estimated 99,000 t. (USGS 2019)

EU resources and reserves [153] *:* During the Minerals4EU (2019) project, no selenium resources were reported by any of the 40 European countries surveyed, irrespective of the different international or national systems of reporting used. However, resources may exist in countries that did not respond to the survey. Copper resources are known to exist in at least 19 European countries and it is highly likely that some of these deposits will contain selenium, but it is not included in reported resources because it is a by-product. There were two active exploration licences reported for Slovakia investigating resources of precious metals with various by-products including Selenium.

None of the 40 European countries surveyed reported selenium reserves, but reserves may exist in countries that did not respond to the survey. Nine European countries reported reserves of copper (Minerals4EU, 2019).

27.4.2.2 World and EU primary production

Total worldwide production of Selenium, averaged over 2012–2016, amounted to 3,355 t per year and the largest producers are China, Japan, and Germany. The segment for 'other

by application of the CRIRSCO template.[152], which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

[153] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for selenium. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for selenium, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for selenium the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019).Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However a very solid estimation can be done by experts.

countries' includes Chile, Uzbekistan, India, Serbia and Armenia. This amount remained fairly constant also in 2017 with 3,326 t.

Between 2012 and 2016, an average of 1,099 t of Selenium was produced in Europe per year, 35% of global production. The largest producer in Europe is Germany, which produces around 57% of the total EU production and 20% of the global production.

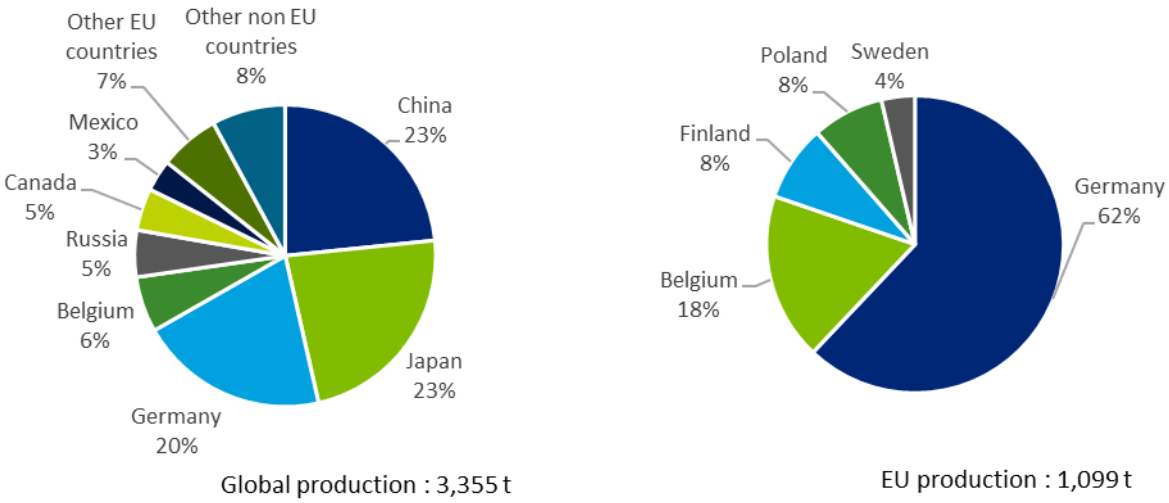


Figure 238: Global and EU primary production of Selenium in t and percentage. Average for the years 2012-2016. (WMD, 2019)

More than 90% of global selenium production is won as a by-product from electrolytic refining of copper. To reach this stage the copper, and its associated by-products including selenium, undergo a number of processing stages. These include traditional mining techniques (either underground or from surface mines), crushing and grinding, froth flotation, roasting, smelting, and the conversion of matte to copper blister. At each stage a proportion of selenium is lost in tailings or residues (Kavlak and Graedel 2013).

Electrolytic refining uses slabs of copper blister as anodes and pure copper as cathodes immersed in an electrolyte. An electrical current is passed through the electrolyte and as the anodes dissolve, copper atoms transfer to the cathodes. Selenium is insoluble during this process and settles at the bottom of the electrolytic cell into what is known as 'anode slimes' or muds. These slimes can subsequently be treated to recover selenium and/or other metals such as silver, gold, or platinum group metals.

Selenium content in these anode slimes has been reported as ranging from 0.4% to 19% (Moats, M. et al 2007). The selenium is recovered from these slimes using a number of available roasting methods followed by grinding and leaching, separation using scrubbers or filters, or vaporisation and precipitation (Willig 2014). Exact processes will depend on the individual composition of the anode slimes and details are not normally published because they contain proprietary information.

Selenium can also be recovered from sludge arising in sulphuric acid plants where base metal ores are roasted, and from electrostatic dust precipitators in copper or lead smelters (Willig 2014).

(Kavlak and Graedel 2013) reported that the recovery rate during the initial concentration is as low as 10%, during the smelting and converting stages the recovery is 50%, and during the treatment of anode slimes as much as 90% of the available selenium is recovered. This is a

reflection of the degree of attention focused on selenium at each stage. During the initial concentration phases, the focus lies on recovering copper or other base metals which are more economically rewarding due to the larger quantities available. In contrast, where recovery of selenium from anode slimes is carried out the equipment used is optimised to ensure the highest possible recovery rate of selenium as this has become the focus.

Once recovered, selenium normally needs to be refined further to obtain the high purity levels needed for many applications. These refining methods may involve selective precipitation; selective leaching and recrystallisation; or oxide, hydride or chloride purification (Willig 2014).

27.4.3Supply from secondary materials/recycling

Many of the end uses of selenium are dissipative, meaning that very little material becomes available for recycling. Selenium contents in glass and metallic alloys are too small to be accounted for during recycling processes and selenium-containing scrap from these sources are not normally segregated from other scrap metal or glass with the result that the selenium is further dispersed rather than concentrated. Selenium used in pigments, chemicals, agricultural and biological products are dissipated in the environment and not recovered (George, M.W. and Wagner 2004).

Electronic products are, therefore, the only secondary source currently available for selenium. The use of selenium in photoreceptors or rectifiers has been declining for some time as selenium-containing compounds are substituted by organic photoreceptors or cheaper silicon-based rectifiers (George, M.W. and Wagner 2004). As a consequence, the availability of material for the recycling of selenium from these products is very minor (personal communication from industry sources). One potential source for recycled selenium are a type of photovoltaic cells known as CIGS (copper indium gallium selenide) but as this is a relatively new technology the quantities of these cells that have reached their end-of-life is still quite small. However, in the longer term supplies of recycled selenium from this source could increase if the use of this type of solar cells increases.

The quantities involved with both types of scrap are very small (personal communication from industry sources). The UNEP report quotes recycled content, which represents the 'old scrap' plus 'new scrap' as a proportion of the total quantity of a material available to manufacturers (which would also include primary material). For selenium this is estimated as 1–10% (UNEP 2011).

27.4.3.1 Post-consumer recycling (old scrap)

End-of-life scrap or 'old scrap' is defined as scrap arising from products that have been used but are no longer required because they have been worn out or become obsolete.

There are many different indicators that can be used to assess the level of recycling taking place for any material. The United Nations Environment Programme (UNEP) estimated the 'end-of-life recycling rate' of selenium as <5%. This is measured as 'old scrap' sent for recycling as a proportion of 'old scrap' generated.

For this criticality assessment, a slightly different indicator was required: the end-of-life recycling input rate (EOL-RIR). This measures the quantity of end-of-life scrap (i.e. 'old scrap') contained within the total quantity of metal available to manufacturers (which would also include primary metal and 'new scrap'). For selenium, insufficient data was found to enable the

calculation of EOL-RIR but as (UNEP 2011) estimated EOL-RR as <5% and the figures quoted by George and Wagner (2004) are also very small, it was concluded that EOL-RIR must be low. Therefore a figure of 1% was used in the assessment (UNEP 2011) (SCRREEN workshops 2019).

27.4.3.2 Industrial recycling (new scrap)

Scrap and other wastes are also generated during the fabrication and manufacture of products (sometimes referred to as 'new scrap' or 'processing scrap'). For selenium ' new scrap' represents the largest source of material for recycling. (European Commission 2017)

27.5Other considerations

27.5.1Environmental and health and safety issues

Selenium is vital for the human organism. Its uptake happens mainly through food and water consumption, but also via contact with selenium containing soil or air. Despite selenium being an essential micronutrient it becomes highly toxic if the dose is too large. Exposure to high amounts is likely in areas close to hazardous waste-sites, or for people working in metal industries, selenium recovering industries, and paint industries using selenium. It can be released by coal and oil combustion and is then inhaled. Health effects include brittle hair and deformed nails, rashes, swelling and severe pains. Depending on the severity of the poisoning it can even cause death. (Lenntech 2019)

A total of four substances containing selenium have been registered with the European Chemicals Agency under the REACH Regulations as shown in Table 135.

Table 135: Substances containing Selenium registered under the REACH regulations (ECHA 2019)

Substance name	EC / List No.	Registration Type
Selenium	231-957-4	Full
Selenium dioxide	231-194-7	Full
Sodium selenite	233-267-9	Full
Silinic acid, zirconium salt, cadmium pigment-encapsulated	310-077-5	Full

27.5.2Socio-economic issues

No specific issues were identified during data collection and stakeholders consultation.

27.6Comparison with previous EU assessments

A revised methodology was introduced in the 2017 assessment of critical raw materials in Europe and both the calculations of economic importance and supply risk are now different hence the results with previous assessments are not directly comparable.

The results of this review and earlier assessments are shown in Table 136.

Although it appears that the economic importance of selenium has reduced between 2014 and 2017 this is a false impression created by the change in methodology for calculating this indicator. In the 2014 assessment, the 'megasector' selected for the glass manufacturing application was listed as "plastic" which had a value added of EUR 98,100,000 . In the 2017 assessment, the 2-digit NACE sector identified as the most appropriate for this sector was "manufacture of non-metallic mineral products" which has a lower value added of EUR 59,170,000. Similarly in the 2014 assessment, the 'megasector' selected for the electronics application was listed as simply "electronics" with a value added of 104,900 thousand Euros. In the 2017 assessment, the 2-digit NACE sector identified as the most appropriate was the more precise "Manufacture of computer, electronic and optical products" which had a value added of EUR 75,260,000. If the 'megasectors' were used instead of the 2-digit NACE sectors then the EI indicator would have been similar to 2014 rather than the decrease onserved in the 2017 assessment. This illustrates exactly why a direct comparison between this review and the previous assessments should be made with caution.

Table 136: Economic importance and supply risk results for Selenium in the assessments of 2011, 2014, 2017 (European Commission, 2011; European Commission, 2014; European Commission 2017) and 2020

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Selenium	Not assessed	Not assessed	6.91	0.19	4.5	0.4	4.9	0.41

27.7Data sources

27.7.1 Data sources used in the factsheet

Boliden (2019) By Products. Available at: http://www.boliden.com/operations/products/by-products (Accessed: 7 November 2019).

DERA (2020) Preismonitor. [online] Available at: https://www.deutsche-rohstoffagentur.de/DE/Themen/Min_rohstoffe/Produkte/Preisliste/pm_19_12.pdf?__blob=publicationFile&v=5

ECHA (2019) Registered Substances. European Chemicals Agency. Available at: https://echa.europa.eu/information-on-chemicals/registered-substances.

EJA (2019) Environmental Justice Atlas [Online]. Available at: https://ejatlas.org/ (Accessed: 5 November 2019).

European Commission (2011) Critical raw materials. Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en (Accessed: 8 July 2019).

European Commission (2014) Report on critical raw materials for the EU - Critical raw materials profiles. Available at: https://ec.europa.eu/docsroom/documents/11911/attachments/1/translations/en/renditions/pdf.

European Commission (2017) Study on the review of the list of critical raw materials. Non-critical raw materials factsheets. European Commission. doi: 10.2873/876644.

European Commission (2019) Negotiations and agreements - Trade. Available at: http://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/ (Accessed: 7 July 2019).

Eurostat (2019a) Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E) [Online]. Available at: https://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2 (Accessed: 11 September 2019).

Eurostat (2019b) Easy Comext database. Available at: http://epp.eurostat.ec.europa.eu/newxtweb/.

George, M.W. and Wagner, L. A. (2004) 'Selenium recycling in the United States in 2004, chapter T of Sibley, S.R.', Flow studies for recycling metal commodities in the United States, pp. 1–16. Available at: http://pubs.usgs.gov/circ/circ1196-Y/.

Kavlak, G. and Graedel, T. E. (2013) 'Global anthropogenic selenium cycles for 1940–2010', Resources, Conservation and Recycling, 73, pp. 17–22. doi: https://doi.org/10.1016/j.resconrec.2013.01.013.

Lenntech (2019) Periodic Table – Selenium [Online]. Available at: https://www.lenntech.com/periodic/elements/se.html (Accessed: 11 September 2019).

Luttrell, G. W. (1959) Annotated Bibliography on the Geology of Selenium. Bulletin 1019-M Contributions to Bibliography of mineral resources. United States Geological Survey. Available at: https://pubs.usgs.gov/bul/1019m/report.pdf.

Minerals4EU (2019) European Minerals Yearbook. Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html (Accessed: 9 July 2019).

Moats, M., Davenport, W., Demetrio, S., Robinson, T. and Karcas, G. (2007) 'Electrolytic copper refining 2007 world tankhouse survey. In Houlachi, G.E., Edwards, J.D. and Robinson, T.G. (Eds), Copper 2007. Vol V: Copper electrorefining and electrowinning (pp.105–242). Canadian Institute of Mining, Montreal. Figures quoted in Will'.

OEC (2019) Observatory of Economic Complexity. Available at: https://oec.world/en/profile/hs92/280490/.

OECD (2019) Export restrictions on Industrial Raw Materials. Available at: https://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials (Accessed: 5 July 2019).

RETORTE GmbH (2019) Selen – Industrielle Anwendungen. Available at: http://www.retorte.de/deutsch/selen2.html (Accessed: 12 September 2019).

Rudnick, R. ~L. and Gao, S. (2003) 'Composition of the Continental Crust', Treatise on Geochemistry, 3, p. 659. doi: 10.1016/B0-08-043751-6/03016-4.

Scoullos, M.J., Vonkeman, G.I., Thornton, I and Makuch, Z. (2001) Mercury-Cadmium-Lead: Handbook for Sustainable Heavy Metals Policy and Regulation. Available at: https://www.springer.com/us/book/9781402002243.

SCRREEN workshop (2019) 'Validation workshop on Critical Raw Materials, 10-12 September 2019, Thon Hotel Brussels City Centre'. Brussels.

STDA (2010) Sources and applications for selenium and tellurium. Selenium Tellurium Development Association. Available at: http://www.stda.org/se_te.html.

UNEP (2011) Recycling rates of Metals - A status Report, A Report of the Working Group on the Global Metal Flows to the International Resource Panel.

USGS (2017) Historical Statistics for Mineral and Material Commodities in the United States – Selenium. Available at: https://www.usgs.gov/centers/nmic/historical-statistics-mineral-and-material-commodities-united-states#selenium (Accessed: 10 September 2019).

USGS (2018a) Selenium and Tellurium, 2016 Minerals Yearbook. August 2018. United States Geological Survey. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/selenium/myb1-2016-selen.pdf.

USGS (2018b) Selenium Mineral Commodity Summary. January 2018. United States Geological Survey. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/selenium/mcs-2018-selen.pdf.

USGS (2019) Selenium Mineral Commodity Summary. January 2018. United States Geological Survey. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/selenium/mcs-2018-selen.pdf.

Willig, F. K. (2014) Selenium Recovery in Precious Metal Technology. Thesis for a Degree Project in Engineering Chemistry. Umeå University with Outotec (Sweden) AB. Available at: http://umu.diva-portal.org/smash/get/diva2:703367/FULLTEXT01.pdf.

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

27.7.2 Data sources used in the criticality assessment

BGS (2019) *World mineral statistics data*, *British Geological Survey* . Available at: https://www.bgs.ac.uk/mineralsuk/statistics/wms.cfc?method=searchWMS (Accessed: 30 July 2019).

European Commission (2017) *Study on the review of the list of critical raw materials. Non-critical raw materials factsheets.* European Commission. doi: 10.2873/876644.

European Commission (2019) *Negotiations and agreements - Trade*. Available at: http://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/ (Accessed: 7 July 2019).

Eurostat (2019b) *Easy Comext database*. Available at: http://epp.eurostat.ec.europa.eu/newxtweb/.

Fraunhofer Institute for Solar Energy Systems, I. (2017) 'Photovoltaics report'. Available at: https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf.

George, M.W. and Wagner, L. A. (2004) 'Selenium recycling in the United States in 2004, chapter T of Sibley, S.R.', *Flow studies for recycling metal commodities in the United States*, pp. 1–16. Available at: http://pubs.usgs.gov/circ/circ1196-Y/.

Hagelstein, K. (2009) 'Globally sustainable manganese metal production and use. Journal of Environmental Management 90, 3736-3740'. Available at: https://www.ncbi.nlm.nih.gov/pubmed/19467569.

OECD (2019) *Export restrictions on Industrial Raw Materials*. Available at: https://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

(Accessed: 5 July 2019).

Scoullos, M.J., Vonkeman, G.I., Thornton, I and Makuch, Z. (2001) *Mercury-Cadmium-Lead: Handbook for Sustainable Heavy Metals Policy and Regulation*. Available at: https://www.springer.com/us/book/9781402002243.

STDA (2010) *Sources and applications for selenium and tellurium. Selenium Tellurium Development Association.* Available at: http://www.stda.org/se_te.html

USGS (2016). *Mineral Commodity Summary - Selenium. http://minerals.usgs.gov/minerals/pubs/commodity/selenium/mcs-2016-selen.pdf*

UNEP (2011) *Recycling rates of Metals - A status Report, A Report of the Working Group on the Global Metal Flows to the International Resource Panel*

USGS (2019) *Selenium Mineral Commodity Summary. January 2018. United States Geological Survey.* Available at: https://minerals.usgs.gov/minerals/pubs/commodity/selenium/mcs-2018-selen.pdf.

27.8Acknowledgments

This factsheet was prepared by the JRC in collaboration with Ms. Marie-Theres Kügerl (Resources Innovation Center Leoben). The authors would like to thank the Ad Hoc Working Group on Critical Raw Materials, in particular Euromines, as well as experts participating in SCRREEN workshops for their valuable contribution and feedback.

28.SILICA SAND

28.1Overview

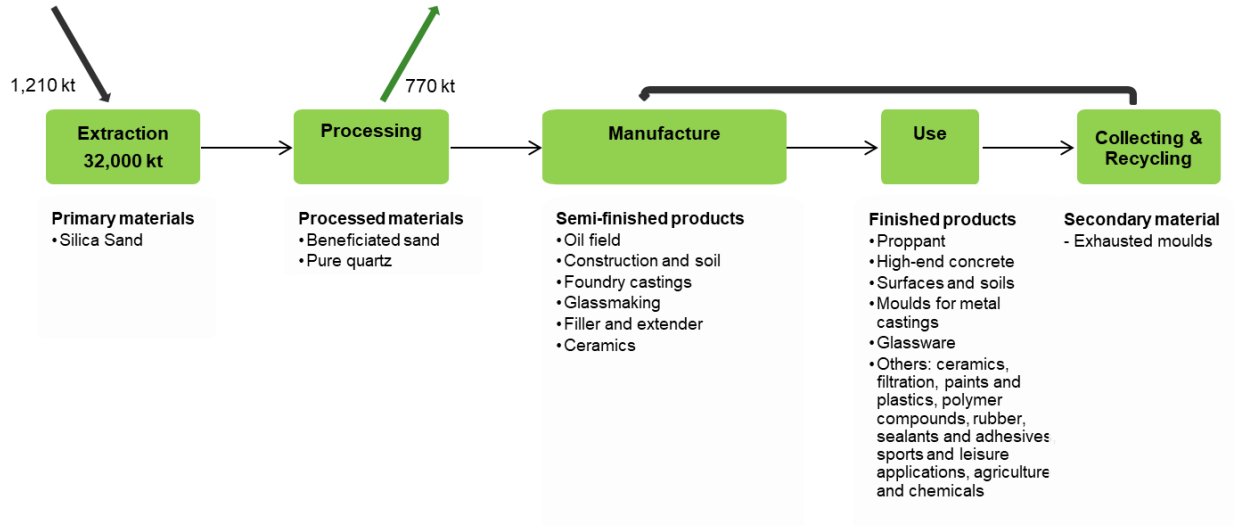


Figure 239: Simplified value chain for silica sand in the EU[154], average 2012-2016

Silica is mainly recovered from silica sand, which is mostly made up of broken down quartz crystals, and its lithified (quartzarenite) and metamorphic (quartzite) equivalents, along with

[154] JRC elaboration on multiple sources (see next sections)

microcrystalline silica (chert, flint). Silica used for industrial applications is characterised by a high content of quartz (or cristobalite) and a low amount of impurities, thus SiO_2 can be up to 99.9%. Other silica sources – diatomite, tripoli, and perlite – are not considered here. Silicon dioxide, SiO_2, also referred to as silica, has a number of crystalline and amorphous polymorphs. Quartz is one of the crystalline silica polymorphs. It is among the most common minerals in the Earth's continental crust, and silica sand is essentially made up of broken down quartz crystals. Quartz crystals consist of almost pure silicon dioxide, containing low quantities of impurities (Kogel, 2019).

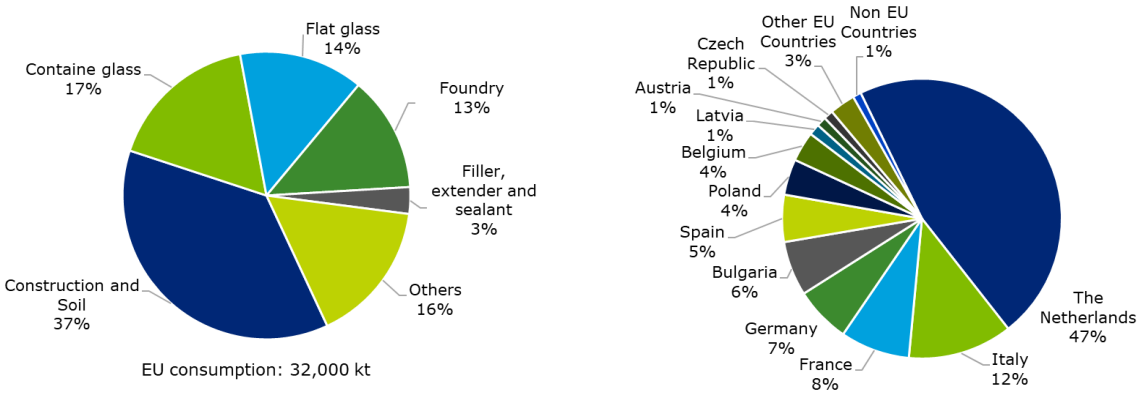


Figure 240: End uses (IMA-Europe, 2018a) and EU sourcing (USGS, 2019a-b; Eurostat, 2019) of silica sand (2012-2016).

Silica sand used for industrial applications is characterised by the high content of quartz (SiO_2) that can be up to 99.9%. For industrial purposes, silica sand with a purity of at least 95% is required. It must be noticed that sands with SiO_2 <95% are widely used as well, essentially in applications with a low value added, as in construction (e.g., ordinary concretes and mortars). Such common sands are not considered here, being not classified as "silica sand". Globally, the major applications for silica sand are in the extraction of petroleum, construction industry and for glass production. Other uses include foundry castings, ceramics, fillers and extenders. Extremely high-purity quartz is used to produce metallurgical grade silicon (see the factsheet on silicon metal) and products tailored for the optical and electronic industries (Kogel, 2019; IMA-Europe, 2018a)

In this this assessment, silica is assessed in the form of silica sand (CN8 code 250510 - silica sand and quartz sands, whether or not coloured) (Eurostat Comext, 2019). Terminology can change in the production statistics, depending on the different countries, and along with "silica sand" it includes "quartzite", "industrial sand", "quartz sand", "glass sand" or "quartz". Quantities are given as raw weight, without any reference to the SiO_2 content.

The world market of silica sand in 2018 is about 315 million tonnes worth around EUR 3,000 million, expected to keep steady by 2020. The majority of silica sand is sold on the open market and only minor amounts are traded on annual contracts. Since silica sand is not monitored (DERA raw materials price monitor) prices have been estimated to vary from 30 to 200 Euro per tonne, depending on purity and silica content (SCRREEN workshops, 2019).

The EU consumption of silica is around 32 million tonnes per year (average 2012-2016) (IMA-Europe, 2018), which are sourced through domestic production, mainly in the Netherlands, Italy, France, Germany, Bulgaria and Spain. Import accounts for less than 1% of the EU

demand and comes mainly from Tunisia and Egypt (Eurostat, 2019). EU's import reliance is <1% between 2012 and 2016.

Silica is used in a wide range of applications even if three sectors are predominant in terms of European consumption (Kogel, 2006; IMA-Europe, 2018a; European Commission, 2017b): construction and soil (36%), glass manufacture (29%), and foundry (14%). In the construction sector, silica sand is utilized to produce high-end concrete, mortar, glues, grouts, etc. as well as composite silica-resin kitchen-tops, equestrian surfaces, sport soils, silica gravel and traction sand, and asphalt. Silica sand is the major ingredient in the manufacture of different kinds of glass (flat, hollow, fiberglass) and technical glassware. In foundry, the main use is as casting moulds. Further silica applications encompass: filler in plastics, polymers and rubber; extender in paints and adhesives; ingredient of ceramics (silicate and carbides), abrasives, and refractories; filtration sands; chemicals; and in fluidized bed incinerator plants. Silica applications are different under a global perspective, since the main use is in the oil field, as proppant (USGS, 2019a; Liang, 2016).

Substitution of silica sands is not routinely pursued for unfavorable benefit/cost ratio, due to a loss of performance (particularly for glass). In other sectors, substitutes are (Kogel, 2019; USGS, 2019a-b): bauxite or kaolin (proppants); zircon or olivine (foundry); calcium carbonate, talc, wollastonite, kaolin, mica, pyrophyllite, feldspar (filler, extender and sealant). In the construction and soil field, silica can be replaced by feldspar or perlite (high-end concrete, mortar, glues, grouts, composite silica-resin kitchen-tops) or simply by low-end by-products or common sand and gravel.

Silica resources, considering raw materials with a minimum SiO_2 amount of 95%, are mostly represented by silica sand or hard rock (e.g., quartzite). They are globally widespread and present in every EU country (but the smallest ones). This picture changes significantly when the highest grades of silica are concerned, because only a limited number of deposits is able to economic supply nearly pure silica (SiO_2 >99%). Information about the SiO_2 title of silica sands is not available in the official statistics of the EU countries. Anyway, high grades of silica are produced at least in the Netherlands, Italy, France, Germany, Bulgaria, Spain, Poland, Belgium, and the Czech Republic. No data are available about reserves, that are generally indicated as "large", both globally and in the EU.

The world annual production of silica is about 315 Mt with 38% of production in the United States, averaged over 2012-2016 (WMD, 2019; USGS, 2019a; BGS, 2019). The European production of silica is around 32 Mt (IMA-Europe, 2018a); it includes sand and quartzite, along with minor shares for other forms (e.g., flint). In many applications, silica cannot be recovered after use, as in the oil field or when utilized in construction and as filler (being retained within the matrix of concrete, mortar, rubber, plastics, etc.). Silica is melted to manufature glass, while in ceramics is dissolved or incorporated in the silicate matrix. In both cases, silica is reused as part of a whole end product, but cannot be recycled as source of pure silica (IMA-Europe, 2018a).

There are no trade restrictions about industrial sand. The main concern is about the toxicity of respirable crystalline silica (quartz, cristobalite) by workers in the mining and manufacturing industries. Various aspects are regulated by the EU Directive 2017/2398 and by CLP Regulation 1278/2008 and Regulation (EC) 1272/2008 (IMA-Europe, 2018b).

28.2Market analysis, trade and prices

28.2.1Global market analysis and outlook

The global silica minerals mining market grew since 2010 (USGS, 2019). Such a growing demand was driven mainly by the glass industry, being silica the major component of glass, because of increased demand from the construction and automotive sectors, especially in developing and transition countries. However, the growing recycling rate of glass is a challenge for the global market. It led to a reduction in the demand of silica sand, as recycled glass (known as cullet) can substitute the primary raw materials. The EU is the leading region for glass recycling: 74% of the glass packaging is recovered sorting more than 25 billion glass containers a year (IMA-Europe, 2018a). On the supply side, one of the major issues is that the silica sand market is regional and market dependent. Given the high cost of transport, specific grades of silica cannot be transported over long distance but different grades of silica cannot be interchanged for different purposes. The combination of these two factors makes the regional market fairly restricted (European Commission, 2017b). Another issue that may affect the future consumption of silica minerals in some sectors is linked to regulation about the toxicity of respirable crystalline silica. All these factors make uncertain the forecast of supply and demand of silica sand.

Table 137: Qualitative forecast of supply and demand of silica sand

Material	Criticality of the material in 2017		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Silica sand		x	+/=	?	?	+	?	?

28.2.2EU trade

As mentioned before, transportation of silica sand over long distances is not affordable, so trade exchanges of silica sands are small with extra-EU countries. The Comext database recorded about 770 kt of silica sands exported on average in 2012-2016 (Eurostat, 2019). In the same period, imports provided by the Comext database amount to about 1,200 kt (Eurostat, 2019).

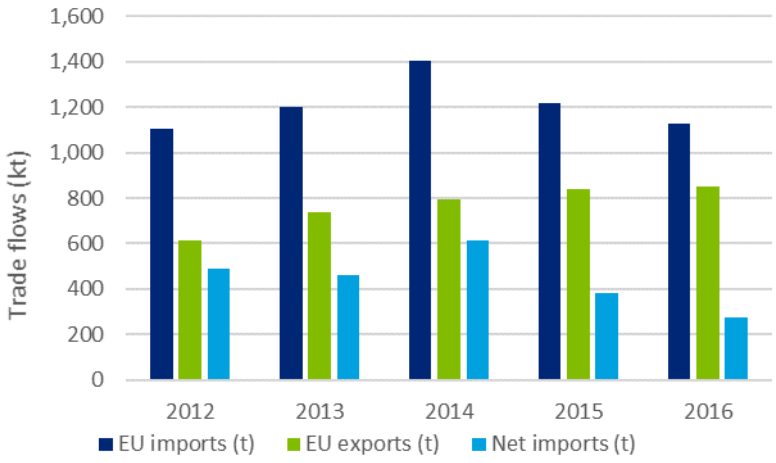


Figure 241: EU trade flows for silica sand (Eurostat, 2019).

Export of silica sand in 2012-2016 was mainly addressed to the United Kingdom (286 kt), Switzerland (142 kt), Turkey (124 kt), Norway (62 kt), and Israel (29 kt), which together account for 84% of total quantity exported from the EU (Eurostat, 2019). Import of silica sand in the same period came principally from Tunisia (487 kt), Egypt (289 kt), United Kingdom (163 kt), Serbia (40 kt), Montserrat and Dominica (51 kt), which represent together 94% of the total import to the EU.

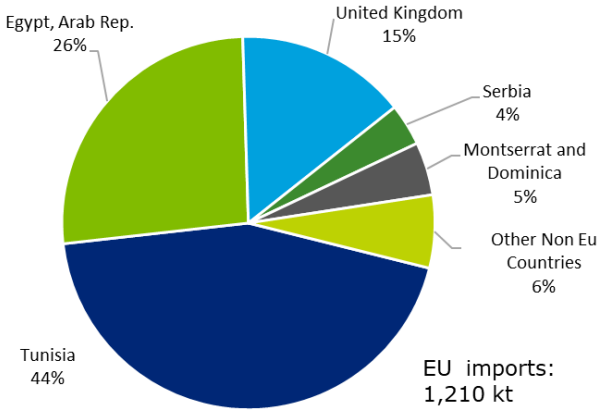


Figure 242: EU imports of silica sand, average 2012-2016 (Eurostat, 2019) (CN8 code 25051000 Silica sand and quartz sand whether or not coloured).

Tunisia and Egypt are supplying silica sand to the EU through two distinct joint ventures involving an Italian mining company. Montserrat and Dominica supply silica sand to the French *départements et région d'outre-mer* of Guadeloupe and Martinique. The import reliance of the EU regarding silica sand supply from extra-EU countries is practically zero (0.4%). The EU is totally independent from extra-EU supply for this commodity, apart some local cases.

At the time of the assessment, there are EU free trade agreements in place with Tunisia, Egypt and Serbia (European Commission, 2019). There are no exports quotas or prohibition in place between the EU and its suppliers (OECD, 2019).

28.2.3Prices and price volatility

Silica sand cost was between EUR 30 and 200 per tonne over the period 2012-2016 (SCRREEN workshops, 2019). The cost depends widely on location of the mine and delivery location. The vast majority is sold on the open market and only small amounts are traded on annual contracts.

28.3EU demand

28.3.1EU demand and consumption

Approximately 32 million tonnes of silica sand were produced and consumed in the EU on average between 2012 and 2016 (IMA-Europe, 2018a).

28.3.2Uses and end-uses of silica sand in the EU

The major end-uses of silica sand averaged over 2012-2016, both at the global and European level, are displayed in Figure 243 (Kogel, 2019; IMA-Europe, 2018a; European Commission, 2017b; USGS, 2019; Liang, 2016). Relevant industry sectors are described using the NACE sector codes (Eurostat, 2019) provided in Table 138. In Europe, there three major end users (construction and soil 36%, glass manufacture 29%, and foundry 14%) plus a plethora of different applications accounting for the remaining 18%. Worldwide, the sector with the faster growth is oil extraction, which could represent 30% of the global consumption of silica sand, followed by construction (26%), glassmaking (21%), and foundry (10%).

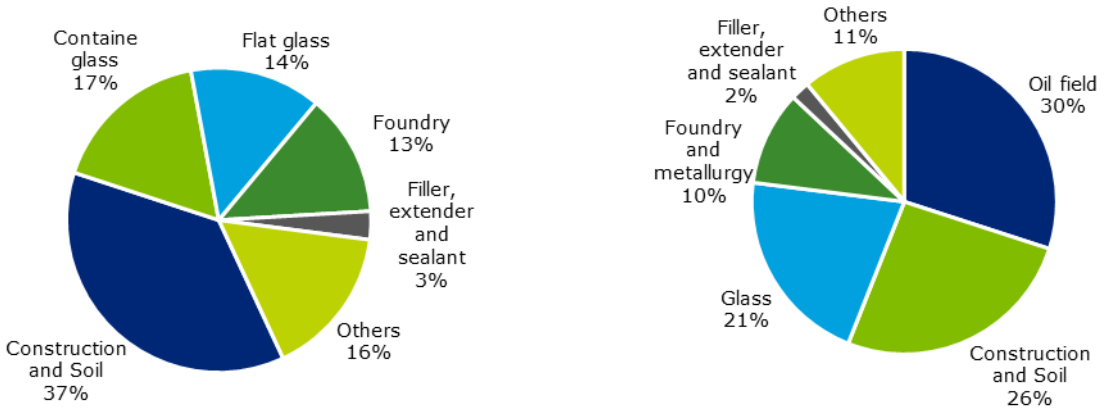


Figure 243: EU uses (left, IMA-Europe, 2018a) and global uses (right, USGS, 2019) of silica minerals (2012-2016).

- Extraction of crude petroleum: silica sand is used as proppant for hydraulic fracturing, and well packing/cementing.
- Construction sector: silica sand is utilized to produce high-end concrete, mortar, glues, grouts, etc. as well as composite silica-resin kitchen-tops, equestrian surfaces, sport soils, silica gravel and traction sand.
- Low-end by-products of silica, used for asphalt and road construction, are not considered here.
- Glass: silica sand is the major ingredient in the manufacture of different kinds of glass (flat, hollow, fiberglass) and technical glassware. Jars and containers are the main glass products followed by flat glass (windows, mirrors), tableware, glass fibre (composite reinforcing and insulation material) and special uses such as plasma screens and optical glass.
- Foundry: the main use is as casting moulds for both ferrous and non-ferrous metallurgy. Silica has a higher melting point than iron, copper and aluminium, therefore can be used at the temperatures required to melt the metals. These casts form an essential part of the engineering and manufacturing industries.
- Quartz is used for precision casting for products such as jewellery and aviation turbines.
- Further silica applications encompass: filler in plastics, polymers and rubber; extender in paints and adhesives; ingredient of ceramics (silicate and carbides), abrasives, and refractories; filtration sands; chemicals; and in fluidized bed incinerator plants.

Table 138: Silica sand applications (IMA-Europe, 2018a), 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2019)

Applications	2-digit NACE sector	Value added of NACE 2 sector (millions €)	4-digit NACE sectors
Construction and Soil	C23 - Manufacture of other non-metallic mineral products	57,255	23.61, 23.64; 20.52, 23.69; 23.99; 43.99; 42.10
Glass	C23 - Manufacture of other non-metallic mineral products	57,255	23.11, 23.13, 23.14
Foundry and metallurgy	C24 - Manufacture of basic metals	55,426	24.10, 24.5
Filler, extender and sealant	C22 - Manufacture of rubber and plastic products	75,980	22.1, 22.2, 20.3, 20.52

28.3.3Substitution

Silica sands are not routinely substituted as any potential substitute would lead to an increase of cost or a decrease of the benefit/cost ratio, due to a loss of performance. This is particularly true for glass, where silica is the major component and plays the irreplaceable function of glass network former. In other sectors, substitution may be envisaged by:
- bauxite or kaolin (as raw materials for proppants in the oil field);
- zircon or olivine (as constituents of casting moulds in foundry);
- a wide range of minerals as filler, extender and sealant (calcium carbonate, talc, wollastonite, kaolin, mica, pyrophyllite, feldspar).

Being extremely varied, the applications in the construction and soil present different chances for the substitution of silica sand. Feldspar or perlite can enter in the formulation of some high-end concrete, mortar, glues, grouts, or composite silica-resin kitchen-tops. Low-end by-products or common sand and gravel may be utilized to produce equestrian surfaces, sport soils, silica gravel and traction sand along with asphalt and road construction.

28.4Supply

28.4.1EU supply chain

Extraction, processing and transformation of silica sand into finished products are performed in the EU, apart minor cases that resort to extra-EU sources. All the life cycle and the value chain of this commodity occur in the EU. The import reliance is practically null (0.4%) and the extra-EU trade is extremely limited, due to the cost of transport.

28.4.2Supply from primary materials

Geological occurrence: Quartz makes up approximately 12% by weight of the lithosphere, making it the second most common mineral in the Earth's crust. Quartz is found in igneous, metamorphic and sedimentary rocks but it is particularly concentrated in some sedimentary types (quartz sand and the lithified counterpart quartzarenite), given its high resistance to physical and chemical weathering, and their metamorphic equivalents (quartzite). Since quartz is almost ubiquitous, deposits of silica sand and quartzite are found in all continents, even if

those able to provide industrial sand of suitable purity at affordable cost are not widespread. Quartz crystals are almost pure silicon dioxide, containing low quantities of impurities. For industrial purposes, silica sand with a purity of at least 95% is usually required. High-technology applications for quartz require extreme quality, with specific low-ppm or sub-ppm requirements for maximum concentrations of certain trace metals (European Commission, 2017b).

Global[155] and EU[156] resources and reserves*:* Silica sand is so abundant in earth that resources and reserves were not quantified at global level. The Minerals4EU project only records data on silica resources for some countries in Europe.

Table 139: Resource data for Europe compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2019)

Country	Reporting code	Quantity	Unit	Grade	Code Res. Type
Norway	None	157	Mt	quartz and quartzite	Estimated
UK	None	40,000	Mt	silica sand	Estimated
Latvia	-	18.8 2.6	? ?	moulding sand glass sand	Stock of deposits
Poland	Nat.Rep.Code	352.89	Mt	quartz sands	A+B+C1
Slovakia	none	10.662 0 0	Mt Mt Mt	foundry sands glass sands quartz	Verified Z1
Czech Republic	Nat.Rep.Code	147,412 145,040	kt kt	foundry sand glass sand	Potentially economic
Ukraine	Russian class.	38,924	kt	quartz sand	P2
Slovenia	Nat.Rep.Code	168.68	Mt	quartz sand	National
Serbia	JORC	65.63	Mt	quartz sand silicious rocks	Total
Kosovo	Nat. rep. code	13	Mt	quartzite sand	Hist. Res. Estimates
Macedonia	Yugoslavian	5,081,465	m^3	quartz	B
Albania	Nat.Rep.Code	100	million m^3	silica sands	A
Greece	USGS	75 3	Mt Mt	quartz silica sand	Indicated

[155] There is no source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of silica sand in different geographic areas of the EU or globally. USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS (2019). Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements.

[156] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for silica sand. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for silica sand, but this information does not provide a complete picture for Europe (Minerals4EU, 2019). It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc).

Reserve data for some countries in Europe are also available in the Minerals4EU website. However, these data cannot be summed as they are partial and they do not use the same reporting code.

Table 140: Reserve data for Europe compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2019)

Country	Reporting code	Quantity	Unit	Grade	Reserve Type
Denmark	None	24.1	million m^3	pure quartz sand	e
Ukraine	Russian classification	41,130 14,007 11,521	kt kt kt	foundry sand glass sand quartz/quartzite for refractories	A
Poland	Nat. rep. code	20.45 144.54 68.11	Mt Mt Mt	foundry sands glass sands quartz sands	-
Czech Republic	Nat. rep. code	127,937 84,755	kt kt	foundry sand glass sand	Economic explored
Slovakia	None	10.662 0 0.107	Mt Mt Mt	foundry sands glass sands 33.64% quartz	Verified Z1
Slovenia	UNFC	16.44	Mt	quartz sand	Proved
Croatia	Nat.Rep.Code	33,035.77	kt	silica sands	-
Kosovo	Nat.Rep.Code	2,312,614	m^3	quartzite sand	A+B
Macedonia	Yugoslavian	5,081,465	m^3	quartz	B

Production of silica sand: World production of quartz sand (including quartzite and other high silica industrial sands) is estimated to be around 315 Mt per year, averaged over 2012-2016 (WMD, 2019; USGS, 2019a; BGS, 2019). The major player are the United States (120 Mt) that supply about 38% of the world total. Other important extra-EU producers are: Turkey (15 Mt), Malaysia (10 Mt), India (8.5 Mt), Brazil (7 Mt), Korea (4.5 Mt), and Australia (3 Mt). The extraction of silica sand in Japan, Mexico, Canada, New Zealand, South Africa, and Iran is between 2 and 3 Mt each. The United Kingdom contributes for 4 Mt per year of silica sand.

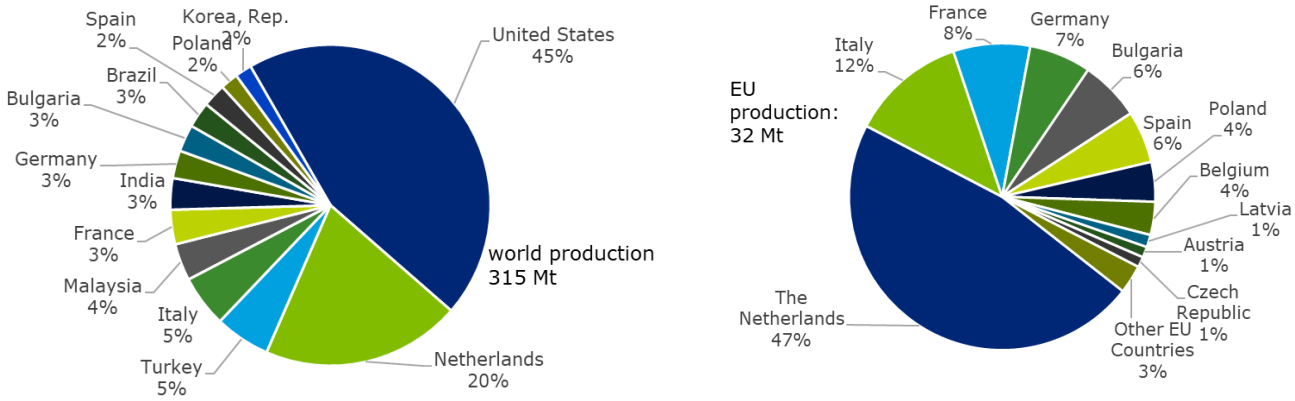


Figure 244: Global and EU production of silica sand, average 2012–2016 (IMA-Europe, 2018a; WMD, 2019; USGS, 2019; BGS, 2019).

Approximately 32 Mt per year of silica sands (quartz sands or industrial sands) were produced in the EU in average between 2012 and 2016 (IMA-Europe, 2018a9). The major countries

extracting and manufacturing silica sand in the EU: the Netherlands, Italy, France, Germany, Bulgaria, Spain, Poland, and Belgium (Figure 244).

28.4.3 Supply from secondary materials

Silica sands cannot be recovered after use in the oil field. Silica utilized in construction and as filler is retained within the matrix of concrete, mortar, rubber, plastics, etc., thus cannot be recycled as silica source. Silica in glass and ceramics is melted and recycled as a whole product. Recycling rates in the EU are on average: hollow glass 74%, flat glass 15%; foundry 79%; ceramics 2%. Silica consumption is 10% foundry, 11% hollow glass and 10% flat glass, 1% ceramics. Thus, the overall recycling rate (EoL-RIR), weighted for the application shares, is 17.5% (IMA-Europe, 2018a; SCRREEN workshops, 2019).

28.4.4 Processing of silica

Silica sand is commonly produced from loosely consolidated sedimentary deposits or by crushing weakly cemented sandstones or processing quartzite, and quartz containing rocks, such as granite. High grade quartz can also be produced by processing naturally pure vein quartz (Kogel, 2019). Quartz is valued for both its chemical and physical properties; each application must have a specific set of these properties and consistency in quality is of critical importance. These include high silica content and low content of impurities, such as iron and aluminium oxide, heavy metals and other metals such as chromium. Specific size distribution of the grains is also an essential requirement for certain applications. The shape of the grains (rounded vs sharp grains) is also important. Given the specificity of the properties for each application, the use of different types of silica sand is not interchangeable. Processing distinguishes industrial sand from common construction sand, because beneficiation is directly related to the purity of the final product. Quartz sands are always washed (to remove clay and other fine-grained minerals), then dewatered (by surge piles or cyclones) prior to a coarse separation (by hydrosizing or wet screening). Further steps may consist in (Kogel, 2019): attrition scrubbing (to remove clay minerals, iron oxides, and surface coatings on the sand grains), flotation (to get high-purity quartz) and drying (fluid bed or rotary dryer).

28.5 Other considerations

28.5.1 Environmental and health and safety issues

From the point of view of occupational health, working with silica sand poses a risk to human health if not handled carefully. Inhalation of crystalline silica dust can cause silicosis, a form of pneumoconiosis. The contraction of this incurable fibrogenic lung disease can be prevented by limiting exposure; all member states have set limits for the exposure to these particles in the work place. Furthermore, in order to prevent the risk of contracting such an illness, the employees and employers of several industrial European sectoral associations that make use of or produce silica sand have signed the Social Dialogue "Agreement on Workers' Health Protection Through the Good Handling and Use of Crystalline Silica and Products Containing it" on 25 April 2006. This social dialogue, known as the European Network for Silica (NEPSI), is the first multisector agreement negotiated, signed and agreed on applying an “Agreement on workers’ health protection through the good handling and use of crystalline silica and products containing it” (OJ 2006/C279/02). This aims at minimising exposure by applying Good Practices and increasing the knowledge about potential health effects of respirable crystalline silica dust.

The EU Directive 2017/2398 on "Protection of workers from exposure to carcinogens or mutagens at work" implements a set of legal limits on exposure to certain substances in industrial workplaces. Among the substances recognized in the legislation is Respirable Crystalline Silica (RCS) that is known to cause lung diseases in workers who are exposed high levels of it regularly for many years. However, Directive 2017/2398 has no impact upon product classification and labelling, which is ruled by other separate legislation (the CLP Regulation 1278/2008). Directive 2017/2398 addresses respirable dust generated by work processes, not the substance itself. Crystalline silica placed on the market is subject to the classification obligation under Regulation (EC) 1272/2008, while crystalline silica dust generated by a work process is not placed on the market and therefore is not classified in accordance with that Regulation (IMA-Europe, 2018b).

28.5.2Socio-economic issues

No specific issues were identified during data collection and stakeholders consultation.

28.6Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. The results of this and earlier assessments are shown in Table 141

Table 141: Economic importance and supply risk results for silica sand in the assessments of 2011, 2014, 2017, 2020 (European Commission, 2011-2014-2017)

Assessment	2011			2014			2017			2020	
Indicator	EI	SR		EI	SR		EI	SR		EI	SR
Silica sand	5.83	0.20		5.76	0.38		2.6	0.3		2.9	0.39

The supply risk remained practically constant over time and as low as 0.3-0.4, denoting no issues in the EU supply chain for silica sand.

28.7Data sources

28.7.1Data sources used in the factsheet

BGS (2019). World Mineral Production 2014-2017, [online] Keyworth, Nottingham British Geological Survey, Available at: https://www.bgs.ac.uk/mineralsuk/statistics/worldStatistics.html

European Commission (2011). Materials. Critical raw materials for the EU, Report of the Ad-hoc Working Group on defining critical raw materials.

European Commission (2014). Communication On the Review of the List of Critical Raw Materials for the EU and the Implementation of the Raw Materials Initiative, COM(2014)297final. Brussels.

European Commission (2017a). Communication on the List of Critical Raw Materials 2017, COM(2017) 490 Final. Brussels.

European Commission (2017b). Study on the review of the list of Critical Raw Materials – Non-critical raw materials factsheets. DG Internal Market, Industry, Entrepreneurship and SMEs (Deloitte Sust., BGS, BRGM, TNO), 476 p.

European Commission. (2019). "Negotiations and Agreements - Trade." http://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/ (July 7, 2019).

Eurostat (2019). "Easy Comext Database." http://epp.eurostat.ec.europa.eu/newxtweb/.

IMA-Europe (2018a). Recycling industrial minerals, 24 p., Brussels.

IMA-Europe (2018b). Using crystalline silica safely, White Paper, 22 p., Industrial Minerals Association, www.safesilica.eu

Kogel, J.E., Trivedi, N.C., Barker, J.M. & Krukowski, S.T. (eds.) (2006). Industrial Minerals and Rocks: Commodities, Markets and Uses, Littleton, Colorado, Society of Mining, Metallurgy and Exploration, 1565 p.

Liang, F., Sayed, M., Al-Muntasheri, G. A., Chang, F. F., & Li, L. (2016). A comprehensive review on proppant technologies. Petroleum, 2, 26-39.

Minerals4EU (2019) European Minerals Knowledge Data Platform (EU-MKDP), www.minerals4eu.eu.

OECD. 2019. "Export Restrictions on Industrial Raw Materials." https://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials (July 5, 2019).

SCRREEN CRM validation workhop (2019). Expert's comment, Brussels, 11 Sep. 2019.

USGS (2019a). Silica, in 2016 Minerals Yearbook, 2019 (advance release), Flanagan, D.M., 66,1-66,15.

USGS (2019b). Sand and gravel (industrial), in Mineral Commodity Summaries, Dolley, T.P., 142-143.

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

28.7.2Data sources used in the criticality assessment

BGS (2019). World Mineral Production 2014-2017, [online] Keyworth, Nottingham British Geological Survey, Available at: https://www.bgs.ac.uk/mineralsuk/statistics/worldStatistics.html

European Commission (2017b). Study on the review of the list of Critical Raw Materials – Non-critical raw materials factsheets. DG Internal Market, Industry, Entrepreneurship and SMEs (Deloitte Sust., BGS, BRGM, TNO), 476 p.

Eurostat (2019). "Easy Comext Database." http://epp.eurostat.ec.europa.eu/newxtweb/.

IMA-Europe (2018). Recycling industrial minerals, 24 p., Brussels.

Kogel, J.E., Trivedi, N.C., Barker, J.M. & Krukowski, S.T. (eds.) (2006). Industrial Minerals and Rocks: Commodities, Markets and Uses, Littleton, Colorado, Society of Mining, Metallurgy and Exploration, 1565 p.

Liang, F., Sayed, M., Al-Muntasheri, G. A., Chang, F. F., & Li, L. (2016). A comprehensive review on proppant technologies. Petroleum, 2, 26-39.

USGS (2019a). Silica, in 2016 Minerals Yearbook, 2019 (advance release), Flanagan, D.M., 66,1-66,15.

USGS (2019b). Sand and gravel (industrial), in Mineral Commodity Summaries, Dolley, T.P., 142-143

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

28.8 Acknowledgments

This factsheet was prepared by the JRC in collaboration with Mr. Michele Dondi (CNR-ISTEC, Faenza, Italy). The authors would like to thank the Ad Hoc Working Group on Critical Raw Materials, in particular Ms. Aurela Shtiza and Ms. Francesca Girardi of IMA-Europe, as well as experts participating in SCRREEN workshops for their contribution and feedback.

29. SILVER

29.1 Overview

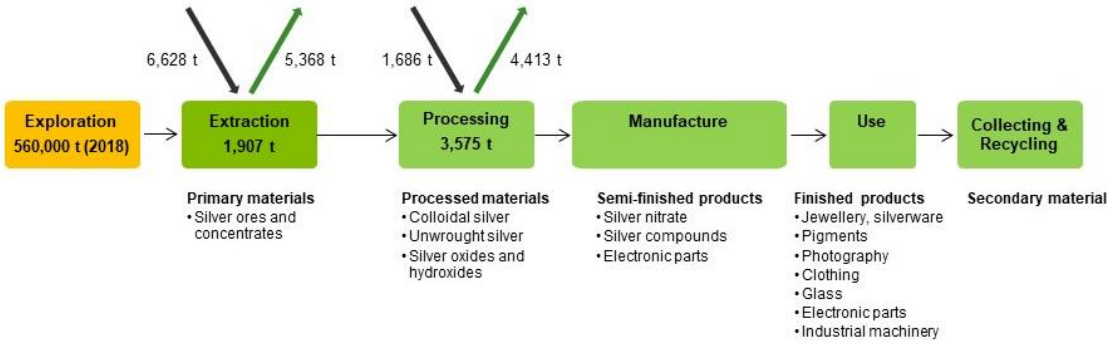
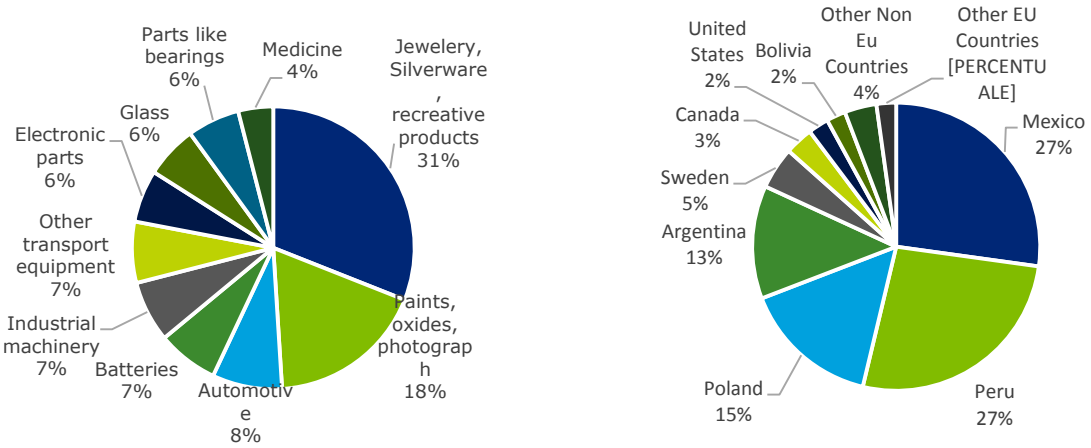


Figure 245: Simplified value chain for silver for the EU, average 2012-2016[157]

Silver (chemical symbol Ag) is a chemical element with atomic number 47. Silver is one of the eight precious, or noble metals which are resistant to corrosion. This metal is soft, very malleable and ductile and has the highest electrical and thermal conductivity of all metals (Lenntech, 2016). The presence of silver in the earth's crust is somewhat rare, with 53 parts per million upper crustal abundance (Rudnick & Gao, 2003).Silver is almost always monovalent in its compounds, but an oxide, a fluoride, and a sulphide of divalent silver are known. It is not a chemically active metal, but reacts with nitric acid (forming the nitrate) and by hot concentrated sulphuric acid. It does not oxidize in air but reacts with the hydrogen sulphide present in the air, forming silver sulphide (tarnish). This is why silver objects need regular cleaning. Silver is stable in water.

Silver is assessed at the extraction stage in the form of silver ores and concentrates, and at the processing/refining stage in the form of colloidal silver, unwrought silver, silver oxides and hydroxides.



EU consumption of Silver ore: 3,167 t
EU consumption of Silver metal: 849 t

EU sourcing of silver ore : 8,535 t

Figure 246: EU end uses of silver and EU sourcing (mine stage). Average 2012-2016 (Silver Institute, 2019; GFMS, 2019; BGS, 2019; Eurostat ComExt, 2019b)

[157] JRC elaboration on multiple sources (see next sections)

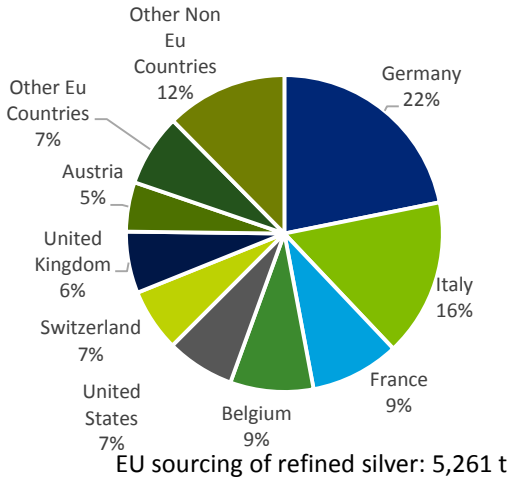


Figure 247: EU sourcing of silver metal, averaged over 2012-2016 (Silver Institute, 2019; GFMS, 2019; BGS, 2019; Eurostat ComExt, 2019b).

The calculation of the supply risk is made using both the global HHI and EU HHI calculation as prescribed in the methodology. Quantities are expressed in t of silver content, and all figures are averaged over 2012–2016 data unless otherwise specified.

The trade codes used in this assessment are (Eurostat Comext, 2019):
•Mining stage (ores and concentrates): CN 26161000 "Silver ores and concentrates";
•Refining stage (silver, silver plated): CN 7106 Silver including silver plated with gold or platinum, semi-manufactured.

The world production of silver takes place in several countries all over the world. What should be mentioned, however, is that only around 30% of the annual supply comes from primary silver mines while more than a third is produced at lead/zinc operations and a further 20% from copper mines (Mining Intelligence, 2019). The polymetallic ore deposits from which silver are recovered account for more than two-thirds of the world's silver resources. Mexico is the world's largest silver ore producer, contributing about 21% of the total world supply, while Peru (14%) and China (13%) follow in production. The EU mine production of silver is concentrated in Poland and Sweden that account for the 5% and 2% of the global production respectfully. For the year 2018 silver imports and exports around the world were estimated at USD 900 million and USD 1.42 billion respectively (UN Comtrade, 2019).

Prices of silver are strongly linked to its monetary uses and investment perspectives, even though these applications are not considered in the criticality assessment of the metal. Following a sharp increase in 2011 to historical high prices, silver prices declined and normalised during recent years. Like gold, however, silver is a precious metal with high volatility. Despite being mainly affected by silver's monetary uses, its prices are also affected by the increasing demand for silver for several industrial uses like in the automotive industry and in the manufacturing of jewellery and silverware.

The EU consumption of silver ores and concentrates between 2012 and 2016 was around 3,167 t per year, which is mainly sourced from Mexico (2,321 t/y or 27%) and Peru (2,266 t/y or 27%) and through domestic production in Poland (1,317 t/y or 15%). The import reliance for silver ores and concentrates is 18%. The annual EU consumption of silver metal was about 849 t. There is no further reliable data and information available with respect to the EU consumption of silver metal. It can be noted, however, that Germany, Italy and France are the major domestic producers.

Besides its monetary uses and investment perspectives that are not taken into consideration in this criticality assessment, silver is mostly used in the production of jewellery and silverware (30%), paints (18%), electronic parts (6%), while it is widely used in the automotive industry (8%), in vehicle batteries (7%) and other transport equipment (7%), in glass coating (6%) and other parts, bearings (6%), as well as in medicine (4%).

Silver can be theoretically substituted by gold and platinum in jewellery and other applications. However, its lower price makes its substitution difficult. Nickel and copper can substitute silver in batteries, while aluminium and copper can substitute silver in electronic parts. Silver wire, however, is generally reserved for more sensitive systems and specialty electronics where high conductivity over a small distance is prioritized (Silver Institute, 2019; GFMS, 2019).

Silver demand should be boosted in the future, due to the expectation for exponential growth of electric vehicles (EVs) and continued investment in solar photovoltaic energy. Furthermore, the use of inductively coupled power transfer technology to wirelessly charge vehicles using silver-plated induction coils, as well as the use of silver in the generation of nuclear energy may significantly contribute to the low-carbon economy that EU is pursuing for 2050.

Silver nowadays is primarily obtained as a by-product from lead-zinc mines, copper mines, and gold mines. The polymetallic ore deposits from which silver is recovered account for more than two-thirds of world resources of silver (USGS, 2019). Most recent silver discoveries have been associated with gold occurrences; however, copper and lead-zinc occurrences that contain by-product silver will continue to account for a significant share of reserves and resources in the future. At the end of 2018 the world's proven and probable silver reserves were estimated to be approximately 560,000 t. Peru, Poland and Australia are hosts of the largest silver reserves (USGS, 2019).

The global silver ore production was 26,793 t per year, as an average over 2012-2016 (USGS, 2019; BGS, 2019). Only around 30% of the annual supply comes from primary silver mines while more than a third is produced at lead/zinc operations and a further 20% from copper mines (Mining Intelligence, 2019). Only six of the top 20 producers are primary silver miners. The polymetallic ore deposits from which silver are recovered account for more than two-thirds of the world's silver resources.

Mexico is the world's largest silver ore producer contributing about 21% of the total world supply. Other important suppliers of silver ores and concentrates are Peru (14%) and China (13%), while Australia (6%), Russia (5%) and Chile (5%) follow. The EU mine production of silver is concentrated in Poland and Sweden that account for the 5% and 2% of the global production respectfully.

The world annual production of silver metal reached 33,764 t, with China (22%) and United States (20%) and India (16%) being the leading producers. Germany is the leading producer within the EU with 1,149 t per year (3.4% of global production), followed by Italy with 847 t per year (2.5%), France with 479 t per year (1.4%) and Belgium with 447 tonnes per year (1.3%). All data regard to average production per year over a period from 2012 to 2016 (Silver Institute, 2019; GFMS, 2019).

The post-consumer functional recycling of silver scrap and silver jewellery and silverware is well established, contributing to silver supply from secondary sources.

There are no major issues regarding silver production and trade. Some minor trade restrictions in terms of export quotas are implied from China, Bolivia and Morocco without, however, disrupting the global supply of silver ores and concentrates. It should be noted, however, that being a precious metal, silver has a high price volatility that is driven mainly by monetary

policies and geopolitical issues. Domestic production within the EU is low and the import reliance may be low for the ores and concentrates (18%) but is rather high for silver metal (527%).

29.2Market analysis, trade and prices

29.2.1Global market

Nowadays, the world production of silver ore is not dominated by a single country. Mexico is the leading producer with a share of 21%. Peru and China are following with 14% and 13% respectively, while a group of countries (Australia, Russia, Chile, Poland, Bolivia and others) have production shares that range from 4% to 6% (GFMS, 2019; Silver Institute, 2019).

The diversity in production is also demonstrated in the global imports and exports of silver. The order of magnitude of the market value of the annual silver imports and exports is estimated at USD 900 million and USD 1.42 billion respectively (UN Comtrade, 2019). As regards the most important export restrictions in place in 2019, China and Bolivia, which had a share of 13% and 5% respectively of silver ores and concentrates production on average over a period from 2012 to 2016, apply an export tax of 10% and 0.05% respectively. Other export taxes posed by India (20%), Turkey and Morocco (0-25%) are considered not so significant, given the low production shares coming from these countries (OECD, 2019).

Though the use of silver in investments and monetary applications is not taken into consideration in this critical assessment, it should be noted that the silver market is quite big, which makes it one of the largest and most important financial markets in the modern economy. Given its size and liquidity, silver is clearly an asset for jewelleries and silverware.

29.2.2Outlook for supply and demand

In 2018, the silver market faced a challenging environment which was reflected in a muted price performance. A slowing Chinese economy, coupled with rising U.S. interest rates, an equity market bull run, and global trade tensions, affected the price performance across many markets, including gold and silver. In 2019, it is expected that the silver market will grow stronger again. The expected slowdown in the U.S. FED rate hiking cycle should benefit silver, which in comparison to gold, has a much more attractive price (Silver Institute, 2019).

Silver demand from industrial fabrication is forecast to rise modestly in 2019 (Silver Institute, 2019). Most sectors are expected to record reasonable growth based on silver's use in a wide variety of applications. For instance, silver demand from brazing alloys and solders as well as electrical and electric applications is expected to rise in 2019. This is on the back of continued demand from the automotive sector, which uses an increasing amount of applications, such as safety features, window defogging and infotainment systems, and for electric and hybrid vehicles. Other industrial sectors in which silver's use is expected to grow are water purification, chemical applications, LED lighting, flexible electronics and screens as well as anti-microbial applications in textiles.

Photovoltaic (PV) demand and in turn the demand for silver has been expanding considerably in recent years due to various countries stepping up the pace to diversify their energy generating portfolio away from conventional fossil fuels and towards a higher share of renewable sources.

Jewellery demand is expected to record a solid year of growth in 2019, with Thailand set to be one of the driving forces behind the rise (Silver Institute, 2019). In the United States, silver jewellery will remain a popular alternative to lower carat gold items, driven by many issues, but especially female self-purchases. Globally, silver jewellery is expected to continue to expand, due to its diversity of design, fine quality and excellent retail margins.

On the other hand, silver supply is not expected to increase, mainly due to struggling silver prices. In addition to the price issues, the two leading silver-producing countries, Mexico and Peru, reported declines in 2018, while Poland and Russia also reported declines. Hence, silver mine production is forecast to decline by 2-3% in 2019 (Silver Institute, 2019). On the contrary, the supply of silver from scrap is forecast to pick up modestly in 2019, following four consecutive years of stable scrap flows. That will be mainly a function of scrap generated from industrial processes but also from jewellery items, which tend to be strongly price elastic.

Overall, it can be said that the silver market balance (total supply less total demand) in 2019 is projected to be the third consecutive year, within the boundaries of margin, where all the silver produced is absorbed by the various downstream sectors (GFMS, 2019; Silver Institute, 2019). This may eventually result in an increase of the world production once again within the next 5-10 years, especially through the increase of lead and zinc production, from which silver is extracted as a by-product.

Table 142: Qualitative forecast of supply and demand of silver

Material	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Silver		x	++	++	+	+	+	+

29.2.3EU trade

EU imports outweigh exports for silver ores and concentrates. Trade statistics reported by Eurostat show that imports and exports of silver to and from the EU have been fluctuating in recent years. While in 2012 the imports outnumbered the exports of silver ores and concentrates, in 2013 and 2014 there were big reductions in the trade flows. More importantly, however, in 2015 and 2016 the exports outnumbered imports and in turn the net imports flow was negative. On the other hand, the trade flows for refined silver shows less fluctuation and the exports are constantly higher than the imports. Same as with the trade flows for ores and concentrates, there has been a decline in the refined silver trade flows in 2013 and 2014. Yet, the situation changed and there was an increase in the following years (2015-2016).

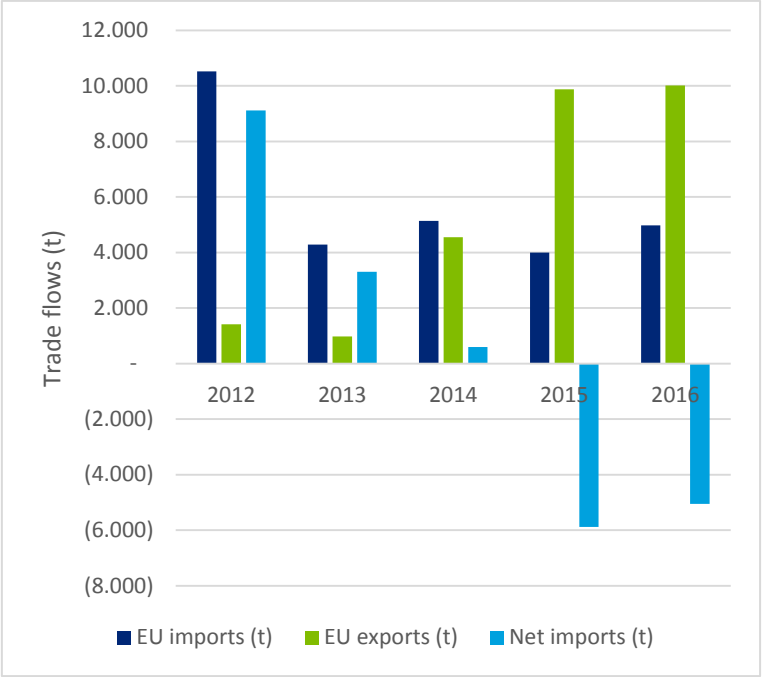


Figure 248: EU trade flows for silver ores and concentrates (Eurostat 2019b)

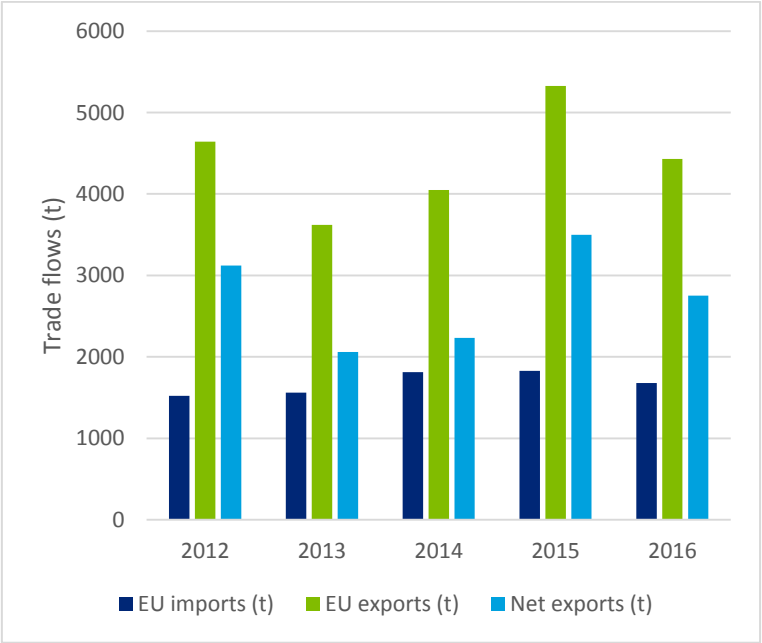


Figure 249: EU trade flows for refined silver metal (Eurostat 2019b)

The origins of silver ores and concentrates trade to the EU are found in Latin America. Peru, Mexico and Argentina together ship over 85% of the traded volume to the EU (see Figure 250).

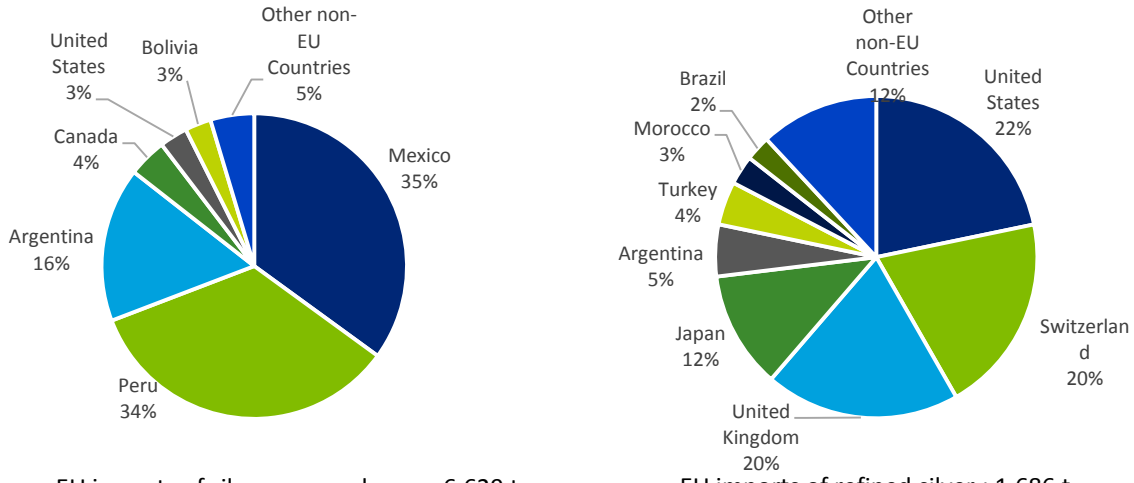


Figure 250: EU imports of silver ores and concentrates and refined silver. Average 2012-2016 (Eurostat 2019b)

In 2019, there were export taxes, quotas or export prohibition for silver ores and concentrates imposed by China, Bolivia and Morocco (OECD 2019).

29.2.4Prices and price volatility

The price of silver is driven by speculation and supply and demand, like several other commodities. Although the application of silver as monetary used is ignored in this criticality assessment study, the effect of monetary policy on the price of silver (in wake of the gold price) is undeniable. The price of silver is notoriously volatile compared to that of gold because the silver market is smaller than that of gold, lower market liquidity and demand fluctuations between industrial uses and investments. At times, this can cause wide-ranging valuations in the market, creating volatility.

The price development of silver is shown in Figure 251. The metal price surged around 2011 and reached a historical maximum of USD 1562 USD/kg (Silverprice, 2019). The efforts of the central banks to reduce the price of precious metals after 2011 have led to a normalization of the price level of silver compared to the pre 2010 level. This normalisation is even more obvious after 2013. The average price of silver between 2014 and 2018 was USD16.9 per troy ounce or 596.2 USD/kg (Silverprice, 2019).



Figure 251. Price of silver in USD/kg, 2000-2019. (silverprice.org, 2019)

The volatility in the equity markets is motivating investors to look for alternative options such as precious metals, which will boost silver investment in the near future (Silver Institute, 2019). In the last decade, global central banks have fought off a slowing economy using ultra-low rates and massive QE. The ability of central banks however, to print massive amounts of currency could potentially weigh on paper currencies in the decades to come, making silver and other hard assets potentially more attractive to long-term investors.

Regardless of the investment uses of silver, monetary policies and geopolitics, this precious metal may potentially benefit from several other key factors including an ongoing rise in industrial demand; these key factors are aforementioned in this study and are discussed in more detail hereinafter.

29.3EU demand

29.3.1EU consumption

As an average for the period 2012-2016, the EU consumes about 3,167 t of silver in form of ores and concentrates (Eurostat, 2019b). As a percentage of apparent consumption, the import reliance for silver is 18%. When it comes to processed silver and silver metal, the EU consumes 849 t in the same period 2012-2016. The EU is a net exporter of Silver metal (Eurostat, 2019b).

29.3.2Uses and end-uses of silver in the EU

The end uses of silver products in the EU are demonstrated in Figure 252.

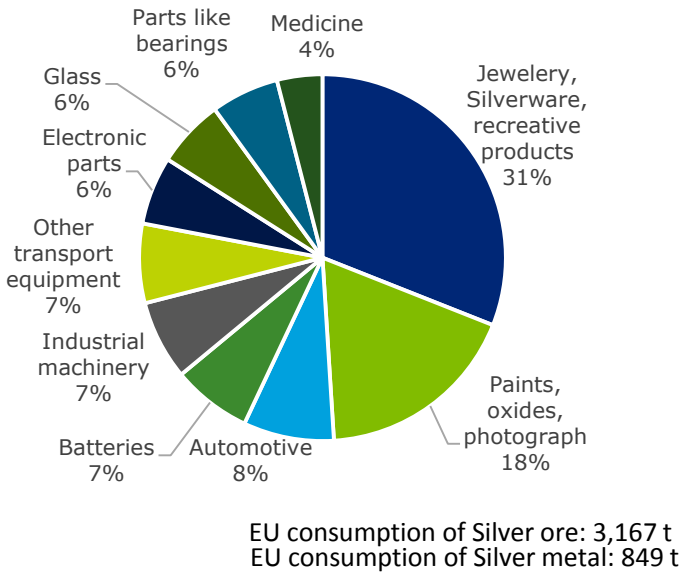


Figure 252: EU end uses and consumption of silver. Average 2012-2016 (Silver Institute, 2019; GFMS, 2019; BGS, 2019; Eurostat ComExt, 2019)

Silver is used for a variety of industrial and aesthetic applications such as electronics and jewelry. Approximately half of world silver demand is in industrial applications, with around 31% used for silverware or jewelry, while a small percentage (4%) is used for medical purposes. Just over one quarter of world silver demand was for investment, a use that is not taken into consideration in this criticality analysis.

The applications of silver are multiple:

- Coins, silverware and jewellery: Malleability, reflectivity, and lustre make silver a beautiful choice. Because it is so soft, silver must be alloyed with base metals, like copper, as in the case of sterling silver (92.5% silver, 7.5% copper). Even though it resists oxidation and corrosion, silver can tarnish, but with a little polish, it can shine for a lifetime. Because it is less expensive than gold, silver is a popular choice for jewellery and a standard for fine dining. Silver-plated base metals offer a less costly alternative to silver.
- Paints: Silver and silver-based compounds are highly antimicrobial by virtue of their antiseptic properties to several kinds of bacterium, while they also have low toxicity and are long-lasting biocides with high thermal stability and low volatility. Hence, a surface coated with silver-nanoparticle paint shows excellent antimicrobial properties, and for this reason silver is very popular in the painting industry (Kumar et al, 2008).
- Photography: silver's high optical reflectivity has given it historical usage for film photography and it had been one of the primary industrial uses of silver until the recent rise of digital media. Thus, this market has been in decline since the late 1990s. Traditional film photography relies on the light sensitivity of silver halide crystals present in film. When the film is exposed to light, the silver halide crystals change to record a latent image that can be developed into a photograph.
- Electrical and electronics: silver's usage in electrical and electronics industry is widespread due to its high electrical and thermal conductivity. For example it is used for electrical contacts, switches and passive electronic components such as multi-layer ceramic capacitors. The end-markets for these components include cell phones, PCs and computers and automotive applications.

- Photovoltaic: silver's use in PV solar cells is mainly as a conductive paste for thick film crystalline silicon cells. The use of silver in thin film solar PV or Concentrating Solar Power (CSP) is more limited.
- Brazing alloys and solders: when metal pieces such as pipes, faucets, ducts and electrical wires are joined together the process is called brazing or soldering based on how much heat is applied to the junction. Without silver, none of these connections would be as strong, leak-proof or as electrically conductive as the original materials.
- Glass: Silver is almost completely reflective when polished. Since the 19th century, mirrors have been made by coating a transparent glass surface with a thin layer of silver, though modern mirrors also use other metals like aluminium. Many windows of modern buildings are coated with a transparent layer of silver that reflects sunlight, keeping the interior cool in the summer.
- Bearings: Engine bearings rely on silver. The strongest bearing is made from steel that has been electroplated with silver. Silver's high melting point allows it to withstand the high temperature of engines. Silver also acts like a lubricant to reduce friction between a ball bearing and its housing. Due to its ability to absorb oxygen, silver is being researched as a possible substitute for platinum to catalyse oxidation of matter collected in diesel engine filters.
- Batteries: Another electronic application of silver is in batteries that employ silver oxide or silver zinc alloys. These light-weight, high-capacity batteries perform better at high temperature than other batteries. Silver-oxide is used in button batteries that power cameras and watches, as well as in aerospace and defence applications. Silver-zinc batteries offer an alternative to lithium batteries for laptop computers and electric cars.
- Ethylene oxide industry: silver oxide is used as a catalyst in this petro-chemical industry for the production of polyester intermediates.
- Other industrial applications: these include coating materials for compact disks and digital video disks, mirrors and cellophane. Silver has also a number of emerging applications such as solid state lighting, RFID-tags, water purification and hygiene. New markets for nano-silver are frequently being discovered.

Relevant industry sectors are described using the NACE sector codes (Eurostat, 2019a) provided in Table 143. The calculation of economic importance is based on the use of the NACE 2-digit codes and the value added at factor cost for the identified sectors.

Table 143: Silver applications, 2-digit and examples of associated 4-digit NACE sectors, and value-added per sector (Eurostat 2019a).

Applications	2-digit NACE sector	Value-added of NACE 2 sector (M€)	Examples of 4-digit NACE sectors
Jewelery, Silverware, recreative products	C32- Other manufacturing	39,160	32.12 - Manufacture of jewellery and related articles
Paints, oxides, photograph	C20 - Manufacture of chemicals and chemical products	105,514	20.59 - Manufacture of other chemical products n.e.c. 20.13 - Manufacture of other inorganic basic chemicals
Automotive	C29 - Manufacture of motor vehicles, trailers and semi-trailers	160,603	29.31 - Manufacture of electrical and electronic equipment for motor vehicles

Batteries	C27 - Manufacture of electrical equipment	80,745	27.20 - Manufacture of batteries and accumulators
Industrial machinery	C28 - Manufacture of machinery and equipment n.e.c.	182,589	28.12 - Manufacture of fluid power equipment
Other transport equipment	C30 - Manufacture of other transport equipment	44,304	30.30 - Manufacture of air and spacecraft and related machinery
Electronic parts	C26 - Manufacture of computer, electronic and optical products	65,703	26.11 - Manufacture of electronic components
Glass	C23 - Manufacture of other non-metallic mineral products	57,255	23.19 - Manufacture and processing of other glass, including technical glassware
Parts like bearings	C25 - Manufacture of fabricated metal products, except machinery and equipment	148,351	28.15 - Manufacture of bearings, gears, gearing and driving elements 25.61- Treatment and coating of metals
Medicine	C21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations	80,180	C21.20 - Manufacture of pharmaceutical preparations

29.3.3Substitution

In terms of substitutability the following commentary is relevant:

- Coins, silverware and jewellery: these applications are all in principle substitutable by other metals. These applications depend on price and quality requirements, which depend on the individual application. Silver is cheaper than gold and platinum but can easily be substituted due to gold being a higher status of elite, power and wealth.
- Electrical and electronics: Silver is considered the best electrical conductor, however its higher cost and low strength limits its use to special applications such as joint plating and sliding contact surfaces (Silver Institute, 2019). For instance, though silver wire is roughly 7% more conductive than a copper wire of the same length, silver is a significantly rarer metal than copper. Combined with silver's tendency to oxidize and lose efficiency as an electrical conductor, the relatively minor increase in conductivity makes copper a more sensible option in several scenarios. Apart from copper, aluminium and other precious metals can replace silver completely or partially in many electrical and electronic uses. Nevertheless, silver wire is generally reserved for more sensitive systems and specialty electronics where high conductivity over a small distance is prioritized.
- Brazing alloys and solders: substitution of silver from these applications with other metals such as tin is possible, and has been occurring over the past decade due to the cost of silver. The physical and chemical performance in these applications of tin is not as good as silver (BGR, 2016).
- Photography: this market has been in decline with the introduction of digital photography.

In the assessment, the total share of substitution in the abovementioned examples are set at 50% for electronics and batteries and 40% for jewellery.

29.4Supply

29.4.1EU supply chain

The industrial fabrication of silver products in the EU has risen steadily since 1990. The largest contributor to refining was the German industry, contributing around 10% of the world's industrial silver. At the same time, use of industrial silver by EU manufacturing has shown a slight decline in recent years. (GFMS, 2011).

The EU relies for the supply of silver for almost 78% of its imports. The extraction activities in the EU mostly feed into European supply chains, reducing the import reliance.

Some trade restrictions are reported by (OECD, 2019). China and India issued an export tax for silver ores and concentrates of 10% and 20% respectively while Bolivia issues a fiscal tax of 0.05% from 2014.

29.4.1.1 EU sourcing of silver ores and concentrates

Figure 253 shows the EU sourcing (domestic production+imports) for silver ores and concentrates. Mexico and Peru are the main sources from which the EU imports silver with 27% of the total supply each. The bigger domestic source of silver ores and concentrates is Poland (15%), while Sweden holds a small percentage of 5% as well. As already mentioned the 78% of EU sourcing for silver ores and concentrates depends on the imports from other countries.

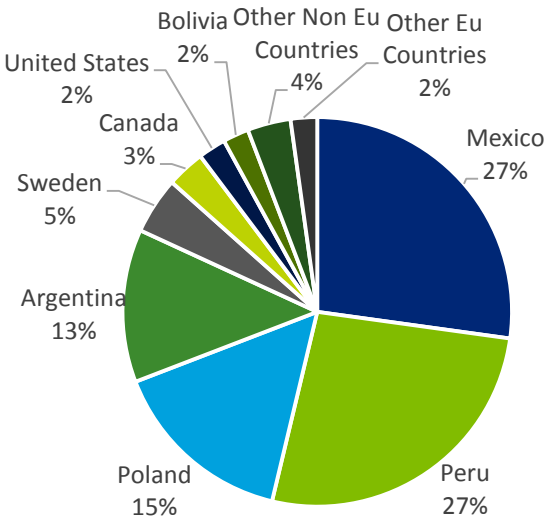


Figure 253: EU sourcing (domestic production+imports) of silver ores and concentrates, average 2012-2016 (Eurostat 2019b).

29.4.1.2 EU sourcing of refined silver and silver metal

The annual EU sourcing for refined silver metal accounts for 5,261 t, between 2012 and 2016. The 68% of this sourcing comes from domestic production within the EU and the remaining

32% is imported from other countries. Germany is the biggest domestic producer with 32% ot EU production. Italy produced 24%, France 13% and Belgium 13% of silver metal respectively. Figure 254 demonstrates the EU domestic production as an average over a period from 2012 to 2016.

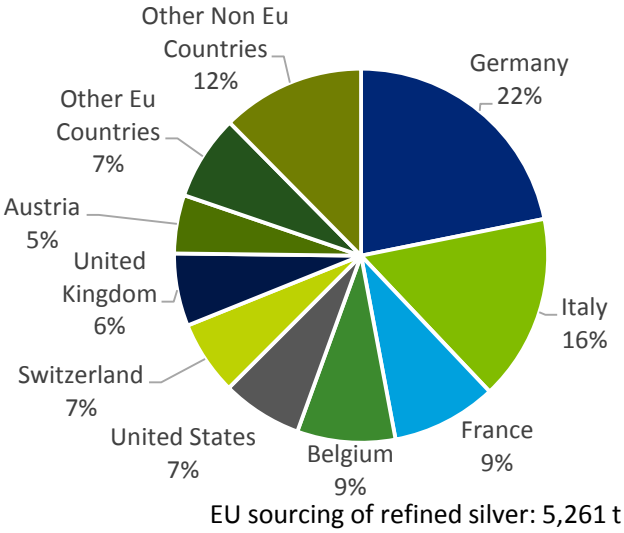


Figure 254: EU sourcing (domestic production+imports) of refined silver, average 2012-2016. (Eurostat 2019b)

29.4.2Supply from primary materials

29.4.2.1 Geology, resources and reserves

Geological occurrence: Silver can be extracted from a variety of deposit types, as it concentrates in numerous geological environments. It usually occurs in four forms: as a native element, as a primary constituent in silver minerals, as a natural alloy with other metals, and as a trace to minor constituent in the ore of other metals. In most cases the economic viability of deposits that contain silver depends upon the presence of other valuable minerals. Therefore, 'silver deposits' rarely exist as such.

Native silver is infrequently found in nature. It is usually associated with quartz, gold, copper, sulphides or arsenides of other metals, and other silver minerals. Most of native silver is associated with hydrothermal deposits, as veins and cavity fillings.

More than 39 silver-bearing minerals can be identified, but only few of them can warrant profitable mining operations, such as acanthite (Ag_2S), proustite (Ag_3AsS_3) and pyragyrite (Ag_3SbS_3). Silver minerals can be sulphides, tellurides, halides, sulphates, sulphonates, silicates, borates, chlorates, iodates, bromates, carbonates, nitrates, oxides, and hydroxides.

As natural silver-alloy, silver is for the most part combined with gold. The term 'electrum' is used for minerals in which the silver/gold ratio is at least 20%. Silver can also be alloyed with mercury (i.e. 'silver amalgam').

However, the major share of Ag is obtained as a by-product from copper, lead or zinc mining. In these ore types, silver either occurs as a substituted element in the ore mineral's lattice, or as an inclusion of native silver or silver-minerals.

According to the website Minerals4EU, there are some exploration activities in The UK, Spain, Portugal, Switzerland, Kosovo, Romania, Slovakia, Hungary, Poland and Sweden, but no more specific information (Minerals4EU, 2019).

Global resources and reserves[158]*:* Although silver was a principal product at several mines, silver was primarily obtained as a by-product from lead-zinc mines, copper mines, and gold mines, in descending order of production. The polymetallic ore deposits from which silver was recovered account for more than two-thirds of U.S. and world resources of silver (USGS, 2019). Most recent silver discoveries have been associated with gold occurrences; however, copper and lead-zinc occurrences that contain by-product silver will continue to account for a significant share of reserves and resources in the future.

At the end of 2018 the world's proven and probable silver reserves were estimated to be approximately 560,000 t. Peru, Poland and Australia are hosts of the largest silver reserves (USGS, 2019).

Table 144: Global reserves of silver in 2018. (USGS 2019)

Country	Estimated silver reserves (t)	Percentage of the total (%)
Argentina	N/A	N/A
Australia	89,000	15.84
Bolivia	22,000	3.91
Chile	26,000	4.63
China	41,000	7.3
Mexico	37,000	6.58
Peru	110,000	19.57
Poland	110,000	19.57
Russia	45,000	8.01
United States	25,000	4.45
Other countries	57,000	10.14
World total (rounded)	560,000	100

EU resources and reserves[159]*:* Data on silver reserves in some countries in Europe are available at Minerals 4EU (2015), see Table 145, but cannot be summed as they are partial and they do not use the same reporting code.

[158] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of silver in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

[159] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for silver. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for silver, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates,

Table 145: Silver reserves data in the EU (Minerals4EU, 2019)

Country	Classification	Quantity (million t of ore)	Grade (% Ag)	Reporting code	Reporting date	Source
Sweden	Proven	517.1	5.22 g/t	FRB-standard	11/2014	(Minerals4EU)
	Proven	12.3	69 g/t	NI 43-101		
Finland	Proven	7.4	14 g/t	NI 43-101	11/2014	(Minerals4EU)
	Proven	1.8	98 g/t	JORC		
Portugal	Proven	16.521	62.37 g/t	NI 43-101	11/2014	(Minerals4EU)
Poland	Total	0.0707	-	Nat. Rep. Code	11/2014	(Minerals4EU)
Slovakia	Z1	7.335	12.04 g/t	None	11/2014	(Minerals4EU)
Ukraine	C1	158×10^{-6}	-	Russian Classification	11/2014	(Minerals4EU)
Kosovo	(RUS)A	0.01325	0.00788%	Nat. Rep. Code	11/2014	(Minerals4EU)
Greece	Proven	0.0022	-	CIM	11/2014	(Minerals4EU)
Turkey	Proven	4.49	27 g/t	NI 43-101	11/2014	(Minerals4EU)
	Proven	20.51	1.3 g/t	JORC		

29.4.2.2 World and EU mine production

The world mine production of silver reached 26,793 t per year as an average over 2012-2016 (USGS, 2019; BGS, 2019). Only around 30% of the annual supply comes from primary silver mines while more than a third is produced at lead/zinc operations and a further 20% from copper mines (Mining Intelligence, 2019). Only six of the top 20 producers are primary silver miners. The polymetallic ore deposits from which silver are recovered account for more than two-thirds of the world's silver resources.

Mexico is the world's largest silver ore producer (Figure 255), contributing about 21% of the total world supply. Other important suppliers of silver ores and concentrates are Peru (14%) and China (13%), while Australia (6%), Russia (5%) and Chile (5%) follow. The EU mine

inferred reserves figures only, etc.). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for silver at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019). Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However a very solid estimation can be done by experts.

production of silver is concentrated in Poland and Sweden that account for the 5% and 2% of the global production respectfully. There are a further seven silver producing countries within the EU, most notably including Bulgaria, Portugal, Greece, Spain, Romania, Finland and Ireland (BGS, 2019). (Figure 255).

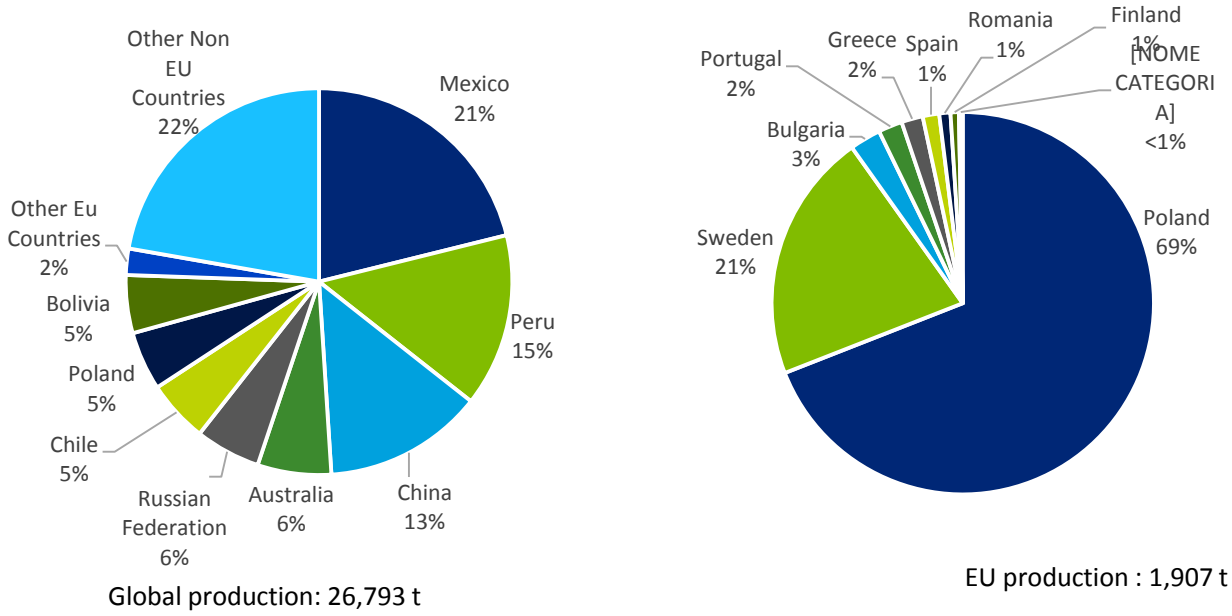


Figure 255: Global and EU mine production of silver (ores and concentrates). Average 2012-2016. (USGS, 2019; BGS, 2019)

29.4.3 Processing of silver ore

29.4.3.1 Silver processing

Specific extractive metallurgy processes are applied to a silver-bearing mineral concentrate depending on whether the major metal is copper, zinc or lead. It should be noted here that heap leaching is quite popular around the world (though not taking place in Europe) as a lower capital cost extraction method not only for gold but for silver containing concentrates as well (Manning and Kappes, 2016).

The smelting and converting of copper sulfide concentrates result in a "blister" copper that contains 97% to 99% of the silver present in the original concentrate. Upon electrolytic refining of the copper, insoluble impurities, called slimes, gradually accumulate at the bottom of the refining tank (McQuinston, 1985). These contain the silver originally present in the concentrate but at a much higher concentration.

The slimes are then smelted in a small furnace to oxidize virtually all metals present except silver, gold, and platinum-group metals. The metal recovered, called doré, is cast to form anodes and electrolyzed in a solution of silver-copper nitrate. Two different electro-refining techniques are employed, the Moebius and Thum Balbach systems (Mooiman and Simpson, 2016). The chief difference between them is that the electrodes are disposed vertically in the Moebius system and horizontally in the Thum Balbach system. The silver obtained by electrolysis usually has a purity of 99.99% silver.

Lead concentrates containing silver are first roasted and then smelted to produce a lead bullion from which impurities such as antimony, arsenic, tin, and silver must be removed. Silver is removed by the Parkes process, which consists of adding zinc to the molten lead bullion. Zinc reacts rapidly and completely with gold and silver, forming very insoluble compounds that float

to the top of the bullion (911Metallurgist.com). These are skimmed off and their zinc content recovered by vacuum retorting. The remaining lead-gold-silver residue is treated by cupellation, a process in which the residue is heated to a high temperature (about 800°C) under strongly oxidizing conditions. The noble silver and gold remain in the elemental form, while the lead oxidizes and is removed. The gold and silver alloy thus produced is refined by the Moebius or Thum Balbach process (Mooiman and Simpson, 2016). The residue from silver refining is treated by affination or parting to concentrate the gold content, which is refined by the Wohlwill process.

Zinc concentrates are also roasted and then leached with sulfuric acid to dissolve their zinc content, leaving a residue that contains lead, silver, and gold—along with 5% to 10% of the zinc content of the concentrates. This is processed by slag fuming, a process whereby the residue is melted to form a slag through which powdered coal or coke is blown along with air. The zinc is reduced to the metallic form and is vaporized from the slag, while the lead is converted to the metallic form and dissolves the silver and gold. This lead bullion is periodically collected and sent to lead refining, as described above (911Metallurgist, 2019).

29.4.3.2 World and EU silver metal production

The world production of refined silver between 2012 and 2016 reached 33,764 t per year, with China (22%) and United States (20%) and India (16%) being the leading producers of the global supply of silver metal, followed by several other countries (GFMS, 2019; Silver Institute, 2019) (Figure 256). Germany is the leading producer within the EU with 1,149 t per year (3.4% of global production), followed by Italy with 847 t per year (2.5%), France with 479 t per year (1.4%) and Belgium with 447 t per year (1.3%). All data regard to average production per year over a period from 2012 to 2016 (GFMS, 2019; Silver Institute, 2019).

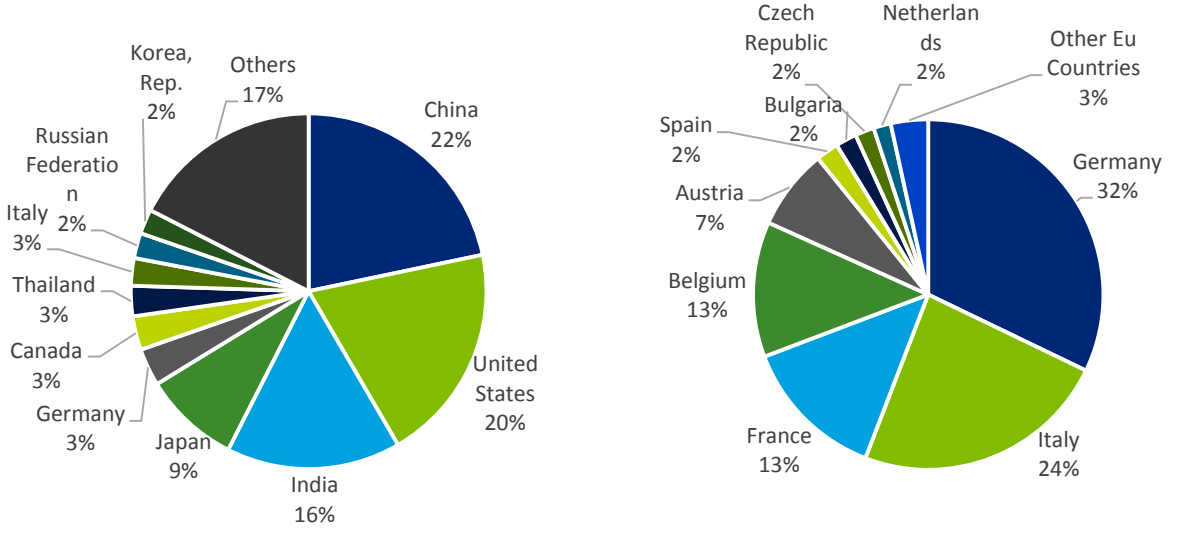


Figure 256: Global and EU production of refined silver. Average 2012-2016. (Silver Institue, 2019)

29.4.4Supply from secondary materials/recycling

The end-of-life recycling input rate for silver is estimated to be 19%. It must be said that several other percentages of the End-of-life recycling input rate (EoL-RIR) are reported,

ranging between 20% (GFMS, 2015; 2019) and 80% (UNEP, 2011)(SCRREEN workshops 2019).

A significant proportion of silver is recycled during the manufacturing process. An estimated 5,200 t of both old and process silver scrap was recycled in 2014 (Silver Institute, 2015; GFMS, 2015; 2019), after this flow had been almost twice as high in 2010 and 2011.

Jewellery, silverware and coins have very high recycling rates, typically greater than 90% due to the ease of collecting and recycling of these applications. Once these applications are excluded from the calculation; the EoL-RR for silver falls in the range 30%-50%. High-grade jewellery scrap is usually re-alloyed on-site rather than being refined. Jewellery sweeps, the fine dust generated in the polishing and grinding of precious metals, are usually smelted to form an impure silver, which is electro-refined. Because of the much lower value of silver scrap, recycling techniques applicable to gold (e.g., cyanidation of low-grade scrap) are uneconomic for silver. Low-grade silver scrap is instead returned to a smelter for processing.

However, the EoL-RR varies considerably by application (UNEP, 2011):

•Vehicles (electric and electronic parts): 0%-5%

•Electronics: 10%-15%

•Industrial Applications: 40%-60%

•Others: 40%-60%

For applications where silver use is less dissipative, such as in electric and electronic parts in vehicles and electronics, losses occur in collection, shredding and metallurgical recovery operations. For electronics specifically, recovery rates at state-of-the-art metallurgical plants can be close to 100% of the silver contained, if the printed circuit boards are appropriately collected and pre-treated. In comparison to electronics, industrial applications such as photography and catalysts have a relatively low recycling rate.

29.5Other considerations

29.5.1Environmental issues

Soluble silver salts, especially $AgNO_3$, are lethal in concentrations of up to 2g. Silver compounds can be slowly absorbed by body tissues, with the consequent bluish or blackish skin pigmentation (argiria). The use of Colloidal silver in medication is therefore closely monitored by health regulators. It is currently used in silver ion filtration canisters for pools, tubes and spas. The use of silver based water treatment is also very important in Europe (GFMS, 2011; 2015; 2019).

29.5.2Contribution to low-carbon and green technologies

Green technologies are meant to better protect the environment while meeting the demands of consumers. Based on this, silver demand should grow in the future, due to the expectation for exponential growth of electric vehicles (EVs) and continued investment in solar photovoltaic energy. A potential game changer for transportation is the use of inductively coupled power transfer technology to wirelessly charge vehicles using silver-plated induction coils. Though current market penetration remains low, improvements in performance and cost can open

significant opportunities for wireless charger adoption in the coming years (Silver Institute, 2019).

Furthermore, silver is also used for the generation of nuclear energy; it is used with other metals to produce the reactors' control rods (an alloy that is 80% silver, 15% indium and 5% cadmium).

29.5.3Health and safety issues

Silver's wide variety of uses allows exposure through various routes of entry into the body. Ingestion is the primary route of entry for silver compounds and colloidal silver proteins. Inhalation of dusts or fumes containing silver occurs primarily in occupational settings, while skin contact can occur from the application of burn creams and from contact with jewellery (Drake and Hazelwood, 2005).

Soluble silver compounds are more readily absorbed than metallic or insoluble silver and thus have the potential to produce adverse effects on the human body. Acute symptoms of overexposure to silver nitrate are decreased blood pressure, diarrhea, stomach irritation and decreased respiration. Chronic symptoms from prolonged intake of low doses of silver salts are fatty degeneration of the liver and kidneys and changes in blood cells.

Long-term inhalation or ingestion of soluble silver compounds or colloidal silver may cause argyria and/or argyrosis. Due to prolonged exposure to silver there is a development of a characteristic, irreversible pigmentation of the skin (argyria) and/or the eyes (argyrosis). The affected area becomes bluish-gray or ash gray and is most prominent in areas of the body exposed to sunlight. Soluble silver compounds are also capable of accumulating in small amounts in the brain and in muscles. Silver in any form is not thought to be toxic to the immune, cardiovascular, nervous, or reproductive systems and is not considered to be carcinogenic (Drake and Hazelwood, 2005).

EU occupational safety and health (OSH) requirements exist to protect workers' health and safety. Employers need to identify which hazardous substances they use at the workplace, carry out a risk assessment and introduce appropriate, proportionate and effective risk management measures to eliminate or control exposure, to consult with the workers who should receive training and, as appropriate, health surveillance .

At EU level, occupational exposure limit values (OELs) are set for silver to prevent occupational diseases or other adverse effects in workers exposed to platinum in the workplace. Workers' and employers organisations should be kept informed by member states about the indicative occupational exposure limit values (IOELVs), which is set for metallic silver and silver soluble compounds by Directive 2009/39/EU and 2006/15/EU.

29.5.4Socio-economic issues

Mining operations producing silver are a major source of income and economic growth, with an important role in supporting sustainable socio-economic development. Societal benefit from the revenues created by silver mining depends upon responsible host governments.

Mexico and Peru are the leading suppliers of silver both at global and EU level. Both countries have strong economies; the economy of Mexico is the 15th largest in the world in nominal terms, while Peru is classified as upper middle income by the World Bank and is the 39th largest in the world by total GDP. Accordingly, other producing countries have significant positive socio-economic impacts from silver mining and processing.

Silver as a co- or by-product of other ore mining projects contributes to the economic viability of these operations in Europe as well.

29.6Comparison with previous EU assessments

The results of the economic importance of silver in this assessment are higher than found in the last study of 2017 but still lower than the studies of previous years. The more detailed allocation to NACE2 sectors has caused silver applications not to be joined to food production and energy generation. As these sectors create relatively large value added, the Economic Importance of silver is smaller when these are excluded. The Supply Risk is set at a numerical value that lies between the previously found values. The value is relatively small in general given the large number of silver supplying countries. The results of this and earlier assessments are shown in Table 146.

Table 146: Economic importance and supply risk results for silver in the assessments of 2011, 2014, 2017, 2020 (European Commission 2011)(European Commission 2014)(European Commission 2017b)

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Silver	5.07	0.27	4.77	0.73	3.8	0.5	4.1	0.68

The assessment has been conducted using the same methodology as for the 2017 list. The revised criticality methodology affects both the economic importance and supply risk calculations of silver, which explains the differences in EI and SR results across the 2011/2014 and the 2017/2020 assessments.

In the 2020 assessment, the value-added data used in the calculation of economic correspond to 5-year average 2012-2016 values. The supply risk has been analysed at both mine and processing stages of the value chain. In the 2017 assessment, the results were based on the analysis of the extraction stage only. For this reason there are two supply risk (SR) indicators calculated. The first one regards to ores and concentrates of silvers and is 0.68 for 2020. The second SR indicators is referring to the refined material from the processing stages of the value chain of silver and is 0.21. In the case of ores and concentrates, the Supply Risk (SR) was calculated using both the HHI for global supply and the HHI for EU supply as prescribed in the revised methodology. The second stage is calculated using the EU HHI only because the EU is a net exporter.

29.7Data sources

The product code for silver ores and concentrates is 2616 1000, and is labelled accordingly.

The applied data sources for world production and international trade have a very strong coverage. They are available on EU level, are available for time series and updated at regular intervals and are publicly available.

29.7.1Data sources used in the factsheet

911 Metallurgist (2019). 911Metallurgist. Available at: www.911metallurgist.com//. (Accessed: 01 June 2019)

BGR (2016). Expert consultation with A. Wittenberg.

BGS (2019) World mineral statistics data, British Geological Survey. Available at: https://www.bgs.ac.uk/mineralsuk/statistics/wms.cfc?method=searchWMS (Accessed: 30 July 2019).

Drake, P. L. and Hazelwood, K. J. (2005). *Exposure-Related health effects of silver and silver compounds: a review*, The Annals of Occupational Hygiene, 49(7): 575-585. doi:10.1093/annhyg/mei019

European Commission (2011) *Critical raw materials*. Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en (Accessed: 8 July 2019).

European Commission (2014) *Report on critical raw materials for the EU - Critical raw materials profiles.* Available at: https://ec.europa.eu/docsroom/documents/11911/ attachments/1/translations/en/renditions/pdf.

European Commission (2017a) *Study on the review of the list of critical raw materials. Critical Raw Material Factsheets*. European Commission. doi: 10.2873/398823.

European Commission (2017b) *Study on the review of the list of critical raw materials. Non-critical raw materials factsheets.* European Commission. doi: 10.2873/876644.

Eurostat (2019a) *Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E)*. Available at: https://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_ R2 (Accessed: 7 July 2019).

Eurostat (2019b) *Easy Comext database*. Available at: http://epp.eurostat.ec.europa.eu/ newxtweb/ (Accessed: 7 July 2019).

GFMS (2011). The future of silver industrial demand. GFMS at Thomson Reuters. Commissioned by the Silver Institute. Available at: http://www.silverinstitute.org/ site/wp-content/uploads/2011/07/futuresilverindustrialdemand.pdf. (Accessed: 01 June 2019).

GFMS (2015). World silver survey 2015. GFMS at Thomson Reuters. Commissioned by the Silver Institute. Available at: https://www.silverinstitute.org/site/wp-content/ uploads/2011/06/WSS2015Summary.pdf. (Accessed: 01 June 2019).

GFMS (2019). World silver survey 2019. GFMS at Thomson Reuters. Commissioned by the Silver Institute. Available at: https://www.silverinstitute.org/wp-content/uploads/2019/04/WSS2019V3.pdf. (Accessed: 01 June 2019).

Kumar, A., Vemula, P. K., Ajayan, P.M. and John, G. (2008). Silver-nanoparticle-embedded antimicrobial paints based on vegetable oil, Nature Materials, 7(3):236-241. doi: 10.1038/nmat2099. Epub 2008 Jan 20.

Lenntech (2016). Silver. Available at: http://www.lenntech.com/periodic/elements/ ag.htm (Accessed: 01 June 2019).

Manning, T.J., and Kappes, D.W. (2016). Chapter 25 – Heap Leaching of Gold and Silver Ores, in Gold Ore Processing (2nd Edition). Pp 413-428. https://doi.org/10.1016/B978-0-444-63658-4.00025-6

McQuiston Jr., F.R., 1985. In: Weiss, N.L. (Ed.), SME Mineral Processing Handbook. Societyof Mining Engineers of AIME, New York

Minerals4EU (2019) *European Minerals Yearbook*. Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html (Accessed: 9 July 2019).

Mining Intelligence (2019). Mining Intelligence Research. Available at: https://www.miningintelligence.com/. (Accessed: 01 June 2019).

Mooiman, M. B. and Simpson, L. (2016). Chapter 34 – Refining of Gold- and Silver-Bearing Doré, in Gold Ore Processing (2nd Edition). Pp 595-615. https://doi.org/10.1016/B978-0-444-63658-4.00034-7

Rudnick, R.L. and Gao. S. (2003). Composition of the Continental Crust. In: Treatise on Geochemistry, Volume 3. Editor: Roberta L. Rudnick. Executive Editors: Heinrich D. Holland and Karl K. Turekian. pp. 659. ISBN 0-08-043751-6. Elsevier, p.1-64.

SCRREEN workshop (2019) 'Validation workshop on Critical Raw Materials, 10-12 September 2019, Thon Hotel Brussels City Centre'. Brussels.

Silver Institute (2019). The Silver Institute. Available at: www.silverinstitute.org/. (Accessed: 01 June 2019)

Silverprice (2019). History of silver price. Available at: http://silverprice.org/silver-price-history.html (Accessed: 01 July 2019)

OECD (2019) *Export restrictions on Industrial Raw Materials*. Available at: https://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials (Accessed: 5 July 2019).

UN Comtrade (2019). United Nations Comtrade Database. Available at: https://comtrade.un.org/data/. (Accessed: 5 July 2019).

UNEP (2011). Recycling rates of metals: A status report, United Nations Environment Programme, Available at: http://wedocs.unep.org/bitstream/handle/20.500.11822/8702 /-Recycling%20rates%20of%20metals%3a%20A%20status%20report-2011Recycling_ Rates.pdf?sequence=3&isAllowed=y (Accessed: 16 September 2019)

USGS (2019) *Mineral Commodity Summaries 2019*. U.S Geological Survey. doi: 10.1007/978-3-540-47108-0-4.

29.7.2Data sources used in the criticality assessment

Argus Media (2019). Weekly price updates. Available at: https://www.argusmedia.com/

BGS (2019). BGS- World Mineral Statistics database; World Mineral Production 2012-2016 reports

European Commission (2011) *Critical raw materials*. Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en (Accessed: 8 July 2019).

European Commission (2014) *Report on critical raw materials for the EU - Critical raw materials profiles.* Available at: https://ec.europa.eu/docsroom/documents/11911/ attachments/1/translations/en/renditions/pdf.

European Commission (2017a) *Study on the review of the list of critical raw materials. Critical Raw Material Factsheets*. European Commission. doi: 10.2873/398823.

European Commission (2017b) *Study on the review of the list of critical raw materials. Non-critical raw materials factsheets.* European Commission. doi: 10.2873/876644.

European Commission (2019). DG Trade website "Agreements", Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/

Eurostat (2019a) *Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E)*. Available at: https://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_ R2 (Accessed: 7 July 2019).

Eurostat (2019b) *Easy Comext database*. Available at: http://epp.eurostat.ec.europa.eu/ newxtweb/ (Accessed: 7 July 2019).

Geology.com (2019). Uses of silver. Available at: https://geology.com/articles/uses-of-silver/. (Accessed: 01 July 2019).

GFMS (2011). The future of silver industrial demand. GFMS at Thomson Reuters. Commissioned by the Silver Institute. Available at: http://www.silverinstitute.org/ site/wp-content/uploads/2011/07/futuresilverindustrialdemand.pdf. (Accessed: 01 June 2019).

GFMS (2015). World silver survey 2015. GFMS at Thomson Reuters. Commissioned by the Silver Institute. Available at: https://www.silverinstitute.org/site/wp-content/ uploads/2011/06/WSS2015Summary.pdf. (Accessed: 01 June 2019).

GFMS (2019). World silver survey 2019. GFMS at Thomson Reuters. Commissioned by the Silver Institute. Available at: https://www.silverinstitute.org/wp-content/uploads/2019/04/WSS2019V3.pdf. (Accessed: 01 June 2019).

Noah, N. (2019). *Chapter 6 - Green synthesis: Characterization and application of silver and gold nanoparticles*, Micro and Nano Technologies, 111-135. https://doi.org/10.1016/ B978-0-08-

OECD (2019a) *Export restrictions on Industrial Raw Materials*. Available at: https://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials (Accessed: 5 July 2019).

OECD (2019b) *Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas*. Available at: https://www.oecd-ilibrary.org/ governance/oecd-due-diligence-guidance-for-responsible-supply-chains-of-minerals-from-conflict-affected-and-high-risk-areas_9789264185050-en (Accessed: 5 July 2019).

Silver Institute (2019). The Silver Institute. Available at: www.silverinstitute.org/. (Accessed: 01 June 2019)

UNEP (2011). Recycling rates of metals: A status report, United Nations Environment Programme, Available at: http://wedocs.unep.org/bitstream/handle/20.500.11822/8702 /-Recycling%20rates%20of%20metals%3a%20A%20status%20report-2011Recycling_ Rates.pdf?sequence=3&isAllowed=y (Accessed: 16 September 2019)

USGS (2019). Mineral Commodity Summaries - Silver reports (2012; 2013; 2014; 2015;2016)

Zhang, P., Jiang, X., Yuan, P., Yan, H. and Yang, D. (2018). *Silver nanopaste: Synthesis, reinforcements and application*, Int. Journal Of Heat and Mass Transfer, 127(A): 1048-1069. https://doi.org/10.1016/j.ijheatmasstransfer.2018.06.083

29.8Acknowledgments

This factsheet was prepared by the JRC in collaboration with Mr. Georgios Barakos (TU Bergakademie, Freiberg, Germany). The authors would like to thank the Ad Hoc Working Group on Critical Raw Materials as well as experts participating in SCRREEN workshops for their contribution and feedback.

30. SULPHUR

30.1 Overview

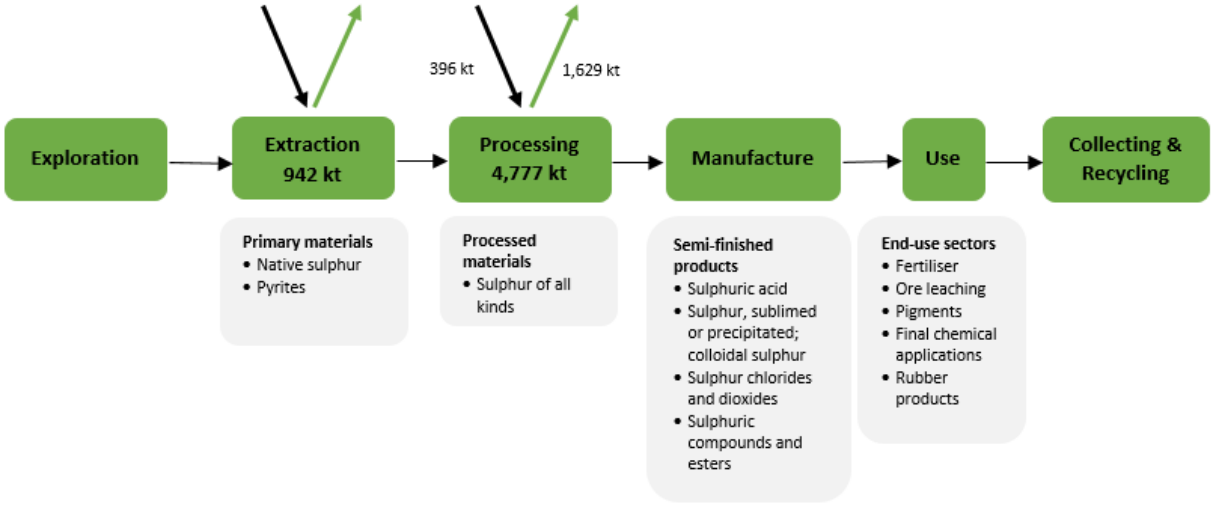
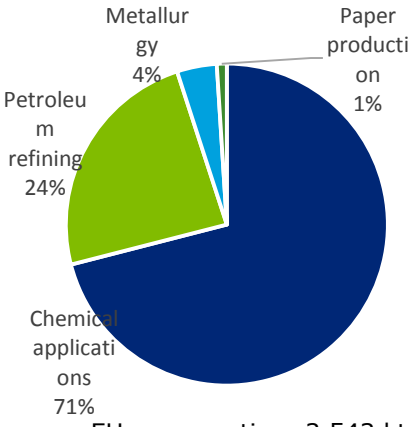
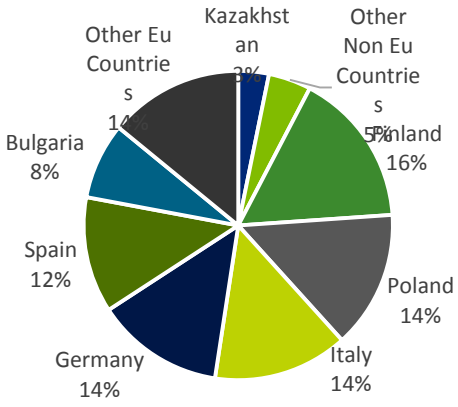


Figure 257: Simplified value chain for Sulphur for the EU, averaged over 2012 to 2016[160]

Sulphur is a non-metallic chemical element with symbol S and atomic number 16. It is a multivalent non-metal, abundant, tasteless and odourless. In its native form sulphur is a yellow crystalline solid. In nature it occurs as the pure element or as sulphide and sulphate minerals (Lenntech, 2016). Sulphur is a valuable commodity and integral component of the world economy used to manufacture numerous products including fertilisers and other chemicals. It is a vital nutrient for people, animals, and plants (The Sulphur Institute, 2019). According to BGS (2019) World Mineral Production data there are only two countries within the EU producing sulphur from discretionary sources – Finland and Poland. All other producers recover sulphur from petroleum and natural gas refining or metal sulphide processing for example. Therefore, the main production is placed at the processing stage.



EU consumption: 3,543 kt



EU sourcing : 5,173 kt

[160] JRC elaboration on multiple sources (see next sections)

Figure 258: End uses and EU sourcing of Sulphur (Eurostat, 2019a; WMD, 2019)

Production data was evaluated using figures reported by World Mining Data 2019 (WMD, 2019).

For trade data the CN8 codes 25030010 Crude or unrefined sulphur (excl. sublimed sulphur, precipitated sulphur and colloidal sulphur), and 25030090 Sulphur of all kinds (excl. crude or unrefined and sublimed sulphur, precipitated sulphur and colloidal sulphur) recorded by Eurostat Comext (Eurostat, 2019a) were used.

At the moment the sulphur market is fairly balanced with produced amount meeting demand. However, production is expected to increase, as the recovery from the oil and gas sector is improved, as well as waste gas purification, incl. higher sulphur recovery, of refineries in developing countries (USGS, 2017a). Over half of elemental sulphur production is traded internationally. China produces 15% of world supply, followed by the USA and Russia (14% and 10%). China is also the largest importer accounting for 31% sulphur imports. The largest exporters in 2016 were the United Arab Emirates and Saudi Arabia (16% and 8.9%). The total market value amounts to USD 2.89 billion (The Sulphur Institute, 2019; OEC, 2019).

In the period of 2012-2016 EU sourced an average of 5,173 kt per year. The main suppliers within the EU are Finland (16%), Poland, Germany, and Italy (14% each), Spain (12%), and Bulgaria (8%). Kazakhstan is providing about 3% of EU consumption, resulting in an import reliance of -35%. The EU is a net exporter of sulphur, between 2012 and 2016 an average of 396 kt per year were imported and 1,629 kt per year were exported.

The main consumer of sulphur is the chemical industry, above all fertiliser production. Sulphur cannot easily be substituted as it is an essential plant nutrient. (The Sulphur Institute, 2015). Other applications are rubber products and pharmaceuticals.

Sulphur can be found in association with different deposits. It occurs in evaporate and volcanic deposits, in natural gas, petroleum, tar sands, and metal sulphides, together with gypsum and anhydrite, in coal, oil shale, and shale rich inorganic matter. (USGS, 2019)

In Europe the main deposits can be found in Finland and Poland, with Poland also being the largest active producer of native sulphur worldwide.

The major producer of sulphur is China, producing an average of 15% of total global supply between 2012 and 2016. Other large suppliers are the United States, Russia and Canada (14%, 10%, and 8% of global supply). The total amount produced in this period is 69,736 kt per year. Producers within the EU are Finland (18% of EU production), Poland (16%), Italy (15%), Germany (14%), Spain, and Bulgaria (13% and 9%). EU countries produce 4,777 kt per year on average from 2012-2016. (WMD, 2019)

There is only minimal production from direct material recycling (no numbers available), however, most sulphur is produced by recovery from petroleum and natural gas production, and from waste air treatment in refineries.

Sulphur in its elemental form is non-toxic, vital for plant growth and cannot be substituted. However, many sulphur compounds are toxic, e.g. sulphur dioxide (SO_2) and hydrogen sulphide (H_2S). Their output from industry, etc. is regulated and has to be closely monitored.

30.2Market analysis, trade and prices

30.2.1Global market analysis and outlook

The average value of sulphur traded between 2012 and 2016 was USD 4.0 billion. In this period the largest exporters were Saudi Arabia, followed by the United Arab Emirates, Russia, and Canada. China was the largest importer, with around 30% market share, followed by Morocco (13%). (OEC, 2019)

With sulphur consumption increasing by 3.5%, the sulphur market was nearly balanced between production and consumption. In 2015, Kazakhstan sulphur stocks were depleted and the availability of sulphur stocks from Canada was reduced as a result of weak economics; both sources had been used to meet global needs during the past decade. Sulphur demand is expected to increase due to fertiliser projects in Brazil, Chana, Egypt, India, and Turkey. However, also production will increase owing to improved recovering from oil and gas production, and the introduction of state-of-the-art waste air treatment in refineries in developing countries. (USGS, 2017a; USGS, 2019).

Table 147: Qualitative forecast of supply and demand of Sulphur

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Sulphur		x	+	+	?	+	+	?

30.2.2EU trade

The EU is a net exporter of sulphur, exporting an average of 1,630 kt per year between 2012 and 2016. Average imports per year amount to 396 kt. Morocco is by far the largest consumer of sulphur from the EU with about 50%, followed by Egypt, Israel, and Turkey (11%, 10%, and 9%).

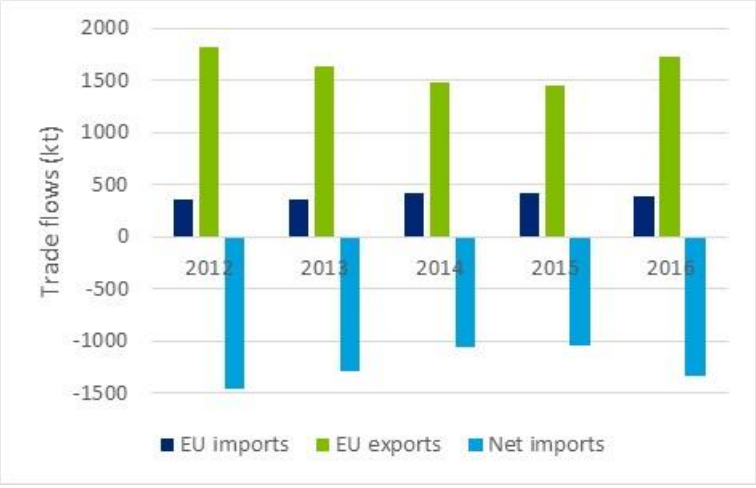


Figure 259: EU trade flows for Sulphur (Eurostat, 2019a)

While sulphur exports remained fairly constant with 1,770 kt and 1,540 kt in 2017 and 2018 respectively, imports increased to 630 kt in 2017 and 570 kt in 2018. The main external sources are Kazakhstan and Russia, together providing about 80% of EU's imports, with both countries no trade agreements are currently in place.

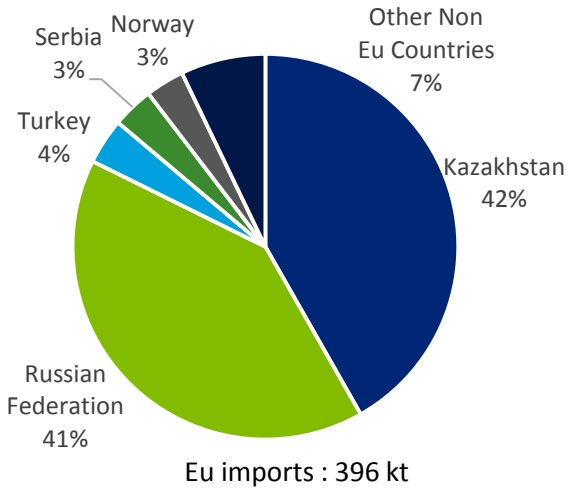


Figure 260: EU imports of Sulphur, averaged over 2012 to 2016(Eurostat, 2019a)

EU demand is mainly met with sulphur produced by EU countries. This results in an import reliance of -35%.

According to OECD (2019) there are currently no export restrictions for sulphur in place. The EU has trade agreements with a number of its trade partners: Canada, Japan, South Korea, Chile, Mexico, and Peru. (European Commission, 2019)

30.2.3Prices and price volatility

Given the global availability of sulphur, we can consider price developments in the United States to illustrate the development of the commodity cost in recent decades. The price shows a remarkable volatility since 1945, with highly unusual spikes between 2005 and 2012. The demand shifts for sulphuric acid and the creation of large stocks and inventories are the cause of this volatility.

The depletion of large sulphur stocks in 2015 in Kazakhstan and the reduction of available sulphur stocks from Canada as a result of weak economics, both were important sources to meet global needs over the past decade, again led to an increase of sulphur prices at the beginning of 2015. (USGS, 2017a)

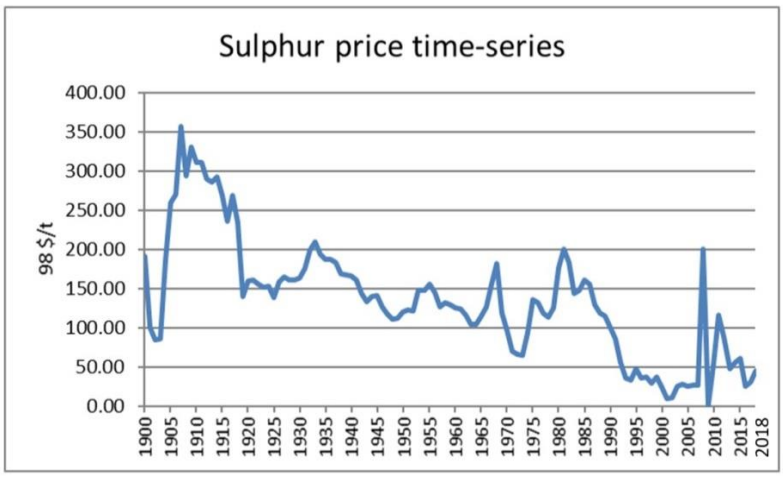


Figure 261: Prices of Sulphur (USD per tonne, converted to 1998 consumer price index) from 1900 to 2018 (USGS, 2017b; USGS, 2019)

The trend of increasing prices continued in 2017 and 2018 to 46.40 and USD 70.00 per tonne respectively. (USGS, 2019)

30.3EU demand

Sulphur was produced in 38 countries worldwide at an average of 69,736 kt per year between 2012 and 2016. The main producer is China with a market share of 15% during this period. In 2017 the sulphur production increased to 73,600 kt. Global market value amounts to USD 2.89 billion in 2016 and decreased slightly in 2017 to USD2.66 billion. (WMD, 2019; OEC, 2019)

30.3.1EU demand and consumption

Sulphur is mainly used by the chemical sector as sulphuric acid (H_2SO_4). The EU had an apparent consumption of sulphur of 3,543 kt per year averaged between 2012 and 2016. Apparent consumption is calculated as imports minus exports plus domestic production.

The EU is also a net exporter, exporting an average amount of 1,623 kt per year between 2012 and 2016. More than 4 times higher than the average amount imported (392 kt). (Eurostat, 2019a; WMD, 2019)

30.3.2Uses and end-uses of Sulphur in the EU

Due to a lack of data on the sulphur industry in the EU Figure 262 shows an overview of sulphur consuming industry sectors based on USGS data.

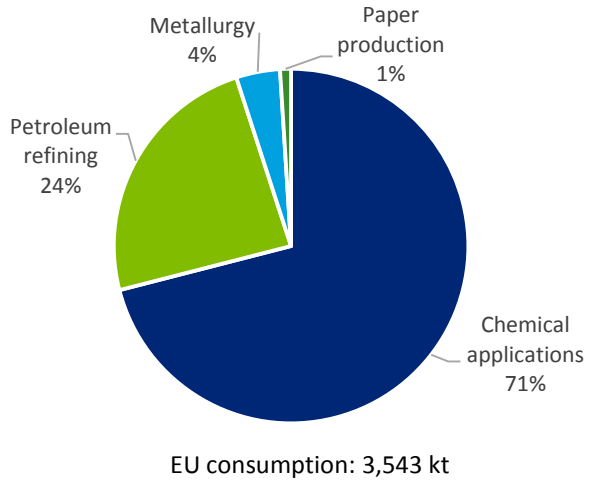


Figure 262: Global end uses (USGS, 2017a)(SCRREEN workshops 2019) and EU consumption of Sulphur (average 2012-2016) (Eurostat 2019a).

Sulphuric acid is the most used chemical worldwide. It is an essential intermediate product in many chemical and manufacturing industries.

The major consumer of sulphuric acid is fertiliser production to manufacture phosphates, nitrogen, potassium, and sulphur fertilisers, as sulphur is an irreplaceable plant nutrient to ensure healthy growth.

However, there are also many other applications for sulphur in the chemical industry:

- Production of pigments and paints
- Soaps and detergents

- Water-treating compounds
- Synthetic rubber production
- Pesticides
- Explosives

Another important consumer of sulphur is the metallurgical industry, especially copper production, where sulphuric acid is necessary for ore leaching.

Moreover, Sulphur is used in the production of pulp and paper products.

Table 148: Sulphur applications, 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2019b)

Applications	2-digit NACE sector	Value added of NACE 2 sector (M€)	4-digit NACE sectors
Use of sulfuric acid (fertiliser production, etc.)	C20 – Manufacture of chemicals and chemical products	105.514	C2013 – Manufacture of other inorganic basic chemicals; C2015 – Manufacture of fertilisers and nitrogen compounds; C2041 – Manufacture of soap and detergents, cleaning and polishing preparations; C2051 – Manufacture of explosives
Petroleum refining and other petroleum and coal products	C19 – Manufacture of coke and refined petroleum products	17,289	C1920 – Manufacture of refined petroleum products
Non-ferrous metallurgical applications	C24 - Manufacture of basic metals	55,426	C2444 – Copper Production
Pulp mills and paper products	C17 – Manufacture of paper and paper products	38,910	C1711 – Manufacture of pulp; C1712 – Manufacture of paper and paperboard

30.3.3Substitution

Sulphur cannot easily be substituted as it is an essential plant nutrient. Over 50% of the produced sulphur is used in agriculture for food production each year (The Sulphur Institute, 2015).

The use of sulphuric acid can be substituted by various other acids. The total size of this substitution is set at 15% in the criticality assessment. The applications of sulphuric acid in industrial processes are numerous and it is difficult to ascertain to what extent these can be changed by substituting H_2SO_4.

However, sulphur can provide opportunities to substitute other materials. Sulphur dioxide can be used as a replacement for selenium dioxide in the production of electrolytic manganese metal. Silicon and sulphur are major substitutes for selenium in low, medium and high voltage rectifiers, and solar photovoltaic cells (see Selenium factsheet).

30.4Supply

30.4.1EU supply chain

The EU has a large domestic sulphur production with 10 countries producing an average of 4,777 kt per year between 2012 and 2016. (WMD, 2019) According to BGS Finland and Poland are the only EU countries also producing sulphur from discretionary sources (942 kt per year). Finland is mining pyrites for sulphur production and Poland utilises the Frasch process.

The sulphur amount imported is comparatively small, with an average of 396 kt per year in the period of 2012-2016. The main suppliers are Kazakhstan (42%), and Russia (41%), other trade partners include Turkey (4%), Serbia, and Norway (3% each). Number one consumer of EU's sulphur is Morocco with about 50% market share. Between 2012 and 2016 the EU exported sulphur in 110 countries Further major buyers are Egypt (11%), Israel (9%), and Turkey (8%). (Eurostat, 2019a)

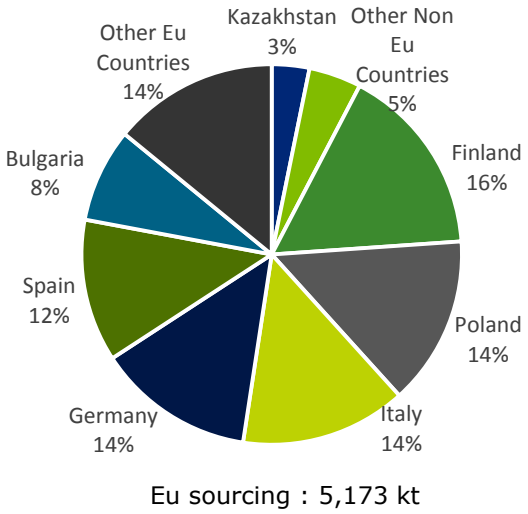


Figure 263: EU sourcing (domestic production + imports) of Sulphur (average 2012-2016)

30.4.2Supply from primary materials

30.4.2.1 Geology, resources and reserves of sulphur

Geological occurrence: Sulphur occurs naturally in the environment and is the thirteenth most abundant element in the earth's crust. Native sulphur is a product of a volcanic origin. However, the majority is created in the process of sulphate reduction (mainly gypsum and anhydrite) with the participation of bacteria and hydrocarbons. (Polish Geological Institute, 2019)

Most of the native sulphur occurs as massive deposits. Many sulphide minerals are known: pyrite and marcasite are iron sulphides; stibnite is an antimony sulphide; galena a lead sulphide; cinnabar a mercury sulphide, and sphalerite is a zinc sulphide. Other, more important sulphide ores are chalcopyrite, bornite, pentlandite, milarite, and molybdenite (Lenntech, 2016).

It can be mined in its elemental form, though this production has reduced significantly in recent years. Since early in the 20th century, the Frasch process has been used as a method to extract sulphur from underground deposits, when it displaced traditional mining principally in Sicily. Most of the world's sulphur was obtained this way until the late 20th century, when sulphur's recovery from petroleum and gas sources (recovered sulphur) became more commonplace. (The Sulphur Institute, 2019)

Global resources and reserves[161]*:* Elemental sulphur resources occur in evaporite and volcanic deposits, moreover, sulphur can be found in natural gas, petroleum, tar sands, and metal sulphides. These resources amount to approximately 5,000 million t. Sulphur is also associated with gypsum and anhydrite providing almost limitless resources. Another source of sulphur is from coal, oil shale, and shale rich inorganic matter, containing about 600,000 million t.

Sulphur reserves in crude oil, natural gas and sulphide ores are large. Most of sulphur production results from fossil fuel processing that implies sulphur supply should be adequate for the foreseeable future. However, the sulphur production may not be in the country to which the reserves were attributed, as petroleum and sulphide ores can be processed long distances from where they were produced. (USGS, 2019)

EU resources and reserves[162]*:* In Poland anticipated economic resources of sulphur amount to 502.5 million t in 2018. (Polish Geological Institute, 2019)

30.4.2.2 World and EU mine production

When considering the sulphur production two different sectors have to be differentiated – the discretionary and the nondiscretionary sector. In 2015, the sulphur production from discretionary sources (mining of sulphur or pyrites is the sole objective) represented only 11% of the total supply. In the nondiscretionary sector, sulphur or sulphuric acid is recovered as an involuntary by-product and the amount of sulphur produced is subject to demand for the primary product and environmental regulations that limit atmospheric emissions of sulphur compounds, e.g. petroleum refineries and natural gas treatment plants. (USGS, 2017a)

[161] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of sulphur in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template[161], which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

[162] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for sulphur. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for sulphur, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for sulphur at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019).Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However a very solid estimation can be done by experts.

Finland is the largest producer in the EU with about 18% of EU production, followed by Poland (16%), Italy (15%), Germany, and Spain (14% and 13%). However, Finland is expected to stop pyrite production by 2020. (First Quantum Minerals Ltd., 2019)

The last active large mining site for native sulphur worldwide is Osiek mine in Poland, where sulphur is mined from the surface using Frasch hot water method. The output amounts to 617 thousand t. (Polish Geological Institute, 2019)

Worldwide the biggest sulphur producers are China, USA, Russia, and Canada. In Europe 11 countries produce sulphur. The annual amount produced worldwide is 68.3 Mt on average between 2012 and 2016. In 2017 the production increased to 73,600 kt.

Figure 264 shows the distribution of sulphur production.

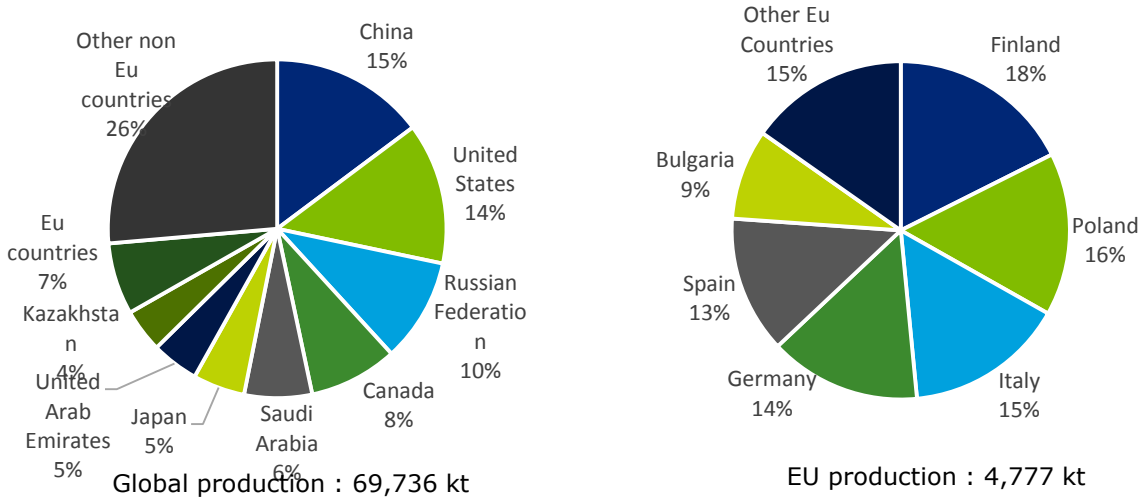


Figure 264: Global and EU mine production of Sulphur in kt and percentage. Average for the years 2012-2016. (WMD, 2019)

30.4.3Supply from secondary materials/recycling

The end-of-life recycling input rate for sulphur is estimated to be 5%. This refers to spent sulphuric acid, which is reclaimed from petroleum refining and chemical processes during any given year.

However, this number requires some further interpretation. The voluntary extraction of sulphur containing ores is made less relevant by the large volumes of sulphur that become available as by-product. The recycling input rate from that perspective is much larger (SCRREEN workshops 2019).

30.4.4Processing of Sulphur

Sulphur is a by-product in most cases, and a co-product in virtually all the other cases. It is estimated that recovered elemental sulphur or by-product sulphuric acid is increasing the percentage of by-product sulphur production to about 90%. Sulphur production as a result of processing of fossil fuels, especially natural gas, accounts for 50% of the annually produced volumes. This had a severe effect on discretionary mining operations, i.e. operations with the

primary goal of extracting sulphur. The large fossil fuel and metal processing industries in the world can be described as non-discretionary: sulphur is obtained as involuntary by-product.

Discretionary sources are either pyrite mines or operations using so called Frasch process.

Non-discretionary sources (apart from fossil fuels and natural gas) are mainly metal refining processes; for instance, the refining of nickel, lead, silver, tin, and copper ores containing sulphides. By far the largest use of manganese (more than 90%) in steel production is as reduction and desulphurisation agent, promoting the separation and collection of sulphur. These sources account for about 40% of the world's supply.

In the Frasch process, native sulphur is melted underground with superheated water and brought to the surface by compressed air. As of 2011, the only operating "Frasch" mines worldwide are in Poland and since 2010 in Mexico. The last mine operating in the United States closed in 2000 (Sulphur Institute 2016).

30.5Other considerations

30.5.1Environmental and health and safety issues

Sulphur is present in many ecologically relevant flows in soil, water, and air. Elemental Sulphur is not toxic, but some sulphur compounds are, for example sulphur dioxide (SO_2) and hydrogen sulphide (H_2S) This is illustrated by the fact that elemental sulphur (and by-product sulphuric acid), produced as a result of efforts to meet environmental requirements, contribute to world supply. Atmospheric sulphur oxides, SO_2 in particular, are emissions that need to be reduced to increase health standards in parts of the EU. The level of sulphur in the environment is strictly regulated. This requires the use of other raw materials to purify water and soils. For instance, a growing amount of limestone is used to remove sulphur dioxide from flue gases, for sewage treatment and for drinking water treatment.

Sulphuric substances can have negative effects on human health, including neurological effects and behavioural changes, disturbance of blood circulation, heart damage, and many more. Effects of sulphur on animals are mostly brain damage, and damage to nervous system.

Besides surplus, instances of dearth of sulphur in the environment are also reported. The incidence of soil sulphur deficiency has rapidly increased in recent years. Three major factors are responsible for increased sulphur deficiency:
a) intensified cropping systems worldwide demand higher sulphur nutrient availability; b) increased use of high-analysis, sulphur-free fertilisers, and c) reduction of sulphur dioxide emissions, particularly in developed regions, reduces atmospheric sulphur deposition, a "natural" sulphur source. (Lenntech, 2019; European Commission, 2017)

EU OSH requirements exist to protect workers' health and safety, employers need to identify which hazardous substances they use at the workplace, carry out a risk assessment and introduce appropriate, proportionate and effective risk management measures to eliminate or control exposure, to consult with the workers who should receive training and, as appropriate, health surveillance[163].

[163] https://ec.europa.eu/social/main.jsp?catId=148

30.5.2Socio-economic issues

The Environmental Justice Atlas (2019) reports examples of mines and refining with social issues related to sulphur production which causes air/water pollution and accompanying socio-economic issues. Among these, Lonmin platinum mine in South Africa; Glencore copper and cobalt mining, Zambia; Mangalore Refinery and Petrochemicals Limited (MRPL), Karnataka, India; Chronic pollution in Eloor, Kerala, India; 1.5.2 Sterlite copper smelter unit, Tamil Nadu, India; 1.5.3 Sponge Iron Plants in Odisha, India Sponge Iron Factories in West Bengal, India; PT Indo Bharat Rayon Viscose Plant, Indonesia.

30.6Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. The results of this and earlier assessments are shown in Table 149.

Table 149: Economic importance and supply risk results for Sulphur in the assessments of 2011, 2014, 2017, 2020 (European Commission, 2017)

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Sulphur	Not assessed		Not assessed		4.6	0.6	4.1	0.27

30.7Data sources

30.7.1Data sources used in the factsheet

BGS (2018). World Mineral Production 2012-2016. p. 69. Available at: https://www.bgs.ac.uk/mineralsuk/statistics/worldArchive.html

European Commission (2017). Study on the review of the list of Critical Raw Materials – Non-critical Raw Materials Factsheets. Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission (2019). Trade – Negotiations and agreements [Online]. Available at: https://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/ (Accessed 12.08.2019)

Eurostat (2019a). International Trade – Comext [Online]. Available at: http://epp.eurostat.ec.europa.eu/newxtweb/ (Accessed: 09.08.2019)

Eurostat (2019b). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E) [Online]. Available at: https://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2 (Accessed: 12.08.2019)

First Quantum Minerals LTD. (2019). Operating Mines – Pyhäsalmi [Online]. Available at: https://www.first-quantum.com/our-business/operating-mines/pyhasalmi/default.aspx (Accessed: 11.09.2019)

Lenntech (2019). Periodic Table – Sulphur [Online]. Available at: https://www.lenntech.com/periodic/elements/s.htm (Accessed: 12.08.2019)

OEC (2019). Sulphur Trade [Online]. Available at: https://oec.world/en/profile/hs92/2503/ (Accessed: 09.09.2019)

Polish Geological Survey (2019). Mineral Resources of Poland – Sulfur. Available at: http://geoportal.pgi.gov.pl/surowce/chemiczne/siarka (Accessed: 12.08.2019)

SCRREEN workshop (2019) 'Validation workshop on Critical Raw Materials, 10-12 September 2019, Thon Hotel Brussels City Centre'. Brussels.

The Sulphur Institute (2015). Sulphur – Vital for Life. Available at: https://www.sulphurinstitute.org/publications/index.cfm

The Sulphur Institute (2019). An Introduction to Sulphur. [online] Available at: https://www.sulphurinstitute.org/learnmore/sulphur101.cfm.

USGS (2017a). 2015 Minerals Yearbook – Sulphur [Advance Release]. Available at: https://www.usgs.gov/centers/nmic/sulfur-statistics-and-information

USGS (2017b) Historical Statistics for Mineral and Material Commodities in the United States – Sulfur. Available at: https://www.usgs.gov/centers/nmic/historical-statistics-mineral-and-material-commodities-united-states

USGS (2019). Mineral Commodity Summaries – Sulfur. Available at: https://www.usgs.gov/centers/nmic/sulfur-statistics-and-information

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

30.7.2 Data sources used in the criticality assessment

European Commission (2019). Trade – Negotiations and agreements [Online]. Available at: https://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/ (Accessed 12.08.2019)

Eurostat (2019a). International Trade – Comext [Online]. Available at: http://epp.eurostat.ec.europa.eu/newxtweb/ (Accessed: 09.08.2019)

OECD (2019). Export restrictions on Industrial Raw Materials [Online]. Available at: https://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/ (Accessed: 12.09.2019)

The Sulphur Institute (2019). An Introduction to Sulphur. [online] Available at: https://www.sulphurinstitute.org/learnmore/faq.cfm#used

USGS (2017a). 2015 Minerals Yearbook – Sulphur [Advance Release]. Available at: https://www.usgs.gov/centers/nmic/sulfur-statistics-and-information

USGS (2019). Mineral Commodity Summaries – Sulfur. Available at: https://www.usgs.gov/centers/nmic/sulfur-statistics-and-information

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

30.8 Acknowledgments

This factsheet was prepared by the JRC in collaboration with Ms. Marie-Theres Kügerl (Resources Innovation Center Leoben). The authors would like to thank the Ad Hoc Working Group on Critical Raw Materials, as well as experts participating in SCRREEN workshops for their valuable contribution and feedback.

31. TALC

31.1 Overview

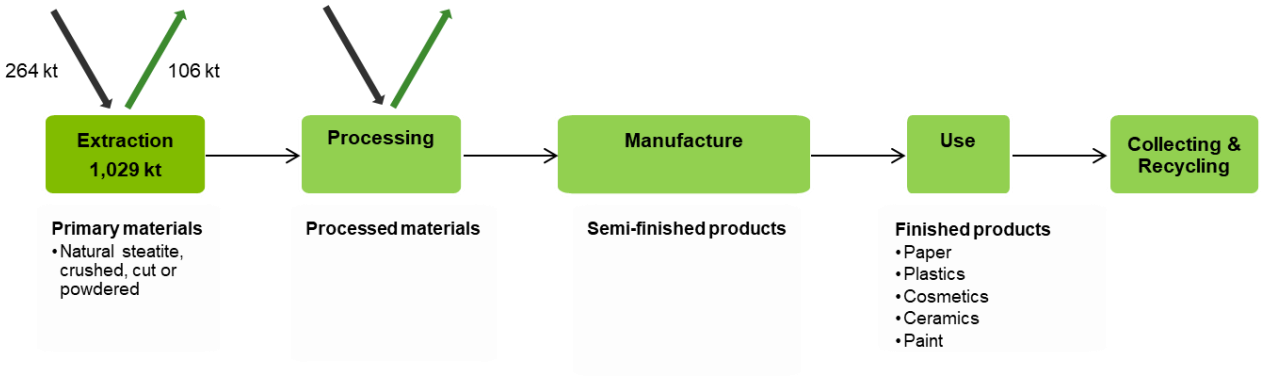
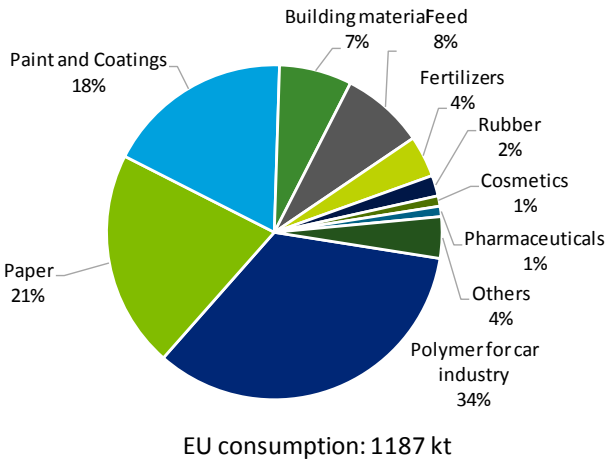


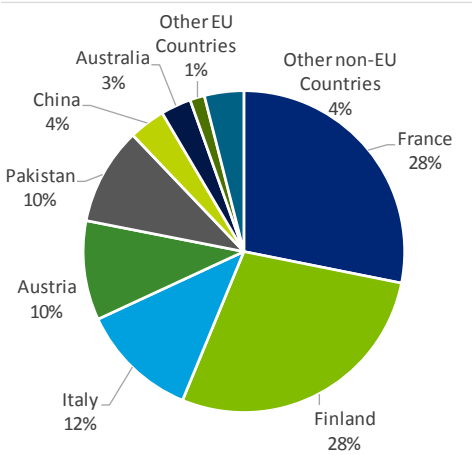
Figure 265: Simplified value chain for talc for the EU[164] (2012-2016)

Talc ($Mg_3Si_4O_{10}(OH)_2$) is a hydrous magnesium silicate mineral (BGS, 2016) and belongs to the group of phyllosilicates. The elementary sheet is composed of a layer of magnesium-oxygen/hydroxyl octahedra, sandwiched between two layers of siliconoxygen tetrahedra. Talc is the world's softest mineral (Mohs' hardness of 1). Talc is formed under hydrothermal conditions and it frequently arises in association with chlorite, magnesite and serpentine. Talc is generated in two different alteration processes, either hydrothermal alteration of ultramafic rocks or siliceous hydrothermal alteration of Mg-limestone or dolomite. This results in two types of deposit, with talc being is a so-called secondary mineral or alteration mineral.

The CN codes used for talc are: 252610 – Natural steatite and talk (not crushed, not powdered) and 252620 (crushed or powdered).



EU consumption: 1187 kt



EU sourcing : 1 293 kt

Figure 266: End uses (IMA-Europe, 2018) and EU sourcing (BGS, 2019; Eurostat, 2019) for talc (2012-2016)

[164] JRC elaboration on multiple sources (see next sections)

Talc growth in several industrial sectors suggests that sales may increase in the next five years (2020-2025). The changes in supply and demand on a longer term are expected to be rather stable and balanced. EU Apparent consumption of 1,187 kt per year (average 2012-2016) was relatively flat in the reporting period, but is estimated to decrease in 2018 owing to decreased imports and increased exports (Eurostat, 2019). Regarding talc imports to the EU between 2012 and 2016, it is seen that the supply is quite stable and shows only minor fluctuations, amounting to 264 kt per year on average in this period. The total share of imports in the EU consumption was also more or less constant. The size of EU trade compared to EU production was small, ranging between 10 and 20% (average 2012-2016).

The price of talc, which is highly influenced by its purity and whiteness, has increased in the period 2009-2018 by almost 90% and reached 195 € per ton in 2018 (USGS, 2019).

The EU net import reliance is 13%, with imports of 264,229 tonnes per year, averaged over 2012-2016. According to Eurostat (Eurostat Comext, 2019), the main contributors for the talc imports were: Pakistan (48%), China (18%) and Australia (15%) and other non-EU countries for around 20%.

The main end-uses of talk (IMA-Europe, 2018) depends on purity and whiteness and involve the sectors of Car Industry as polymers (34%), Paper (21%), Paints and Coatings (18%), Construction as building materials (7%) and other uses including fertilizers, rubber, cosmetics, pharmaceuticals, etc (20%). Potential substitutes for talc are: Bentonite, chlorite, feldspar, kaolin, and pyrophyllite in ceramics; compared to kaolin talc is more expensive but it performs better than kaolin. For paint, talc could be substituted by chlorite. It is possible to use mica and kaolin as substitute as well, but properties are different and the requirements of the use should not be demanding.

Talc deposits are widespread and mined worldwide. The biggest talc reserves are located in the US (140 million tonnes), India (110 million tonnes), Japan (100 million tonnes), China (820 million tonnes), Brazil (44 million tonnes), Korean republic (8 million tonnes), whereas in Europe large large resources are known in Finland, France, Italy and Autria (USGS, 2019).

The global production of talc between 2012 and 2016 was annually 7,500 kt on average. In 2011, China was the largest talc producer with 26% of the total output. India, the Republic of Korea, the United States and Brazil were other main producers. The large share of other countries extracting talc indicates that operations are widespread and locations significantly depend on transport costs. The talc production from EU countries amounts to 1,030 kt, which represent 14% of the global talc production (average 2012-2016). Talc is within the EU mainly produced in Finland (35% of EU sourcing), France (35% of EU sourcing), Italy (15% of EU sourcing) and Austria (12.5% of EU sourcing).

Information on export restrictions are accessed by the OECD Export restrictions on Industrial Raw Materials database (OECD, 2019). There are no export restrictions, quotas or prohibitions identified that may impact on the availability of talc.

31.2Market analysis, trade and prices

31.2.1Global market analysis and outlook

Growth in several industrial sectors suggests that sales of talc may increase in the next five years (USGS, 2019). The changes in supply and demand on a longer term are expected to be rather stable and balanced compared to each other, see Table 150.

Table 150: The outlook of talc supply and demand

Material	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Talc		x	+	0/+	0/+	+	0/+	0/+

Apparent consumption was relatively flat between 2014 and 2017. Production and apparent consumption in 2018 were about 42% and 32% lower, respectively, than in 1995.

Several US talc markets have declined over the last two decades (USGS, 2019), with the largest decreases taking place in the ceramics (talc use fell by an estimated 58%), cosmetics (57%), roofing (47%), paint (24%), and paper (21%) industries. Ceramic tile and sanitaryware formulations and the technology for firing ceramic tile changed, reducing the amount of talc required for the manufacture of some ceramic products. For paint, the industry shifted its focus to production of water-based paint (a product for which talc is not well suited because it is hydrophobic) from oilbased paint, in order to reduce volatile emissions. Paper manufacturing began to decrease beginning in the 1990s, and some talc used for pitch control was replaced by chemical agents. For cosmetics, manufacturers of body dusting powders shifted some of their production from talc-based to corn-starch-based products. In contrast, sales of US talc for plastics increased by an estimated 34% from 1995 to 2018, primarily as the result of increased use in automotive plastics, but a significant share of the increased demand has been met with imported talc. The quantity of talc used in rubber production increased by 11% in 2018 compared with that in 1995.

31.2.2EU trade

The international trade of talc between 2012 and 2016 is quite stable and shows only minor fluctuations, with an import of 264 kt per year on average (2012-2016). The total share of imports in the EU consumption is also constant over this period. The size of EU trade compared to EU production is small, ranging between 10 and 20%.

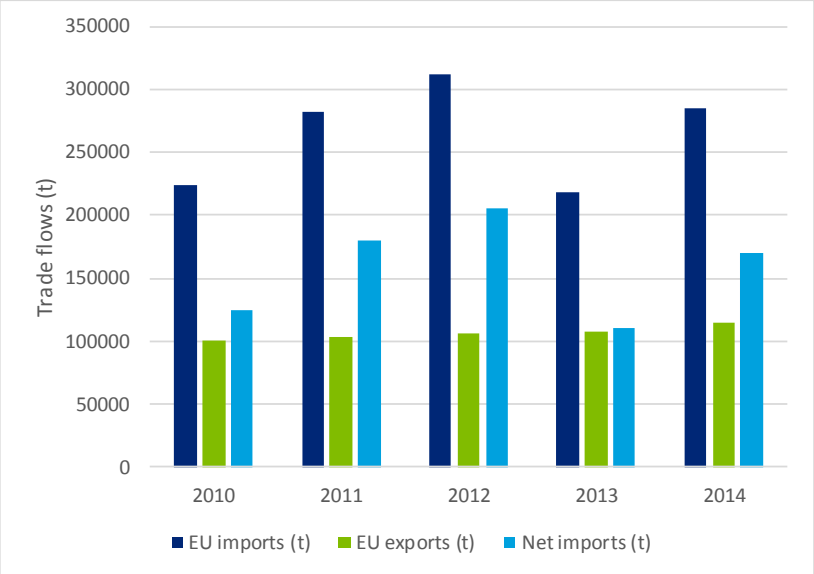


Figure 267: EU trade flows for talc (Eurostat 2019)

According to the Eurostat data, for a total of 264kt imported to Europe, the biggest amount of talc was exported by Pakistan (48%), China (18%) and Australia (15%).

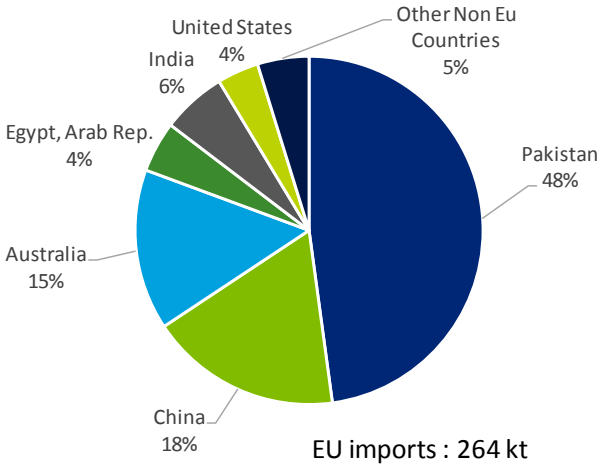


Figure 268: EU imports of talc, average 2012-2016 (Eurostat, 2019).

EU trade is analysed using the group codes 252610 – Natural steatite and talk (not crushed, not powdered) and 252620 (crushed or powdered). It is possible that materials are part of product groups also containing other materials and/or being subject to re-export, the "Rotterdam-effect". This effect means that materials can originate from a country that is merely trading instead of producing the particular material.

31.2.3Prices and price volatility

The price of talc increases has increased over 2009-2018 by almost 90% (USGS, 2019).

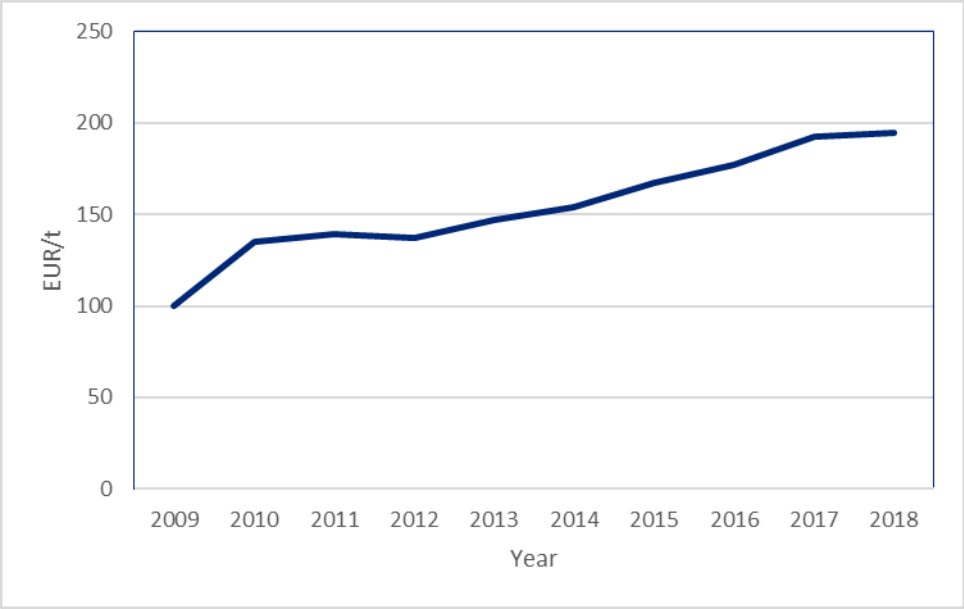


Figure 269: Evolution of price of talc, average 2009-2018 (USGS, 2019).

31.3EU demand

31.3.1EU demand and consumption

The annual average EU consumption was around 1,200 kt between 2012 and 2016. The annual EU production over the period 2012-2016 was 1,030 kt, while the average annual imports to the EU over the same period were 264 kt and the average annual exports 106 kt.

31.3.2Uses and end-uses of Talc in the EU

Talc has numerous applications in various sectors, always depending on purity and whiteness (IMA-Europe, 2018; IMA-Europe, 2019). It can be used, among others, for the production of:

- polymers for the car industry
- both uncoated and coated rotogravure papers where it enhances printability and reduces surface friction, improving productivity at the paper mill and print house; it also improves mattness and reduce ink scuff in offset papers
- in interior and exterior decorative paints, offering a whole range of benefits to coatings and acting as extender to improve hiding power and titanium dioxide efficiency; talc's lamellar platelets makes paint easier to apply and improves cracking resistance and sagging; it also enhances matting
- building materials; talc as a phyllosilicate imparts a wide range of functions to floor and wall tiles, sanitary-ware, tableware, refractories and technical ceramics; in traditional building ceramics (tiles and sanitaryware) it is used essentially as a flux, enabling firing temperatures and cycles to be reduced
- additives in food or feed, cosmetics, pharmaceuticals or fertilizers.

In Europe, the largest applications of talc involve the sectors of car industry as polymers (34%), paper (21%), paints and coatings (18%), construction as building materials (7%) and other uses including fertilizers, rubber, cosmetics, pharmaceuticals, etc.

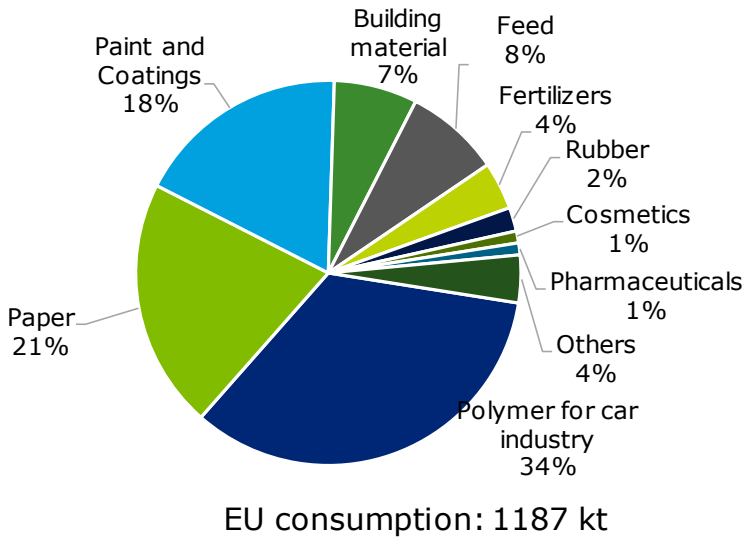


Figure 270: EU end uses of talc (IMA-Europe, 2018), average 2012-2016.

The calculation of economic importance is based on the use of the NACE 2-digit codes and the value added at factor cost for the identified sectors. The value added data correspond to 2012-2016 figures.

Table 151: Talc applications (IMA-Europe, 2018), 2-digit NACE sectors associated 4-digit NACE sectors and value added per sector (period 2012-2016, Eurostat, 2019).

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (millions €)
Polymer for car industry	C22 - Manufacture of rubber and plastic products	C22.21 -Manufacture of plastic plates, sheets, tubes and profiles	75,980
Paper	C17 - Manufacture of paper and paper products	C17.23 -Manufacture of paper stationery	38,910
Paint and Coatings	C20 - Manufacture of chemicals and chemical products	C20.30 - Manufacture of paints, varnishes and similar coatings, printing ink and mastics	105,514
Building material	C23 - Manufacture of other non-metallic mineral products	C23.32 - Manufacture of bricks, tiles and construction products, in baked clay	57,255
Feed	C10 - Manufacture of food products	C10.89 - Manufacture of other food products n.e.c.	155,880
Fertilizers	C20 - Manufacture of chemicals and chemical products	C20.15 - Manufacture of fertilisers and nitrogen compounds	105,514
Rubber	C22 - Manufacture of rubber and plastic products	C22.21 -Manufacture of plastic plates, sheets, tubes and profiles	75,980
Cosmetics	C21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations	C21.20 -Manufacture of pharmaceutical preparations	80,180
Pharmaceuticals	C21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations	C21.10 - Manufacture of basic pharmaceutical products	80,180
Others	C21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations	C21.10 - Manufacture of basic pharmaceutical products	80,180

31.3.3Substitution

According to the various end-uses of talc, different properties of the minerals are required for the given application. Depending on these properties there are potential substitutes for talc.

Bentonite, chlorite, feldspar, kaolin, and pyrophyllite in ceramics; compared to kaolin talc is more expensive but it performs better than kaolin.

Talc can be replaced by kaolin in paper coating in gravure printing application. Talc is normally more expensive than kaolin and this condition has spurred the search for substitute materials. Talc cannot be replaced by calcium carbonate or kaolin when used as "pitch and stickies" preventing agent.

Mica can replace talc in plastics when high stiffness is required. The downside is the drastic reduction of impact resistance. In summary mica is a niche market vs talc and its cost is generally higher. Wollastonite can replace talc in come specific products (from all kinds of applications). As for mica, the use is not wide (2%) and its cost is normally higher than talc (IMA-Europe, 2019).

For paint, talc could be substituted by chlorite. It is possible to use mica and kaolin as substitute as well, but properties are different and the requirements of the use should not be demanding.

For agrochemical applications talc is sometimes substituted by fuller's earth, kaolin, diatomite, perlite, gypsum, and sepiolite.

31.4Supply

31.4.1EU supply chain

As with many industrial minerals, the industry (mineral products, construction materials, chemical productions, paper manufacturing) in the EU takes the raw materials inputs directly from extraction and wholesale businesses.

The EU relies for the supply of talc for 21% on its imports, averaged over 2012-2016. The imported talc is either specifically aimed at an application or shipped along with other minerals.

The only country imposing significant trade restrictions related to talc is China. It applied an export quota between 500 kt and 700 kt between 2010 and 2014, an export tax of 10% and a licensing requirement (OECD, 2016).

31.4.2Supply from primary materials

31.4.2.1 Geology, resources and reserves of talc

Geological occurrence: Talc ($Mg_3Si_4O_{10}(OH)_2$) is a hydrous magnesium silicate mineral (BGS, 2016) and belongs to the group of phyllosilicates. The elementary sheet is composed of a layer of magnesium-oxygen/hydroxyl octahedra, sandwiched between two layers of siliconoxygen tetrahedra (IMA, 2019). The main or basal surfaces of this elementary sheet do not contain hydroxyl groups or active ions, which explains talc's hydrophobicity and inertness. In its massive and impure form the mineral is also known as steatite and soapstone. The mineral has a greasy feel because of its very low hardness. On the Mohs scale of hardness talc is ranked at "1", thus it is the softest mineral on this scale, and its density varies from 2.7 to 2.8 g/cm^3 (Tufar, 2000). Talc is practically insoluble in water and in weak acids and alkalis; talc's melting point is 1,500°C.

Although all talc ores are soft, platy, water repellent and chemically inert, talc ores are almost never similar (IMA, 2019). Talc originates from environments of weak metamorphism. It is formed under hydrothermal conditions and it frequently arises in association with chlorite, magnesite and serpentine. Talc is generated in two different alteration processes, either hydrothermal alteration of ultramafic rocks or siliceous hydrothermal alteration of Mg-limestone or dolomite. This results in two types of deposit, with talc being is a so-called secondary mineral or alteration mineral.

Talc ores also differ according to the type and proportion of associated minerals present. They can be divided into two main types of deposits: talc-chlorite and talc-carbonate. Talc-chlorite ore bodies consist mainly of talc (sometimes 100%) and chlorite, which is hydrated

magnesium and aluminium silicate. Chlorite is lamellar, soft and organophilic like talc. It is however slightly less water repellent than talc. Talc-carbonate ore bodies are mainly composed of talc carbonate and traces of chlorite. Carbonate is typically magnesite (magnesium carbonate) or dolomite (magnesium and calcium carbonate). Talc-carbonate ores are processed to remove associated minerals and to produce pure talc concentrate. (IMA-Europe, 2019).

Global resources and reserves*:*

Talc deposits are widespread and mined worldwide. USGS (2019) provides some rough data about global [165] and EU [166] reserves of talc. It is not likely that more accurate reserve estimations will be available in the coming years.

Table 152: Global reserves of talc in year 2018 (USGS, 2019).

Country	Talc Reserves (tonnes)
United States	140,000,000
India	110,000,000
Japan	100,000,000
China	82,000,000
Brazil	44,000,000
Korean republic	8,000,000
Finland	Large
France	Large
Other countries	Large
World total (rounded)	*Large*

31.4.2.2 World and EU mine production

Mining and processing: Extracted talc minerals are first subjected to a comminution process that involves crushing, grinding and sieving. After that, talc beneficiation usually uses hand picking, photoelectric picking, electrostatic dressing, flotation, dry or wet magnetic separation, dry grinding air classification, micro powder technology and talc layered, selection process. At present, the mature beneficiation research and test technology contain photoelectric pick and bleaching. In addition to the grinding work, the beneficiation plant also can use flotation

[165] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of talc in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template (www.crirsco.com), which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

[166] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for talc. The Minerals4EU (2019) project is the only EU-level repository of some mineral resource and reserve data for talc, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU (2019) data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for talc at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system. Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system.

process to select low grade ores and can do comprehensive recovery of beneficial associated minerals (Zenith, 2016).

The global production of talc between 2012 and 2016 was annually 7,500 kt on average. In 2011, China was the largest talc producer with 26% of the total output. India, the Republic of Korea, the United States and Brazil were other main producers. The large share of other countries extracting talc indicates that operations are widespread and locations significantly depend on transport costs. The talc production from EU countries amounts to 1,030 kt which represent 14% of the global production. Talc is within the EU mainly produced in Finland (35% of EU sourcing), France (35% of EU sourcing), Italy (15% of EU sourcing) and Austria (12.5% of EU sourcing).

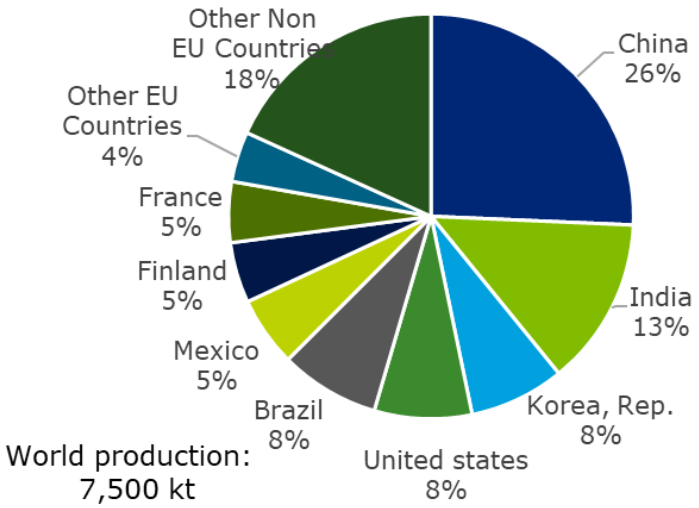


Figure 271: Global mine production of talc, average 2012–2016 (BGS World Mineral Statistics database, 2016 and 2019).

31.4.3Supply from secondary materials/recycling

The recycling rate of talc is high in several industrial sectors (IMA-Europe, 2018, Eurotalc, 2019). More specifically:

As talc used in polymers for car manufacturing is concerned, recycled plastics are mainly used for under-the-bonnet automotive parts, arch liners, cable harness plugs, water and sewage pipes, furniture feet, chair arm rests and electric motor housings. Thus, to calculate the talc recycling rate in this application the average recycling rate of end-of-life vehicles in the EU, which is 88%, can be used.

Paper fibres are recycled 3.6 times on average in the EU, significantly outperforming the world average of 2.4 times. The recycling rate in Europe increased to 72.5% in 2016.

Interior and exterior paints, which represent 50-60% of the total amount of paint consumed, are recycled the most, principally in aggregates and other construction materials. Therefore, the figures of the recycling of construction and demolition waste can be reasonably used and, considering the large disparities in recycling rates in EU countries, an average recycling rate of 50% can be taken for construction and demolition waste. Also 50% can be used as recycling rate for talc used as building material.

By taking into account that other uses for talc are diverse, it is difficult to establish recycling figures. For instance, talc is used for its functional properties as an additive in food or feed, cosmetics, pharmaceuticals or fertilizers. It is therefore entirely consumed with the relevant products and ultimately returned to nature.

As the calculation of supply risk is concerned, end of life recycling input rate (EoL-RIR) for talc was estimated at 16% (SCRREEN workshops, 2019).

31.5Other considerations

31.5.1Environmental and health and safety issues

In recent years, stakeholders in the talc industry proved successfully that their products do not contain asbestos as defined by the European directive 83/477/EEC. Asbestiform is a term that is used to describe the mineral habit of minerals that are formed in a fibrous state that resembles asbestos (Eurotalc, 2016). The suggestion that lung cancer might be correlated to mining operations are dismissed for several years (Wild & Coll, 2002).

The assessment of carcinogenicity of talc should take into account if talc contains or not asbestos, as done in earlier reviews (International Agency for Research on Cancer, IARC 1987; NIOSH, 1980). The IARC classifies talc containing asbestos as "carcinogenic to humans" (group 1). However, by taking into account that animal studies provide limited data and human studies are very few and rather incomplete, the IARC classifies inhaled talc without asbestos as "not classifiable as to carcinogenicity in humans" (group 3) (IARC, 2010). The U.S. National Toxicology Program (NTP) has not fully reviewed talc as a possible carcinogen (NTP, 2000).

In an earlier study it is mentioned that pure cosmetic or pharmaceutical-grade talc should not be considered as carcinogen since there is no credible evidence of a cancer risk from inhalation by humans (Wehner, 2002). The US Food and Drug Administration (FDA) issued a safety alert warning in June 2019 consumers not to use certain cosmetic products tested positive for asbestos (FDA, 2019).

A recent study provides data for China, the largest talc-producing country, and indicates that nonasbestiform talc might still increase the risk of lung cancer and mentions that further epidemiological studies are required to evaluate the safety of workers with occupational talc exposure (Chang et al., 2017). Similar studies need to be conducted in other major talc producing countries, including India and Brazil (Fitzgerald et al., 2019). So far, major studies for talc have been conducted mainly in Europe and North America (Drechsel et al., 2018; Mandarino et al., 2019; Taher et al., 2019).

31.5.2Socio-economic issues

Talc production has been an important commercial activity in Europe for over a hundred years and has contributed economically and socially to the local communities where the producers operate. Talc's technical and environmental advantages make it a commercially viable product in the long term. It will continue to create value for local economies and to contribute to building a sustainable future for the global talc industry (Eurotalc, 2019).

Socio-economic issues are very important for the areas (and the countries) where talc is mined or processed since such activities contribute to social welfare and economic growth. To ensure environmental protection offsets the adverse effects of mining and processing, EUROTALC member companies operate environmental management systems in line with international standards such as the ISO 14000 series (Eurotalc, 2019).

In order to meet the criteria of sutainable growth and environmental protection, sustainable development indicators (SDIs) need be used at all stages, including exploration, mining, processing and post-mining. So that social, economic and environmental improvement is achieved in the areas of concern (Tzeferis et al., 2013; Blengini et al., 2013; Komnitsas et al., 2013). Also, when planning, building and opening new mines and/or processing facilities, care needs to taken to mitigate the visual impact of mining and processing operations. This planning also includes rehabilitation/restoration of the environment and its biodiversity during mining and when an operation is closed.

31.6Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. The results of this and earlier assessments are shown in Table 153.

Table 153: Economic importance and supply risk results for talc in the assessments of 2011, 2014 (European Commission, 2011-2014-2017)

Assessment year	2011			2014			2017			2020	
Indicator	EI	SR		EI	SR		EI	SR		EI	SR
Talc	4.02	0.3		5.10	0.26		3.0	0.40		4.0	0.4

The economic importance of talc is reduced given the mega sector considered in the previous analysis. The increase in supply risk is due to the weight that the new methodology places in very low end-of-life recycling input rates. The input values relate to substitution and indicate that the change in supply risk is due to the new methodology applied in last two assessments.

31.7Data sources

There are two CN product groups that cover talc (or products dominated by talc content). Those are coded 2526 10 00 (labelled "Natural steatite, whether or not roughly trimmed or merely cut, by sawing or otherwise, into blocks or slabs of a square or rectangular shape, and talc, uncrushed or unpowdered") and 2526 20 00 (labelled "Natural steatite and talc, crushed or powdered").

The data used for the period 2012-2016 are mainly coming from (BGS, 2016 and 2019; Eurostat, 2019).

31.7.1Data sources used in the factsheet

Blengini, G.A., Moltrer, A., Valbusa, M., Komnitsas, K., Agioutantis, Z., Garbarino, E., (2013). Data and methodologies for a resource-efficient planning of primary and secondary aggregates in South East Europe (SEE) countries, Proceedings 6th International Conference "Sustainable Deveoplemt in the Minerals Industry (SDIMI)", 30 June - 3 July 2013, Milos, Greece, http://sdimi2013.conferences.gr/sdimi2013-home.html

Chang, C.-J., Tu, Y.-K., Chen, P.-C., Yang, H.-Y. (2017). Occupational exposure to talc increases the risk to lung cancer: A meta-data analysis of occupational cohort studies, Can Respir J. 1270608.

Drechsel,D.A., Barlow, C.A., Bare, J.L., Jacobs, N.F., Henshaw, J.L. (2018). Historical evolution of regulatory standards for occupational and consumer exposures to industrial talc, Regulatory Toxicology and Pharmacology, 92, 251-267.

Eurotalc (2016). Health and safety. [online] Available at: http://www.eurotalc.eu/health-and-safety

European Commission (2011). Critical raw materials for the EU. [online] Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission (2014) Report on critical raw materials for the EU – Non Critical raw materials profiles.

European Commission (2019). DG Trade. Agreements [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/

Eurostat (2019a). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2019b). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2 (last update 19/08/19)

Eurotalc (2019). https://www.eurotalc.eu/sustainability (accessed Aug. 13, 2019)

FDA 2019. US Food and Drag AAdministration, https://www.fda.gov/cosmetics/cosmetic-ingredients/talc (accessed on June 15, 2019).

Fitzgerald, S., Harty, E., Joshi, T.K., Frank, A.L. 2019. Asbestos in commercial indian talc, American Journal of Industrial Medicine, in press, https://doi.org/10.1002/ajim.22969.

IARC (1987). Evaluation of the carcinogenic risk of chemicals to humans: silica and some silicates. *IARC Monographs*, 42:13–32.

IARC (2010). Working Group on the Evaluation of Carcinogenic Risks to Humans. Carbon black, titanium dioxide, and talc. *IARC monographs on the evaluation of carcinogenic risks to humans/World Health Organization, International Agency for Research on Cancer*, 93:1–413.

IMA (2018). Recycling Industrial Minerals, August 2018, www.ima-europe.eu

IMA (2019). Factsheet talc. Available at: https://www.ima-europe.eu/about-industrial-minerals/industrial-minerals-ima-europe/talc

Komnitsas, K., Agioutantis, Z., Shields, D., Blengini, G.A., Tzeferis, P.G. (2013). Stakeholder identification in the planning phase of aggregate and quarrying projects, Proceedings 6th International Conference "Sustainable Deveoplemt in the Minerals Industry (SDIMI)", 30 June - 3 July 2013, Milos, Greece, pp. 294-301, http://sdimi2013.conferences.gr/sdimi2013-home.html

Mandarino, A., Gregory, D.J., McGuire, C.C., Leblanc, B.W., Witt, H., Mejias Rivera, L., John J. Godleski, J.J., Fedulov, A. V. (2019). The effect of talc particles n phagocytes in co-culture with ovarian cancer cells, Envieonmental Reseacrh, in press, https://doi.org/10.1016/j.envres.2019.108676

Minerals4EU (2019). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

NIOSH (National Institute for Occupational Safety and Health, 1980), Occupational exposure to talc containing asbestos, US Department of Health, Education and Welfare, Technical Report, Publication No 80-115, https://www.cdc.gov/niosh/docs/80-115/pdfs/80-115.pdf.

National Toxicology Program (NTP) (2000). *Draft Report on Carcinogens Background Document for Talc Asbestiform and Non-Asbestiform*.Research Triangle Park, NE, National Toxicology Program; 2000.

OECD (2019). Export restrictions on Industrial Raw Materials database [online]. http://qdd.oecd.org/table.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

Taher, M.K., Farhat, N., Karyakina, N.A., Shilnikova, N., Ramoju, S., Gravel, C.A., Krishnan, K., Mattison, D., Wen, S-W., Krewski, D. Critical review of the aasociation between perinal use of talc powder and ovarian cancer, Reproductive Toxicology, in press, https://doi.org/10.1016/j.reprotox.2019.08.015.

SCRREEN CRM validation workhop (2019). Expert's comment, Brussels, 11 Sep. 2019.

Tufar, W. (2000). Talc. Ullmann's Encyclopedia of Industrial Chemistry. Available at: http://onlinelibrary.wiley.com/doi/10.1002/14356007.a26_047/abstract

Tzeferis, P., Kavalopoulos, Komnitsas, K., (2013). Production data and Sustainable Development Indicators (SDIs) for the Greek Mining/Metallurgical Industry in the period 2007-2011, Proceedings 6th International Conference "Sustainable Deveoplemt in the Minerals Industry (SDIMI)", 30 June - 3 July 2013, Milos, Greece, pp. 269-276, http://sdimi2013.conferences.gr/sdimi2013-home.html

USGS (2019). U.S. Geological Survey, Mineral Commodity Summaries, February 2019, https://prd-wret.s3-us-west-2.amazonaws.com/assets/palladium/production/atoms/files/mcs2019_all.pdf

Wehner, A.P. (2002). Cosmetic talc should not be listed as a carcinogen: Comments on NTP's deliberations to list talc as a carcinogen, Regulatory Toxicology and Pharmacology, 36(1), 40-50.

Wild P., ColI. A (2002) Cohort mortality and nested case-control study of French and Austrian workers. Occup. Environ. Med 2002; 59; 98-105.

Zenith (2016). Talc beneficiation process. [online] Available at: http://www.miningcrushing.com/news/talc-beneficiation-process.html

31.7.2Data sources used in the criticality assessment

BGS (2016). World Mineral Production 2010-2014 [online]. Keyworth, Nottingham British Geological Survey, Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.html

BGS (2019). World Mineral Production 2014-2017, [online] Keyworth, Nottingham British Geological Survey, Available at: https://www.bgs.ac.uk/mineralsuk/statistics/worldStatistics.html

European Commission (2014). Report on critical raw materials for the EU. Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

Eurostat (2019a). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2019b). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2 (last update 19/08/19)

IMA (2018). Recycling Industrial Minerals, August 2018, www.ima-europe.eu

IMA (2019). Factsheet talc. Available at: https://www.ima-europe.eu/about-industrial-minerals/industrial-minerals-ima-europe/talc

OECD (2019). Export restrictions on Industrial Raw Materials database [online]. http://qdd.oecd.org/table.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

31.8Acknowledgments

This factsheet was prepared by the JRC in collaboration with Prof. Konstantinos Komnitsas (Technical University Crete). The authors would like to thank the Ad Hoc Working Group on Critical Raw Materials, in particular Ms. Aurela Shtiza and Ms. Francesca Girardi of IMA-Europe, as well as experts participating in SCRREEN workshops for their valuable contribution and feedback.

32. TELLURIUM

32.1 Overview

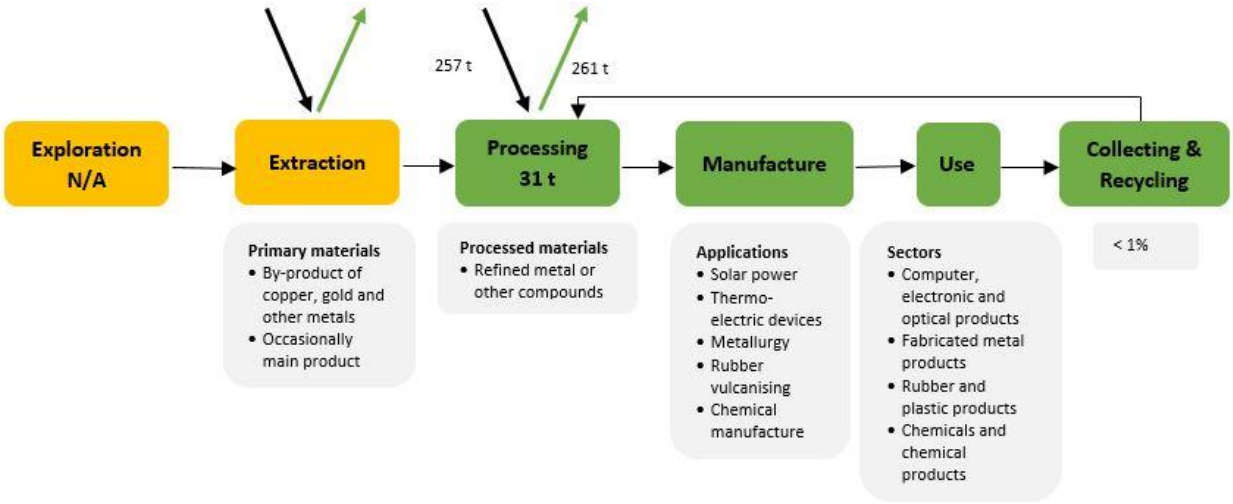
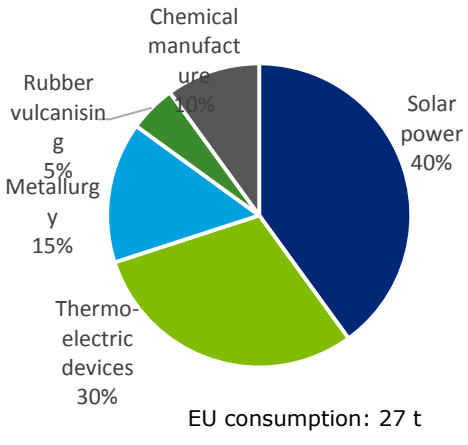


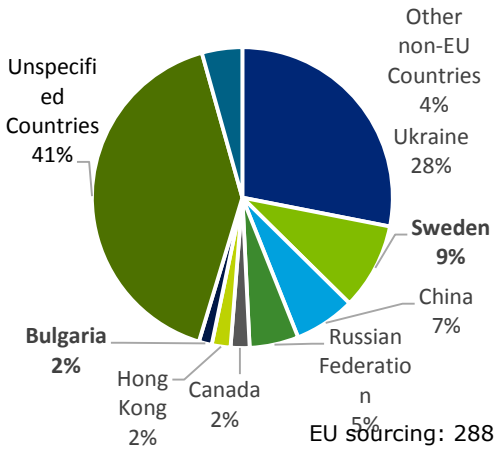
Figure 272: Simplified value chain for Tellurium for the EU (average 2012-2016)[167]

Tellurium (chemical symbol Te) is a chemical element with the atomic number 52. It is considered a semi-metal and has both metallic and non-metallic properties. Tellurium is very rare, its share in the earth's crust is about 0.01 ppm. It can be found in its native form, but usually it occurs in telluride minerals – tellurium compounds with lead and silver (most common), gold, selenium, or platinum. Native tellurium appears as a soft, silvery-white material, with a metallic shine. (Lenntech, 2019; ISE, 2019; USGS, 2015; GTK, 2019)

For trade data Eurostat Comext is consulted, using CN8 code 28045090 "Tellurium" and production figures reported by World Mining Data 2019 are analysed. As the trade data is not specified in detail it is assumed as 100% tellurium and the production data is reported as tellurium content, therefore, no adaptations had to be made. (Eurostat, 2019a)



EU consumption: 27 t



EU sourcing: 288 t

[167] JRC elaboration on multiple sources (see next sections)

Figure 273: End uses and EU sourcing of Tellurium (2012-16)
(STDA, 2010; Eurostat, 2019a; WMD, 2019; SCRREEN workshops, 2019)

Tellurium is traded in many different forms, e.g. powder or pieces, commonly with a grade of at least 99.95%. In 2018 tellurium was traded at USD 79 per kilogram. Tellurium prices are generally subject to high fluctuations and are expected to increase in the future (USGS, 2019).

The EU had an average apparent consumption of tellurium of 27 t per year between 2012 and 2016. The main application for tellurium is the production of CdTe (cadmium-tellurium) solar panels. The EU was a net exporter exporting 261 t on average. EU sourcing (imports plus domestic sources) amounted to 288 t per year on average (Eurostat, 2019a; WMD, 2019).

Tellurium can be substituted in many applications by various other materials, however, often with a loss in efficiency and product characteristics. For example, alternatives for CdTe solar panels are amorphous silicon and copper indium gallium selenide. In free-machining steels tellurium can be replaced by bismuth, calcium, lead, phosphorus, selenium, or sulphur (USGS, 2019).

As a material used for solar power panels tellurium can support the transition to renewable energy sources.

The largest Tellurium reserves are located in China, Peru, and the United States. In the EU Sweden has large reserves in Kankberg mine operated by Boliden. Total worldwide reserves are estimated at about 31,000 t (USGS, 2019).

Tellurium is mainly extracted as a by-product in electrolytic copper and nickel production; about 90% of global tellurium production are recovered from anode slimes at copper refineries (USGS, 2019). The major tellurium producing countries are China (54%), the United States (14%), and Japan (10%). (WMD, 2019) Secondary sources for tellurium are of low importance, as its recycling rate is below 1% (UNEP, 2011).
Tellurium, along with eight of its compounds, is listed by the European Chemicals Agency. It is classified as fatal in contact with skin, toxic if swallowed, harmful if inhaled, etc. (ECHA, 2019).

32.2Market analysis, trade and prices

32.2.1Global market analysis and outlook

Tellurium is traded in various forms, e.g. powder or granules, ingots or pieces, usually with a grade of 99.5% or higher. (MMTA, 2016)

Between 2018 and 2022 the tellurium market is expected to grow by 3% per year, mainly due to its use in solar panels, but also because of new applications that are currently being investigated (see Uses and end-uses of Tellurium in the EU). (Cleantech, 2018)

Table 154: Qualitative forecast of supply and demand of Tellurium

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Tellurium		x	+	+	?	+	+	?

32.2.2EU trade

The trade code used for tellurium in the criticality assessment was CN 2804 5090 'Tellurium'. This code does not distinguish the particular form of tellurium traded and therefore it has been

assumed this represents 100% tellurium and no adjustment has been made for tellurium content of the trade flows. (Eurostat 2019a)

Depending on the year EU is a net exporter or net importer of tellurium. On average, the EU is a net exporter. In 2012 exports were significantly higher than in following years. In 2014 both imports and exports increased, imports were almost 3.5 times higher than in the years before and after.

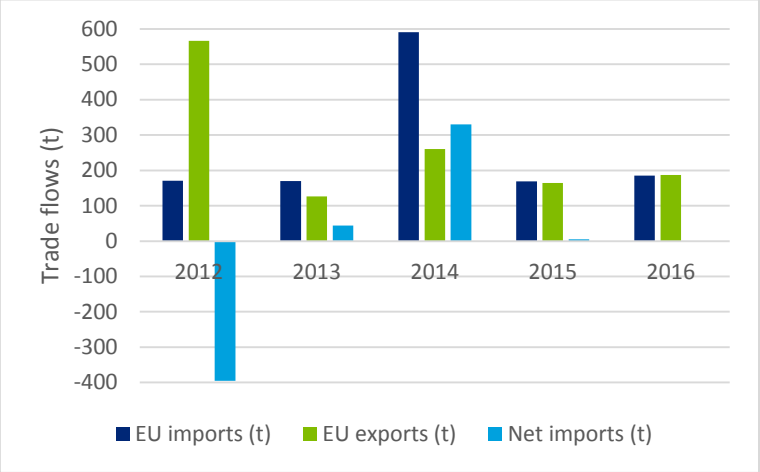


Figure 274: EU trade flows for Tellurium (Eurostat, 2019a)

More recently imported and exported amounts increased significantly. In 2017 the EU imported 266 t and exported 478 t and in 2018 import numbers almost tripled to 777 t, whereas exported tellurium amounts remained fairly constant at 417 t.

The main countries supplying tellurium to the EU can be seen in Figure 275. The largest supplier is the Ukraine, providing 32% of imported tellurium, followed by "Unspecified countries" (Countries and territories not specified for commercial or military reasons in the framework of trade with third countries). The main consumers of EU's tellurium exports are China (46%), Morocco (18%), and Thailand (16%)

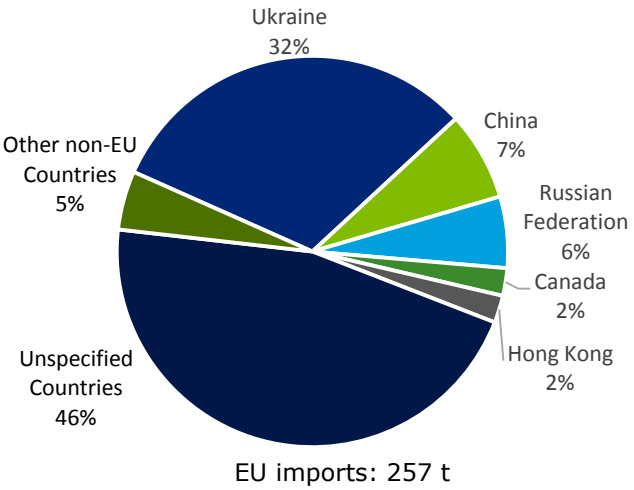


Figure 275: EU imports for Tellurium, average 2012-2016 (Eurostat, 2019a)

According to OECD (2019) no export restrictions for tellurium were in place for the period of 2012-2016. The EU has trade agreements with the United States, Canada, Ukraine, and Peru.

32.2.3Prices and price volatility

Tellurium prices are published by relevant trade journals, but a subscription is normally required to access the information. However, USGS records tellurium prices since 1917. Figure 276 shows the trend of tellurium value from 1917 to 2016.

Between 2008 and 2011 tellurium prices showed a significant increase to values almost 4 times higher than in the years before (maximum 349 USD per kg). In 2012 prices fell by half and continued to decrease until reaching a minimum of USD 36 per kg in 2016. In 2017 prices recovered to USD 38 per kg and USD 79 per kg in 2018.

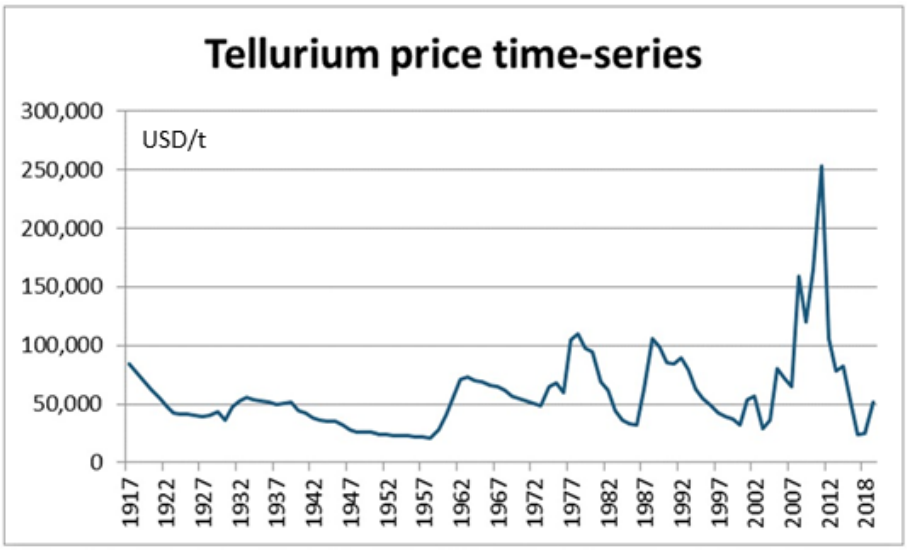


Figure 276: Tellurium price trend based on yearly averages (USD per tonne, converted to 1998 consumer price index) from 1917 to 2018; 99.95% content minimum (data sourced from USGS, 2017b; USGS, 2019)

32.3EU demand

Worldwide an average of 367 t of tellurium was produced per year between 2012 and 2016. In 2017 production increased significantly to 659 t. Prices were subject to fluctuation with a unit value of USD 150 per kg in 2012 decreasing to USD 36 per kg in 2016 and again recovering in the following years. (WMD, 2019; USGS, 2017a and 2019)

32.3.1EU demand and consumption

The EU had an average apparent consumption of 27 t per year in the period 2012-2016 (Eurostat, 2019a; WMD, 2019). This consumption is calculated as EU-imports minus EU-exports plus EU production. Imports and exports were fairly balanced, except in 2012 when exports were more than three times higher than imports. Considering these numbers it can be assumed that the evaluated trade code might not record tellurium contained in other materials, for example intermediate copper products imported for further refining.

32.3.2Uses and end-uses of Tellurium in the EU

Figure 277 presents the main uses of tellurium worldwide, as no EU-specific data could be found.

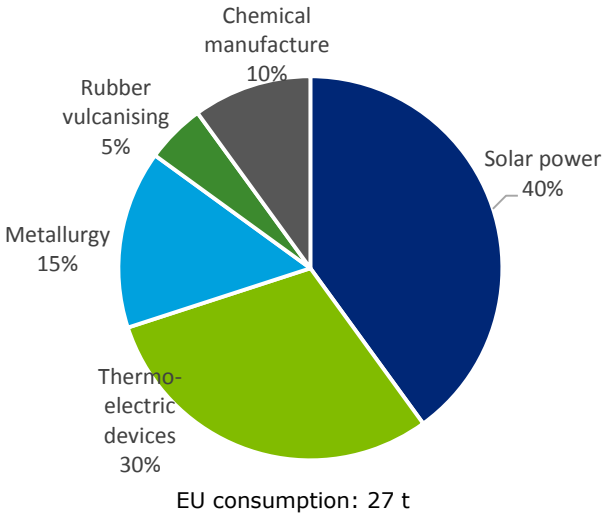


Figure 277: End uses of Tellurium (STDA, 2010) (SCRREEN workshops 2019)

Relevant industry sectors are described using the NACE sector codes in Table 155. The applications of tellurium remained unchanged since the last criticality study in 2017.

Tellurium, combined with cadmium, forms the active layer in photovoltaic thin-film solar panels. These are the second most common type of solar cell (behind crystalline silicon) but represent only 5% of the global photovoltaic market.

Thermo-electric devices are semi-conductor electronic components that can turn a temperature variation into electricity or electricity into a temperature variation. These devices can be used for power generation or as a heat pump or for cooling. This application sector also includes mercury-cadmium-telluride (MCT) used in infrared detectors and CZT (cadmium-zinc-telluride) semi-conductors for gamma- and x-ray detection (radiation mapping, nuclear medical imaging, astrophysics, and homeland security) (Fenixam, 2019).

Tellurium is used as an additive in steel or copper alloys to improve machinability, and in lead alloys to improve strength, hardness, and resistance to vibration. It is also used as a vulcanising agent and accelerator in the processing of rubber, as a catalyst in the production of synthetic fibre or in oil refining, and as a chemical in photoreceptor devices.

Tellurium adds blue and brown colours when used as a pigment in glass and ceramics. It can also be used as a chemical in rewritable CDs or DVDs, and as an additive in lubricants. (European Commission, 2017)

The use of tellurium in batteries as an alternative to lithium-ion batteries is currently investigated. Enhancements of performance, lifespan and storage capacity seem possible. Another possible use for tellurium in the future is tellurium-based nanoparticle technology for the desalination of water. (Cleantech, 2018)

Table 155: Tellurium applications, 2-digit and associated 4-digit NACE sectors, and value added per sector

Applications	2-digit NACE sector	Value added of NACE 2 sector (millions €)	Examples of 4-digit NACE sector(s)
Solar power	C26 – Manufacture of computer, electronic and optical products	65,703	C2611 – Manufacture of electronic components
Thermo-electric devices	C26 – Manufacture of computer, electronic and optical products	65,703	C2611 – Manufacture of electronic components
Metallurgy	C25 – Manufacture of fabricated metal products, except machinery and equipment	148,351	C2511 – Manufacture of metal structures and parts of structures; C2599 – Manufacture of other fabricated metal products n.e.c.
Rubber Vulcanising	C22 – Manufacture of rubber and plastic products	75,980	C2219 – Manufacture of other rubber products
Chemical Manufacture	C20 – Manufacture of chemicals and chemical products	105,514	C2059 – Manufacture of other rubber products; C2012 – Manufacture of dues and pigments; C2059 – Manufacture of other chemical products n.e.c.

32.3.3Substitution

The main application of tellurium is as already mentioned in the production of cadmium telluride (CdTe) solar panels. However, within the solar power sector, the most significant material in use is currently silicon. Considering only thin film solar panels such as the CdTe panels, there are three alternatives:

- Amorphous silicon solar panels
- Copper gallium indium diselenide (CIGS) solar panels
- Organic photovoltaic (OPV) cells

Compared to these alternatives CdTe cells have the advantage of absorbing sunlight as close to the ideal wavelength as currently possible. This means that they can capture energy at shorter wavelengths for optimal sunlight to electricity conversion. CdTe panels can also be manufactured at low costs. Nevertheless, the toxicity of CdTe has to be taken into consideration, especially regarding the end-of-life disposal of the panels. CIGS panels offer a high efficiency, similar to traditional silicon panels and they use the toxic cadmium at lower levels as CdTe panels. The main disadvantages of CIGS panels are the high production costs. Amorphous silicon solar panels use very little toxic materials; they are also less subject to cracks compared to traditional panels. A disadvantage is, however, their low efficieny compared to the other options. OPV cells also struggle with the efficiency, but they offer a lot of benefits for the building-integrated photovoltaic market, as the can be coloured or made transparent to fit the purpose. (Energysage, 2019)

One aspect that needs to be considered is the criticality of the materials: Silicon, indium and gallium were all assessed as being 'critical' in the previous EU criticality assessments

(European Commission, 2014 and 2017). Indium, gallium and selenium are similar to tellurium in that they are by-product metals.

In free-machining steels several materials can be used instead of tellurium: bismuth, calcium, lead, phosphorus, selenium, and sulphur. Tellurium as a catalyst can be replaced by other catalysts or non-catalysed processes. Alternatives for niobium and tantalum tellurides as electrical-conducting solid lubricants are selenides and sulphides of those metals. Substitutes for Tellurium in the vulcanisation process in rubber production are selenides and sulphides. However, a replacement of tellurium usually means a loss in efficiency or product characteristics. (USGS, 2019)

32.4Supply

32.4.1EU supply chain

Tellurium is mined in one location with the EU, at the Krankberg Mine in the Boliden Area of Sweden as a by-product of gold mining. The same company, Boliden, also operates a smelter/refinery at Rönnskär in Sweden, which recovers tellurium in addition to other metals.

Reported production of refined tellurium within the EU (i.e. from Sweden and Bulgaria) amounted to an average of 31 t per year (averaged over the 2012-2016 period). Imports to the EU from the rest of the world were 257 t per year, while total exports (i.e. from both producing and non-producing countries) were 260 t per year (again both averaged over the 2012-2016 period). Figure 278 shows the EU sourcing (domestic production + imports).

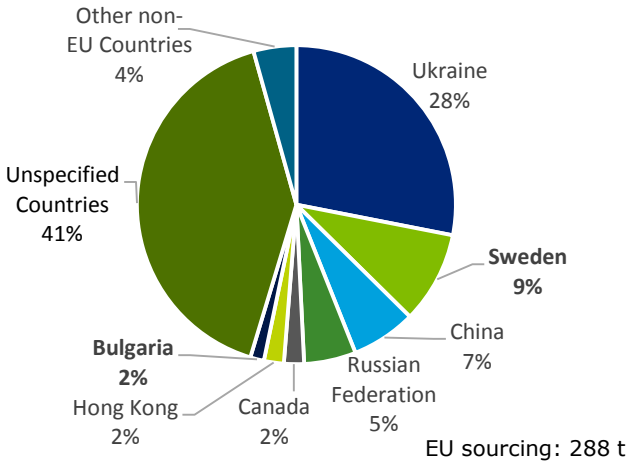


Figure 278: EU sourcing of Tellurium (Eurostat 2019a, WMD 2019)

Aurubis operates copper refineries in Germany and Bulgaria and tellurium is known to occur in the anode slimes at these refineries. Although the company mentions that tellurium is a recovered by-product no details are provided as to what form it takes or what happens to it. Atlantic Copper operates a refinery in Spain that recovers copper telluride from its anode slimes. This material is then further refined elsewhere.

Metallo Chimique operates a copper refinery in Belgium, which is believed to have a small amount of tellurium in its anode slimes but these are sold as "tankhouse slimes" to other

companies for treatment and recovery of those metals. One company that processes these kinds of anode slimes is Umicore, located in Hoboken, Belgium.

KGHM operate a copper refinery in Poland that may have a very small amount of tellurium in its anode slimes, but there is nothing on the company website to suggest that it is actually recovered. There are also copper refineries in Austria, Cyprus, Finland and Italy but there is no information available as to whether tellurium occurs in the anode slimes of those plants. Not all of these copper refining plants source the feed material from within the EU. Similarly not all copper that is mined in the EU is refined within Europe.

Copper mines are known to exist in many European countries but it is not known whether these deposits contain any tellurium. Similarly gold is mined in Europe but, other than Sweden, it is not known whether any of these other mines contain by-product tellurium. Gold ores mined in Finland are known to contain small concentrations of tellurium (in the range of 1-10 ppm), but there is no information available indicating that any of tellurium is recovered (GTK, 2019).

32.4.2Supply from primary materials

32.4.2.1 Geology, resources and reserves of Tellurium

Geological occurrence: Tellurium is one of the rarest elements in the earth's crust with an abundance of only 10 parts per billion (ppb). It is also widely distributed meaning that concentrations which are sufficient in size to allow economic extraction in their own right are rare. Tellurium rarely occurs as a native metal, it is more commonly found in compounds with precious or base metals, primarily as tellurides but other compounds also exits.

It is a chalcophile element, meaning it preferentially combines with sulphur rather than oxygen, but it cannot easily replace sulphur in a compound because it has a much larger ionic radius. Instead it preferentially forms tellurides with metals of large ionic radii such as gold, silver, bismuth, lead, mercury, and the platinum group elements.

Tellurium can occur in a wide range of deposit types including magmatic, metasomatic and hydrothermal types. It occurs especially in association with epithermal gold and silver vein deposits, which are formed by relatively low-temperature hydrothermal processes (<300°C) at shallow crustal depths, but it is also frequently present in copper or copper-gold porphyries, and sulphide deposits containing copper, nickel, lead, or iron.

Global resources and reserves[168]*:* Global reserves are listed in Table 156. The largest reserves are located in China, followed by Peru, and the USA. In total there are about 31,170 t

[168] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of tellurium in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template[168], which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

of tellurium reserves worldwide. Resources are not documented, as the main source (90% of total production) for tellurium is anode slime from copper refining. However, potential sources include bismuth telluride and gold telluride ores. (USGS, 2019)

Table 156: Global reserves of Tellurium in year 2016 (USGS, 2019)

Country	Tellurium Reserves (t)	Percentage of total (%)
Peru	3,600	11.5
United States	3,500	11.2
Canada	800	2.6
China	6,600	21.2
Sweden	670	2.1
Other countries	16,000	51.3
World Total (rounded)	*31,170*	*100*

The reserves estimated by USGS include only tellurium contained in copper reserves assuming that more than half of tellurium contained in unrefined copper anodes is recoverable.

In 2018, a project by Deer Horn Capital Inc. moving towards pre-feasibility in Canada was reported, with indicated resources of 414,000 t containing 5.12 g/t gold, 157.50 g/t silver, and 160 ppm tellurium (66,000 kg Tellurium contained), as well as inferred resources of 197,000 t at 5.04 g/t gold, 146.50 g/t silver and 137 ppm tellurium (27 t Tellurium contained). (Cleantech, 2018; Deer Horn Capital, 2019)

EU resources and reserves[169]*:*

According to Minerals4EU (2019) about 3,200,000 t reserves of tellurium ores are located in the EU and 2,100,000 t resources of tellurium ores, all of which are located in Sweden.

There is continuing exploration at Kankberg mine (Sweden) to explore further gold resources and reserves, but with this also tellurium resources are expanded as they are recovered as a by-product of gold production at Kankberg. (Geological Survey of Sweden, 2016)

Resources may also exist in other countries that did not respond to the survey. Copper resources are known to exist in at least 18 European countries and gold resources in 19 European countries, as well as Sweden, and it is likely that some of these resources also contain tellurium which is not reported as a resource because it is a by-product. (Minerals4EU, 2019)

[169] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for tellurium. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for tellurium, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for tellurium the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019).Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However a very solid estimation can be done by experts.

Table 157: Resource and Reserve data for the EU compiled in the European Minerals Yearbook at Minerals4EU (2019)

Country	Reporting code	Quantity	Unit	Grade	Code Resource Type
Sweden	FRB-standard	0.11	Mt	149 g/t	Measured
Sweden	FRB-standard	0.15	Mt	205 g/t	Indicated
Sweden	FRB-standard	1.89	Mt	232 g/t	Inferred
Sweden	FRB-standard	0.88	Mt	172 g/t	Proven
Sweden	FRB-standard	2.39	Mt	185 g/t	Probable

32.4.2.2 World and EU mine/refinery production

The vast majority of the tellurium produced worldwide is as a by-product of electrolytic copper refining with smaller quantities extracted as a by-product of gold, lead or other metals. Within the EU, tellurium is mined as a by-product of gold at the Krankberg Mine in the Boliden Area of Sweden and it is also refined nearby at the Rönnskär Smelter (Boliden 2018).

Sweden produced 7% of world supply between 2012 and 2016. The largest supplier is China providing 54% of available tellurium. Further suppliers include the USA (14%), Japan (10%), and Russia (9%). Worldwide only eight countries produce tellurium. Between 2012 and 2016 the average amount produced per year was about 367 t. In 2017 production increased significantly to 659 t (WMD, 2019).

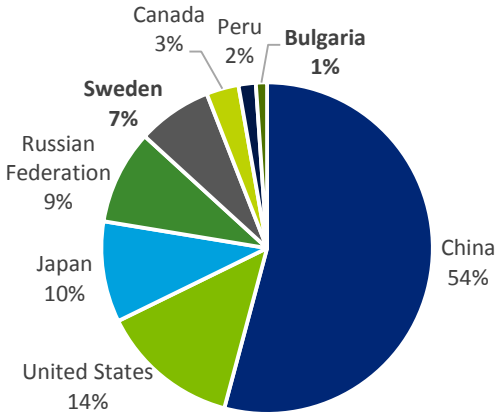


Figure 279: Global mine production of Tellurium. Average for the years 2012-2016. (WMD, 2019)

In 2013 worldwide tellurium production increased by about 73 t (+29%) due to increases of production in China and Sweden. There was another significant increase of production from 2014 to 2015 of about 100 t (+26%), mainly owing to an increase of Chinese supply.

32.4.3Supply from secondary materials/recycling

Many of the end uses of tellurium are dissipative, meaning that very little material becomes available for recycling. Tellurium contents in metallurgical applications are too small to be

separated during recycling processes with the result that they become further dispersed rather than concentrated. A very small quantity is currently recovered from end-of-life electrical products. In the future, more significant quantities of tellurium are likely to become available for recycling from cadmium-tellurium photovoltaic solar cells but this is a relatively new technology and few of the cells have reached the end-of-life stage so far.

There are two sources of scrap for recycling: end-of-life scrap and processing scrap. End-of-life scrap (sometimes termed 'old scrap') is defined as scrap arising from products that have been used but are no longer required because they have been worn out or become obsolete. Scrap and other wastes are also generated during the fabrication and manufacture of products (sometimes referred to as 'new scrap' or 'processing scrap'). For tellurium the quantities involved with both types of scrap are very small.

There are many different indicators that can be used to assess the level of recycling taking place for any material. The United Nations Environment Programme (UNEP) estimated the 'end-of-life recycling rate' of tellurium as <1% (UNEP, 2011). This is measured as 'old scrap' sent for recycling as a proportion of the 'old scrap' generated. The UNEP report was not able to source or calculate any other indicators with regards to tellurium.

For this criticality assessment, a slightly different indicator was required: the end-of-life recycling input rate (EOL-RIR). This measures the quantity of end-of-life scrap (i.e. 'old scrap') contained within the total quantity of metal available to manufacturers (which would also include primary metal and 'new scrap'). For tellurium, insufficient data was found to enable the calculation of EOL-RIR but as UNEP (2011) estimated EOL-RR as <1%, it was concluded that EOL-RIR must be very low. Therefore a figure of 1% was used in the assessment. (SCRREEN workshops 2019)

32.4.4Processing of Tellurium

To reach the refining stage, copper, and its associated by-products including tellurium, undergo a number of processing stages. These include traditional mining techniques (either underground or from surface mines), crushing and grinding, froth flotation, roasting, smelting and the conversion of matte to copper blister. At each stage a proportion of the tellurium is lost in tailings or residues.

Electrolytic refining uses slabs of copper blister as anodes and pure copper or stainless steel as cathodes immersed in an electrolyte. An electrical current is passed through the electrolyte and as the anodes dissolve, copper atoms transfer to the cathodes. Tellurium is either insoluble during this process, settling to the bottom of the electrolytic cell into what is known as 'anode slimes' or muds, or is held in suspension in the electrolyte. These muds or liquids can subsequently be treated to recover tellurium and/or other metals such as silver, gold or platinum group metals using a variety of proprietary techniques. The resulting tellurium-containing products, such as crude tellurium dioxide (approximately 70% Te), copper telluride (20–45% Te) or low grade tellurium concentrates (approximately 10% Te), are subsequently further refined to produce tellurium metal.

The recovery rate during the initial concentration stages is as low as 10%, during the smelting and converting stages the recovery is 50%, and during the treatment of anode slimes as much as 90% of the available tellurium is recovered. This is a reflection of the degree of attention focused on tellurium at each stage. During the initial concentration phases, the focus is on recovering copper or other base metals which will be more economically rewarding due to the larger quantities available. In contrast, where recovery of tellurium is carried out the

equipment used is optimised to ensure the highest possible recovery rate of tellurium as this has become the focus. (European Commission, 2017)

32.5Other considerations

32.5.1Environmental and health and safety issues

As already mentioned tellurium and eight of its compounds are registered by the European Chemicals Agency. Already small amounts of tellurium can cause bad smelling breath and body odour when inhaled. Other effects include drowsiness, metal taste, headache, and nausea.

In its elemental form tellurium is not readily soluble and ingestion is classified as harmful to health, but not toxic. However, some tellurium compounds, such as tellurates of alkali metals, are readily soluble and react to poisonous dimethyl telluride when swallowed. This can harm blood, liver, heart, and kidneys.

Tellurium can be released into the environment by industrial use, such as abrasion processing (cutting of textile, machining or grinding of metals, etc.). However, it can also be released by outdoor- and indoor-uses of materials with low release rates (such as metal construction and building materials). Tellurium can be found in many complex articles with no release intended (batteries, computers, etc.). (ECHA, 2019)

EU OSH requirements exist to protect workers' health and safety, employers need to identify which hazardous substances they use at the workplace, carry out a risk assessment and introduce appropriate, proportionate and effective risk management measures to eliminate or control exposure, to consult with the workers who should receive training and, as appropriate, health surveillance[170].

32.5.2 Socio-economic issues

No specific issues were identified during data collection and stakeholders consultation.

Table 158: Substances containing tellurium registered under the REACH regulations (ECHA, 2019)

Substance name	EC / List No.	Registration Type
Tellurium	236-813-4	Full
Tellurium dioxide	231-193-1	Full
Cadmium telluride	215-149-9	Full
Se-Te-Concentrate	932-075-9	Intermediate
Slags, tellurium	273-828-5	Intermediate
Elemental tellurium and bismuth concentrate resulting from leaching and cementation	700-872-9	Intermediate
Leach residues, tellurium	273-814-9	Intermediate
Lead telluride	215-247-1	Intermediate
Precipitate from tellurium containing acid solutions by copper metal cementation	943-528-5	Intermediate

[170] https://ec.europa.eu/social/main.jsp?catId=148

32.6Comparison with previous EU assessments

A revised methodology was introduced in the 2017 assessment of critical raw materials in Europe and both the calculations of economic importance and supply risk are now different hence the results with the previous assessments and not directly comparable.

Table 159: Economic importance and supply risk results for Tellurium in the assessments of 2011, 2014, 2017 (European Commission, 2011; European Commission, 2014; European Commission, 2017) and 2020

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Tellurium	7.90	0.56	5.98	0.19	3.40	0.70	3.6	0.51

Although it appears that the economic importance of tellurium has reduced between 2014 and 2017 this is a false impression created by the change in methodology for calculating this indicator. In the 2014 assessment, the 'megasector' selected for solar power and thermo-electric devices was 'electronics' with a value added of 104,900 thousand Euros. In the 2017 assessment, the 2-digit NACE sector identified as the most appropriate for these application sectors was 'manufacture of computer, electronic and optical products' which is more precisely constrained and has a lower value added of 75,260 thousand Euros. If the 'megasectors' were used instead of the 2-digit NACE sectors then the EI indicator in 2017 would have increased when compared with 2014 rather than the decrease suggested inTable 159. This illustrates exactly why a direct comparison between this review and the previous assessments should not be made. The change in SR value is due to the fact that the distribution of world producer is different in nature and share in this assessment compared to the previous ones, due to a change in datasource. Moreover, the substitution parameter was higher in the 2017 assessment, triggering an increase in the supply risk.

32.7Data sources

Market data for tellurium trade is not readily available. Usually subscriptions or paid reports are required to access data.

32.7.1Data sources used in the factsheet

Boliden (2018) Boliden Summary Report 2018 Kankberg-Åkulla Östra. Available at: https://www.boliden.com/globalassets/operations/exploration/mineral-resources-and-mineral-reserves-pdf/resources-and-reserves-kankberg-2018-12-31.pdf (Accessed: 29 January 2020).

Cleantech (2018). Investing News [Online]. Available at: https://investingnews.com/innspired/tellurium-market-renewable-energy/ (Accessed: 17.09.2019)

Deer Horn Capital Inc. (2019). Deer Horn project overview [Online]. Available at: https://www.deerhorncapital.ca/key-project/overview (Accessed: 17.09.2019)

European Chemicals Agency (ECHA) (2019). Substance Information – Tellurium [Online]. Available at: https://echa.europa.eu/de/substance-information/-/substanceinfo/100.033.452?_disssubsinfo_WAR_disssubsinfoportlet_backURL=https%3A%2F%2Fecha.europa.eu%2Fde%2Fhome%3Fp_p_id%3Ddisssimplesearchhomepage_WAR_disssearchportlet%26p_p_lifecycle%3D0%26p_p_state%3Dnormal%26p_p_mode%3Dview%26p_p_c

ol_id%3Dcolumn-1%26p_p_col_count%3D2%26_disssimplesearchhomepage_WAR_disssearchportlet_sessionCriteriaId%3D (Accessed: 16.09.2019)

Energysage (2019). Types of thin film solar panels [Online]. Available at: https://www.energysage.com/solar/101/about-solar-panels/thin-film-solar-panels-amorphous-cadmium-telluride-and-cigs/ (Accessed: 17.09.2019)

European Commission (2011). Critical raw materials for the EU [Online]. Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission (2014) Report on critical raw materials for the EU – Non Critical raw materials profiles [Online]. Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission (2017) Report on critical raw materials for the EU – Non Critical raw materials profiles [Online]. Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

Eurostat (2019a). Comext International Trade [Online]. Available at: http://epp.eurostat.ec.europa.eu/newxtweb/mainxtnet.do (Accessed: 12.09.2019)

Eurostat (2019b). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E) [Online]. Available at: https://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2 (Accessed: 16.09.2019)

Fenixam (2019). Fenix Advanced Materials. Expert feedback. Mr. Dan Oliric Manaig

Geological Survey of Sweden (2016). Exploration Newsletter March 2016. Available at: https://www.sgu.se/en/mineral-resources/geological-information-for-mineral-exploration/exploration-newsletter/

GTK (2019). Geological Survey of Finland. Expert feedback. Eili, Pasi; Pokki, Jussi; Salo, Aleksi; Michaux, Simon; Kivinen, Mari

ISE (2019). Tellur [Online]. Available at: mahttps://institut-seltene-erden.de/seltene-erden-und-metalle/strategische-metalle-2/tellur/ (Accessed: 16.09.2017)

Lenntech (2019). Periodic Table – Tellurium [Online]. Available at: https://www.lenntech.com/periodic/elements/te.htm (Accessed: 16.09.2019)

Minerals4EU (2019). European Minerals Yearbook – Data for Tellurium [Online]. Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/pages/bycommodity.jsp?commodity=Tellurium (Accessed: 13.09.2019)

Minor Metals Trade Association (MMTA) (2016). Tellurium [Online]. Available at: https://mmta.co.uk/metals/te/ (Accessed: 16.09.2019)

OEDC (2019). Export restrictions on Industrial Raw Materials [Online]. Available at: https://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials (Accessed: 03.09.2019)

SCRREEN workshop (2019) 'Validation workshop on Critical Raw Materials, 10-12 September 2019, Thon Hotel Brussels City Centre'. Brussels.

UNEP (2011). Recycling Rates of Metals – A Status Report. Available at: https://www.resourcepanel.org/reports/recycling-rates-metals

USGS (2015). Tellurium – The Bright Future of Solar Energy. Available at: https://pubs.usgs.gov/fs/2014/3077/

USGS (2017a). Mineral Commodity Summaries – Tellurium. Available at: https://www.usgs.gov/centers/nmic/ selenium-and-tellurium-statistics-and-information

USGS (2017b). Historical Statistics for Mineral and Material Commodities in the United States – Tellurium. Available at: https://www.usgs.gov/centers/nmic/historical-statistics-mineral-and-material-commodities-united-states

USGS (2018). 2016 Minerals Yearbook – Selenium and Tellurium [Advance Release]. Available at: https://www.usgs.gov/centers/nmic/historical-statistics-mineral-and-material-commodities-united-states

USGS (2019). Mineral Commodity Summaries – Tellurium. Available at: https://www.usgs.gov/centers/nmic/ selenium-and-tellurium-statistics-and-information

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

32.7.2 Data sources used in the criticality assessment

BGS (2019). BGS World Mineral Production. Available at: https://www.bgs.ac.uk/mineralsUK/statistics/worldStatistics.html

European Commission (2017) Report on critical raw materials for the EU – Non Critical raw materials profiles [Online]. Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission (2019). Negotiations and agreements [Online]. Available at: https://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/ (Accessed 12.09.2019)

Eurostat (2019a). Comext International Trade [Online]. Available at: http://epp.eurostat.ec.europa.eu/newxtweb/mainxtnet.do (Accessed: 12.09.2019)

Fraunhofer (2019). Fraunhofer Institute for Solar Energy Systems, ISE. Photovoltaics report. Available at: https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf

Nassar, N.T. (2015). By-product metals are technologically essential but have problematic supply; Science Advances 03 Apr 2015: Vol. 1, no. 3, e1400180. https://advances.sciencemag.org/content/1/3/e1400180

OEDC (2019). Export restrictions on Industrial Raw Materials [Online]. Available at: https://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials (Accessed: 03.09.2019)

Rombach et al. (2014). Rombach, E. and Friedrich, B. 2014 Recycling of Rare Metals (Chapter 10, page 139) in Worrell E. and Reuter, M.A. (Eds) Handbook of Recycling: state of the art for practitioners, analysts and scientists. Elsevier.

STDA (2017). Selenium Tellurium Development Association. Available at: http://www.stda.org/se_te.html

UNEP (2011). Recycling Rates of Metals – A Status Report. Available at: https://www.resourcepanel.org/reports/recycling-rates-metals

USGS (2017). Mineral Commodity Summaries – Tellurium. Available at: https://www.usgs.gov/centers/nmic/ selenium-and-tellurium-statistics-and-information

USGS (2019). Mineral Commodity Summaries – Tellurium. Available at: https://www.usgs.gov/centers/nmic/ selenium-and-tellurium-statistics-and-information

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

32.8Acknowledgments

This factsheet was prepared by the JRC in collaboration with Ms. Marie-Theres Kügerl (Resources Innovation Center Leoben). The authors would like to thank the Ad Hoc Working Group on Critical Raw Materials, in particular Euromines and GTK, as well as experts participating in SCRREEN workshops for their valuable contribution and feedback.

33.TIN

33.1Overview

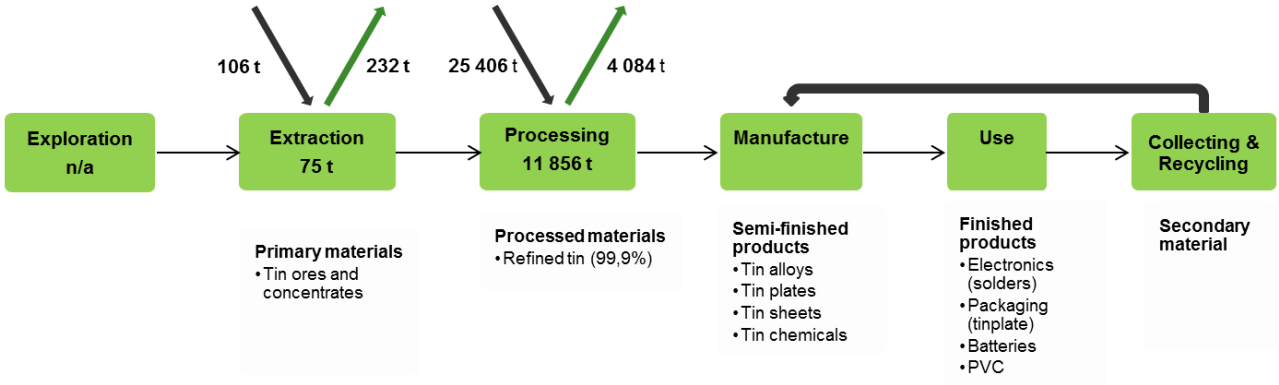
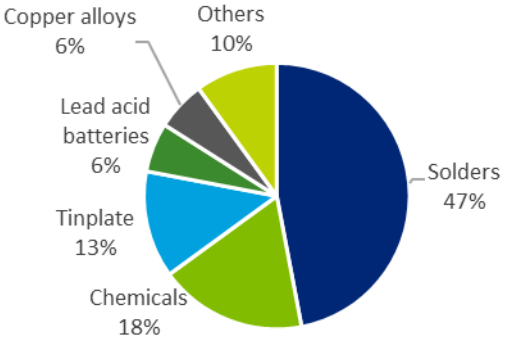


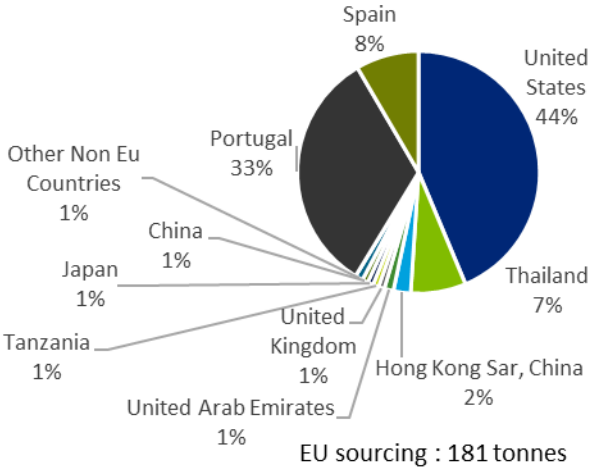
Figure 280: Simplified value chain for tin for the EU, average 2012-2016[171], n/a: flow unknown

Tin (chemical symbol Sn, from the Latin term 'stannum') is a soft, malleable, ductile and highly crystalline silvery-white metal. It is malleable and has a low melting point (232 °C). It is one of the few metals which has been used and traded by humans for more than 5,000 years. The earliest record of its use was in 3,500-3,200 BC for weapons, and it was shortly after alloyed with copper to make bronze, notably by the Romans in the first century AD. Despite this prehistoric use, its abundance in the upper continental crust (2.1 ppm) is estimated lower than that of other industrial metals like aluminium, copper, and lead (Rudnick, 2003).

Tin has been proved to be non-toxic and is used in a variety of applications, including solder, tinplate, tin chemicals and copper alloys. It is resistant to corrosion, and a good electrical conductor. Thanks to those properties, it is primarily used today as coating for steel sheet in tinplate (food containers, etc.) and for industrial solders in electronics.



EU apparent consumption: 33.200 tonnes (refined)



EU sourcing : 181 tonnes

[171] JRC elaboration on multiple sources (see next sections).

Figure 281: Global end uses (International Tin Association, 2019a) and EU sourcing of tin concentrates (BGS, 2018; Eurostat, 2019; International Tin Association 2019b) average 2012-2016

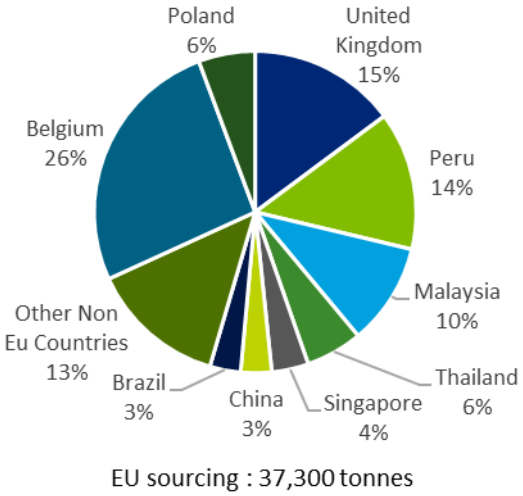


Figure 282: EU sourcing of tin metal (BGS, 2018; Eurostat, 2019; International Tin Association, 2019b). Average 2012-2016.

In the EU in particular, other important end-uses include wines and spirits capsules and disc brake pads for automobiles. It also finds applications as an alloy with other metals (bronze, brass, fusible and bearing alloys) and in compound form as organic and inorganic chemical.

For the purpose of this assessment tin is analysed at both extraction and processing stage. Mine production is expressed in terms of metal content. Trade data is analysed using codes CN2609 0000, which is labelled "Tin ores and concentrates" with a 70% tin content, and CN8001 1000 "Unwrought tin: Tin, not alloyed (at > 99% tin)". (Eurostat, 2019)

Global tin supply has been in deficit since 2018 according to the International Tin Association (ITA) data. Global usage of refined tin amounted to 371,000 tonnes in 2018 (International Tin Association, 2019b), and EU apparent consumption of refined tin was 33,000 tonnes.

Average yearly LME prices decresead by 7% from US$21,093 per tonne in 2012 to US$19,653 per tonne in 2016.

On a global scale, the main use of tin are solders with almost half of the demand. The major part of that, around 85%, is used in electronics. Further relevant uses are as compound in the chemicals sector (mainly as polymer additives), tinplate (packaging), lead acid batteries and copper alloys like tinned copper or bronzes. Figure 281 shows the share of the various main tin applications in the world. Tin is also used in the making of flat window glass, as tin powder, and electroplating anodes. In the EU, tin is also used for tin capsules of wine and spirits.

Due to low smelting capacities in the EU, the imports are low with only 106 tonnes per year of tin in concentrates. The EU sources 37,300 tonnes per year refined tin, which is more than 10% of the global supply (361,000 tonnes per year). This makes the EU a relevant player in the global tin supply chain, in contrast to the mine stage (BGS, 2018; Eurostat, 2019).

The apparent EU tin consumption in the period 2012-2016 is 33,000 tonnes per year.

Tin is the dominant material for solders, especially in electronics, where epoxy raisins and lead tin are used as substitutes with lower performance compared to tin. Also in the chemicals sector tin cannot be substituted well, as potential substitutes like barium-zinc or calcium-zinc

do not reach the performance of tin. Tinplate, however, for example used for packaging, can be substituted by aluminium or plastics. Tin is an important material for lead acid batteries, while this type of batteries is increasingly replaced by lithium-ion batteries because of better technical performances.

Technology opportunities for tin in lithium-ion batteries have been identified, mainly in high-capacity anode electrode materials, but also in solid-state and cathode materials (International Tin Association, 2019a).

The estimated abundance of tin in the upper continental crust is 2.1 ppm (Rudnick, 2003), which is low compared to other industrial metals. Tin is invariably found in association with granitic rocks, either in situ within the granite or certain rocks associated with the granite, or as alluvial or eluvial deposits resulting from the weathering of the original tin-bearing rock. Cassiterite (SnO_2) is by far the most important tin ore.

Global reserves of tin at the end of 2018 were estimated at around 4,700 ktonnes (USGS, 2019), with China accounting for a quarter of the global total, followed by Indonesia (800 ktonnes), Brazil (700 ktonnes) and Bolivia (400 ktonnes) (USGS, 2019). According to the International Tin Association (2016), the world's reported tin resources at the end of 2015 totalled some 11,700 ktonnes, including 2,200 ktonnes of reserves i.e. about half of the USGS (2019) estimate. In Europe, tin resources were reported in Portugal, Sweden, Czech Republic, Finland and France (Minerals4EU, 2019), while the data quality is unsatisfactory.

During the period 2012-2016, about 305,000 tonnes per year of tin was mined globally. China was the main producer and accounted for 35% of the global mine production, followed by Indonesia (27%) and Myanmar (10%), while nearly all Myanmar output is further processed in China. In contrast, Indonesian production has plummeted by a third since the government banned exports of unprocessed tin concentrates in 2014. The global production of refined tin amounted on average for the period 2012-2016 about 361,000 tonnes, mainly concentrated in East Asia. China was by far the main producer (47%), followed by Indonesia (19%) and Malaysia (9%), Peru (6%) and Thailand (5%).

With an annual average production of 75 tonnes in the period 2012-2016, the EU accounted for less than 1% of global tin mine production. Within the EU, Portugal is the major producer of tin ore in Europe (59 tonnes per year, 80%), followed by Spain (15 tonnes per year, 20%), resulting in EU mine production of 75 tonnes per year. In contrast, the turnover of refined tin in the EU are a multiple. The EU production of refined tin is located in Belgium and to a minor part also in Poland. Together, they produce around 12,000 tonnes per year (3.3%) of the global production.

Tin is recycled from various applications, whereat the end-of-life recycling rate depends on the applications, with tinplate in food and beverages cans having the highest (around 65%), followed by solders in electronics (40%). The end-of-life recycling input rate (EoL-RIR) of tin, including refined and unrefined forms, was calculated as 31% in 2016 (ITRI, 2017).

The general trend of miniturisation in electronic goods influences also the tin demand negatively. Further, the conflict minerals regulations require additional efforts to manage supply chains properly.

Export taxes on refined tin are reported for Vietnam and China, for tin ores in addition for Bolivia and Rwanda. The only country with export quota is China (between 17,000 and 18,000 tonnes per year, in the period 2012 to 2016). In 2017, export tax and quota were removed by China.

33.2Market analysis, trade and prices

33.2.1Global market analysis and outlook

Global tin supply has been in deficit since 2018 according to the International Tin Association (ITA) data.

Tin use in lead-acid batteries continues to grow strongly as use markets in automotive, motive, telecoms and now utility grid storage expands. The trend towards higher performance products such as new stop-start hybrid vehicles will benefit tin in the medium-term, although threats from lithium-ion batteries are already apparent and the important China e-bikes market will decline sharply. The global tin market is expected to move into balance or even deficit 2019 from a 13,100-tonne deficit in 2018, mainly due to weaker demand in top market China (International Tin Association, 2019b). The ITA expected that the use of tin in lead-acid batteries would rise from its estimated 2016 level of 21,305 tonnes per year and possibly would peak by 2025.

In the longer term, tin is expected to benefit from robust demand from rising technologies like electric vehicles, renewable energy, and robotics (World Bank, 2019).

In addition, innovative applications are upcoming, like usage as plasma source for extreme-ultraviolet lithography and niobium-tin superconductor.

Table 160: Qualitative forecast of supply and demand of tin

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Tin		x	+	+	?	+	+	?

33.2.2EU trade

The EU exported 232 tonnes per year of tin concentrates on average, mostly to Malaysia, averaged over 2012 to 2016. These trade data were not supported by experts at and after the validation worksop, including the International Tin Association. The values seem implausible as neither relevant activities of smelting tin concentrates are known in the EU, nor exports of concentrate at this high level. In particular imported quantities of Comtrade were highly questioned, as the imports from the United States reached in average 79 tonnes per year, and in total EU imports 106 tonnes per year (Eurostat, 2019). As the United States have not mined tin ores since 1993 (USGS, 2019) and not produced tin concentrates, such exports would need to be re-exports; however, this trade flow is not supported by U.S. trade statistics. Nevertheless, Comtrade was used for the criticality assessment due to lack of better data for imports from the United States, Thailand, and the other contributors to EU imports of tin ores and concentrates (Eurostat, 2019).

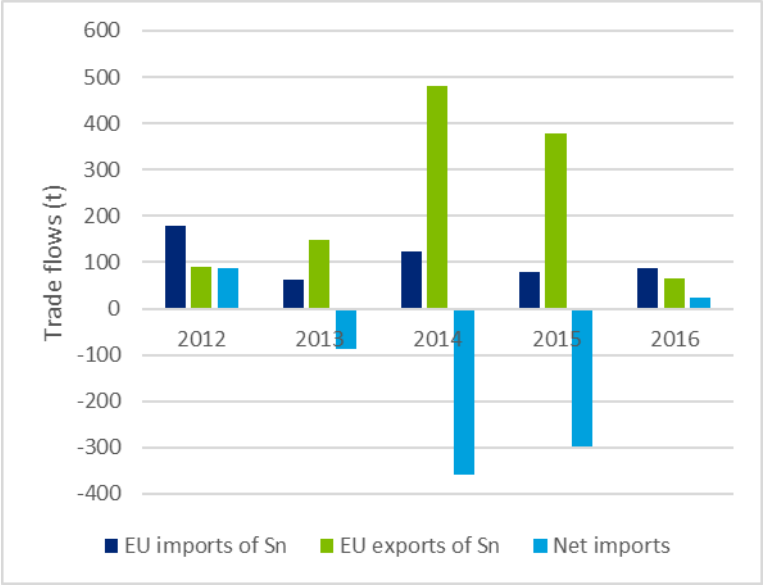


Figure 283: EU trade flows for tin concentrates (Eurostat, 2019)

The EU imported 25,000 tonnes per year of refined tin on average between 2012 and 2016, mainly coming from the United Kingdom (22%), Peru (20%) and Malaysia (15%). EU exports of refined tin are reported in average about 4,000 tonnes per year, see Figure 284. The EU import reliance for refined tin was calculated as 64%.

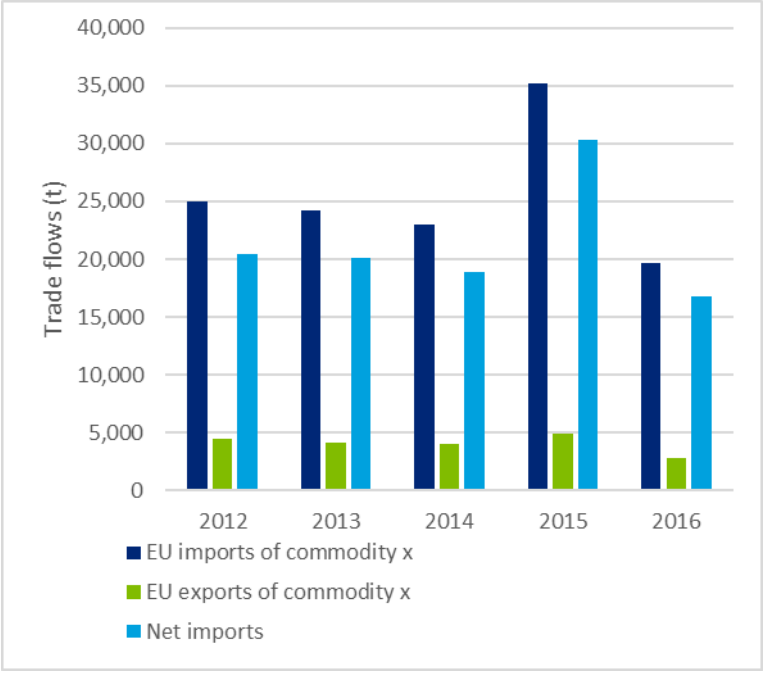


Figure 284: EU trade flows for refined tin (Eurostat, 2019)

The average (2012-2016) EU imports of tin concentrates and of refined tin are shown in Figure 285.

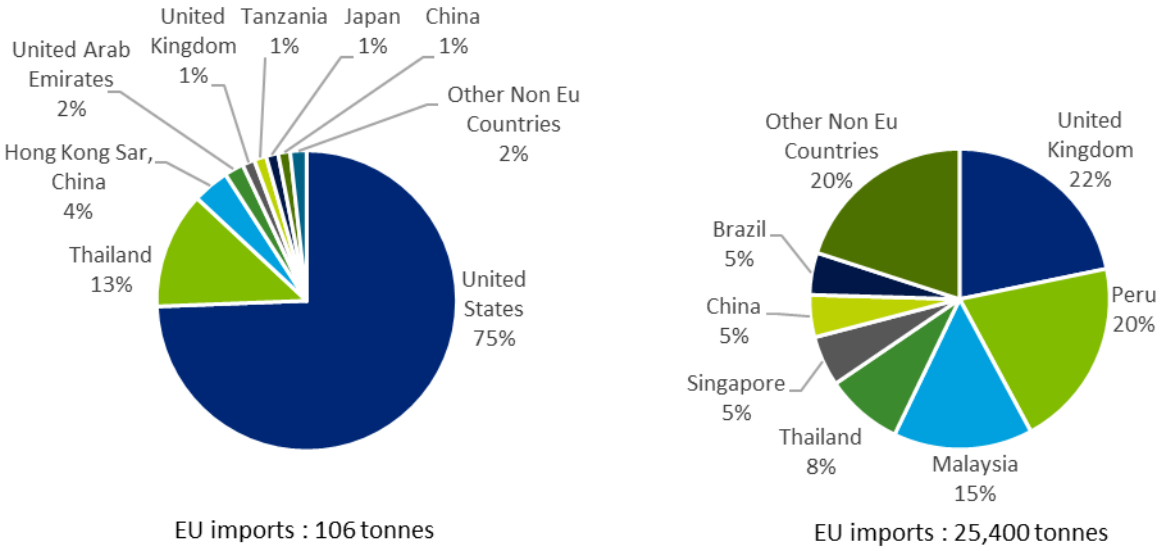


Figure 285: EU imports of tin concentrates (left) and refined tin (right) (Eurostat, 2019).

China restricted refined tin exports by imposing an export tax of 10% on unwrought tin and export quota which amounted to 17,261 tonnes per year during the period 2012-2016 (OECD, 2016). These trade restrictions, which were introduced in 2008, were removed in 2017 (ITRI, 2017). Currently there are EU free trade agreements in place with Peru and Japan (OECD, 2018).

33.2.3 Prices and price volatility

Tin is traded on the major exchanges around the world including the London Metals Exchange (LME), the Shanghai Metal Exchange (SHME), the Jarkarta Futures Exchange and the Indonesia Commodities and Derivatives Exchange (ICDX). The LME trades a contract on tin ingots that are minimum 99.85% pure. Each contract represents 5 tonnes of tin and is quoted in US$ (LME, 2019).

After reaching all-time highs in 2011 mostly driven by China's economic boom and lead-free solder, tin price dropped to an approximate US$15,000-25,000 range until 2019.

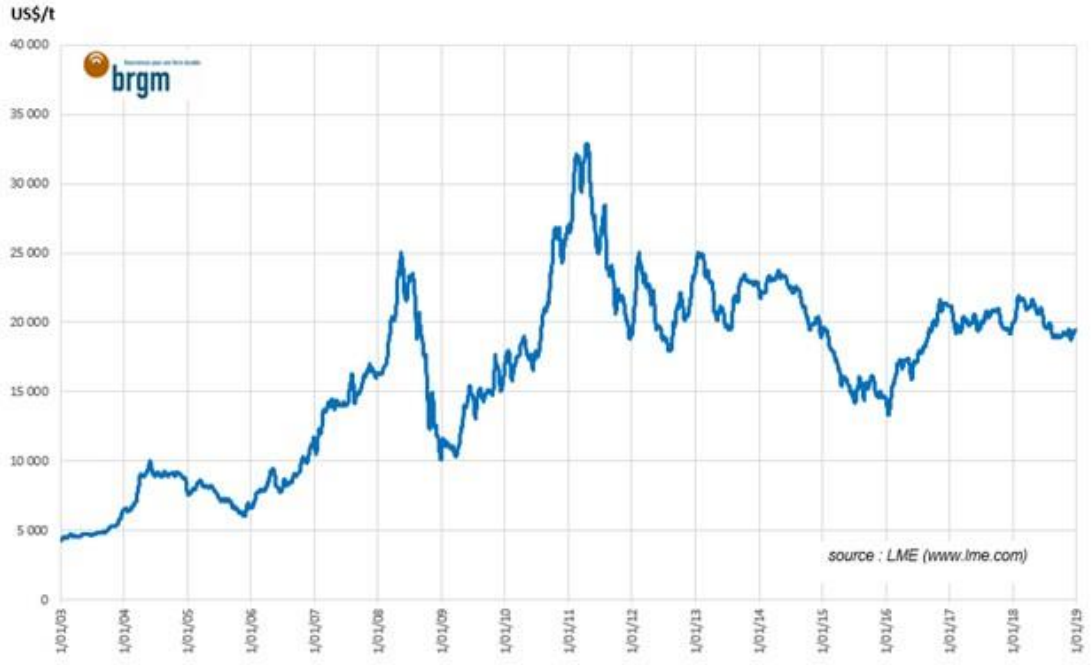


Figure 286: Refined tin prices (US$ per tonne, 7–day moving average) from January 2003 to December 2018 (LME, 2019)

The annual average LME prices during the period 2012-2016 was US$19,897.60 (US$21,178 in 2012, US$22,303 in 2013, US$21,893 in 2014, US$16,070 in 2015 and US$18,044 in 2016) (in LME cash prices).

The long-term prices of tin are shown in Figure 287. The price curve shows real prices.



Figure 287: Tin prices in US$ per tonne. Vertical dashed line indicate breaks in price specification.(Buchholz *et al.*, 2019)

33.3EU demand

33.3.1EU demand and consumption

The EU annual apparent consumption of refined tin was 33,200 tonnes on average over the period 2012-2016. This is 61% of the EU consumption reported by the International Tin Association (International Tin Association, 2019a).

33.3.2Uses of tin in the EU

Figure 288 presents the main uses of tin in the world in 2017 (ITRI, 2019).

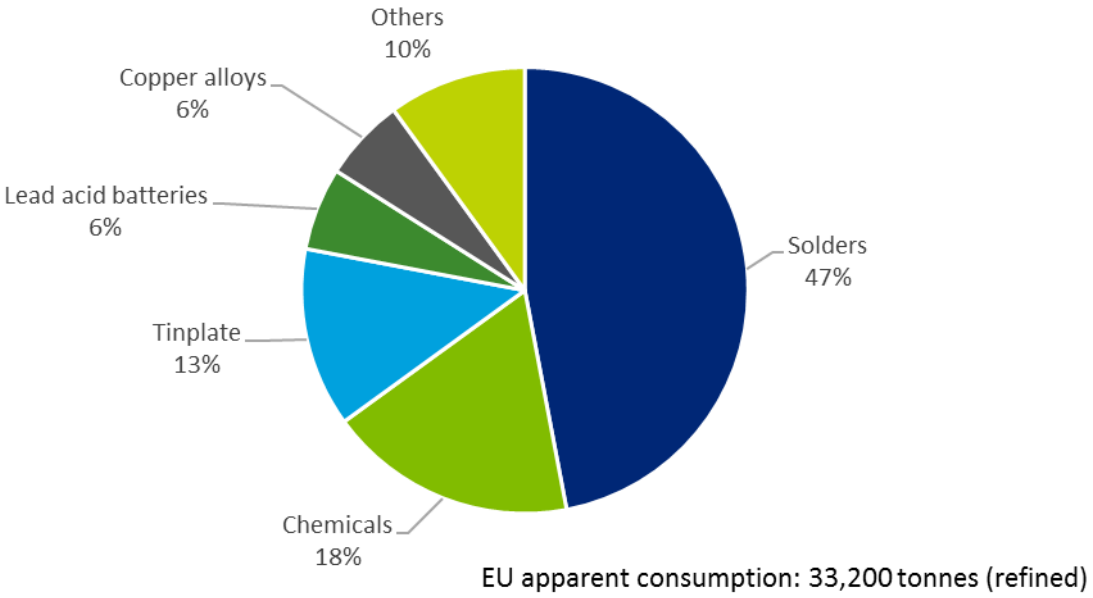


Figure 288: Global end uses of tin in 2017 (International Tin Association, 2019)

Almost half of tin demand globally is for solders, around 85% in electronics (solders found in the electric circuits of the majority of electronic appliances) and the remainder in industrial uses (joining copper pipes, electrical joining, DIY/crafts and solar ribbon for PV.). Solders are an essential part of modern life, joining together all of the electronic and electrical systems that society relies on today and in the future. Tin alloys have a low melting range and can be used to join other metals, notable copper, at lower temperature than brazing or welding. Under regulatory pressure, mainly from Europe, 70% of solders are now lead-free tin alloys, with 95% tin, with a residual amount of tin-lead solders (60% tin), especially in industrial markets, expected to transition to lead-free over the 2020s. Lead-free alloys contain small amounts of other metals, commonly copper, silver, bismuth or other elements. (International Tin Association, 2019b)

The tin chemicals sector has seen consistent growth in the tin market over the last decade. The largest use is for polymer additives, especially PVC stabilisers that prevent PVC degrading to give a brittle plastic in the presence of light, heat or atmospheric oxygen. Many of these are organotins and have been largely phased out in Europe under regulatory pressure, but are still essential in some applications and in other regions. Tin chemicals are also used as catalysts for polyurethane and silicone production. There are numerous other uses including electroplating, ceramics, glass melting & coating, relay contacts, pharmaceuticals, fire retardants, catalysts etc., but also polyurethane foam used increasingly for building insulation. (International Tin Association, 2019b)

Tinplate for packaging, especially food cans, remains an important sector of consumption. It is produced by coating steel in a thin layer of tin. Because of its non-toxicity and resistance to corrosion, tinplated steel is commonly used as containers and/or closures for packaging food, drink, dry products, oils, paints and chemicals. Compared to alternatives tinplate packaging is highly recyclable, with high rates of collection. It is physically robust and able to provide long shelf-life low-cost nutritious food, with little waste. (International Tin Association, 2019b)

Tin is added to lead-calcium lead-acid battery grids at up 1.6% to improve casting and cycling performance in high end maintenance-free AGM/VRLA products, notably used in automotive markets, especially start-stop hybrids. Up to 2% tin may be contained in lead tin alloy posts and straps connecting the grids These can replace lead-antimony alloys containing 0.2% tin that are still widely used in flooded products. Stationary batteries for UPS, mobile communications, renewable energy and utility grid balancing typically use flooded products. Tin is also important in motive applications such as electric forklifts or China e-bikes. Lithium-ion batteries are already taking market share but lead-acid batteries are expected to continue long-term in important uses, notably as auxiliary batteries in hybrid and electric vehicles. (International Tin Association, 2019b)

Copper alloys such as brass and bronze are used in many industrial applications (bearings, springs and electrical connectors for example), as well as sculpture, coins, bells and musical instruments Bronze is an alloy of copper and tin and some brasses are an alloy of copper, zinc and tin. For both brass and bronze, varying the amount of copper and other elements in the composition will change the properties of the alloy. Tinned copper and bronze wire products are increasingly used in automotive and electrical components. (International Tin Association, 2019b)

Tin and other alloy products have a wide variety of uses. Tin is used in the Pilkington process for making flat window glass, whereby molten glass is floated on top of molten tin at 1,100 °C. Other applications include pewter items, tin powders, wine and spirit capsules, bearing alloys and electroplating anodes.(International Tin Association, 2019b)

Relevant industry sectors are described using the NACE sector codes (Eurostat, 2019).

Table 161: Tin applications, 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2019)

Applications	2-digit NACE sector	Value added of NACE 2 sector (M€)	4-digit NACE sectors
Solders	C26 - Manufacture of computer, electronic and optical products	65,703	C26.10- Manufacture of electronic components
Chemicals	C20 - Manufacture of chemicals and chemical products	105,514	C20.16- Manufacture of plastics in primary forms, main use is PVC in this category, but also used for glass coatings, pigments, etc.
Tinplate	C25 - Manufacture of fabricated metal products, except machinery and equipment	148,351	C25.92- Manufacture of light metal packaging

Applications	2-digit NACE sector	Value added of NACE 2 sector (M€)	4-digit NACE sectors
Lead acid batteries	C27 - Manufacture of electrical equipment	80,745	C27.20- Manufacture of batteries and accumulators
Copper alloys	C24 - Manufacture of basic metals	55,426	C24.44- Semi-finished products of copper or copper alloys
Others	C25 - Manufacture of fabricated metal products, except machinery and equipment	148,351	C25.7 Others (including tin and bronze powders, wine capsules, pewter, tin coatings and float glass). These end-uses are mostly found in C25 - Manufacture of fabricated metal products, except machinery and equipment

33.3.3Substitution

For many applications of tin substitutes are available. Solders in some high-end uses may be substituted by alternate technologies such as conductive adhesives or embedded components, although these can be more expensive and less reliable and their use is currently marginal. Conductive adhesives are used in some displays, RFID tags and LCD connections, typically with temperature-sensitive components. Embedded component technologies, using components built inside the circuit board, can be used in high-volume high-end uses such as mobile phones where capital costs can be justified. Other technologies exist including pressfit, printed electronics and copper-to-copper, but these are not likely to have a significant impact on mainstream electronics production. As in the above uses, leaded solders have been largely substituted by lead-free products (silver-copper and other alloys with higher tin content) due to health and safety concerns over the toxicity of lead. There has also been extensive economisation in solder use for electronics assembly, including conversion to miniaturised products, which has flattened solder use in the 2010s. More recently new low-temperature 58% bismuth-tin solders have been introduced but are limited by bismuth supply. Industrial solder use in copper pipes is impacted by the increasing use of plastic piping in construction markets. (International Tin Association, 2019b)

Alternatives to some tin chemicals have been developed calcium-zinc products can be used as PVC stabilisers and are cheaper than tin stabilisers. Iron sulphate is an alternative to tin sulphate or chloride in cement additives applications. However, inferior properties of these alternatives have prevented them from penetrating deep into the market (Coherent Market Insight 2019, International Tin Association 2019b, USGS 2019).

In tinplate, tin can be replaced by other packaging materials including glass, plastic, aluminium, pouchs, tin-free steel or cartons depending on price, quality, or manufacturer preference. Aluminium is largely replacing tinplate in beverage markets and competes in aerosol products. Food cans is typically a robust market for tinplate, with strong sustainability credentials, although this has recently been challenged by producers of polymer-laminated steel.(International Tin Association, 2019b)

The shift from lead-acid batteries to lithium-ion batteries in several sectors does impact tin usage, especially in the important China e-bikes market. The share of Lithium-ion batteries is

estimated 40-80% (International Tin Association, 2019b). For the criticality assessment, the average value 60% was applied.

The use of tin can also be impacted by aluminum alloys, alternative copper-base alloys like zinc-copper alloys, and plastics acting as substite for tin-copper alloys (bronze), as well as plastics for bearing metals that contain tin (USGS, 2019). The relevance of such substitutability was however questioned (International Tin Association, 2019b).

33.4Supply

33.4.1EU supply chain

The EU does not have significant smelting capacities. Accordingly, the imports of ores are very low with only 106 tonnes per year of tin in total (averaged over 2012-2016). Within the EU, Portugal is the major producer of tin ore in Europe (80%, 59 tonnes per year), followed by Spain (20%, 15 tonnes per year), together contributing to more than two thirds of the EU sourcing. EU Sourcing of tin ores and concentrates is shown in Figure 289 (BGS, 2018; Eurostat, 2019; International Tin Association 2019b). However, also the EU mine production is small with in average 75 tonnes per year for the period 2012-2016.

In contrast, the EU sources around 37,000 tonnes per year refined tin, which is more than 10% of the global supply (361,000 tonnes per year) (Figure 292:). This makes the EU a relevant player in the global tin supply chain, in contrast to the mine stage (BGS, 2018; Eurostat, 2019).

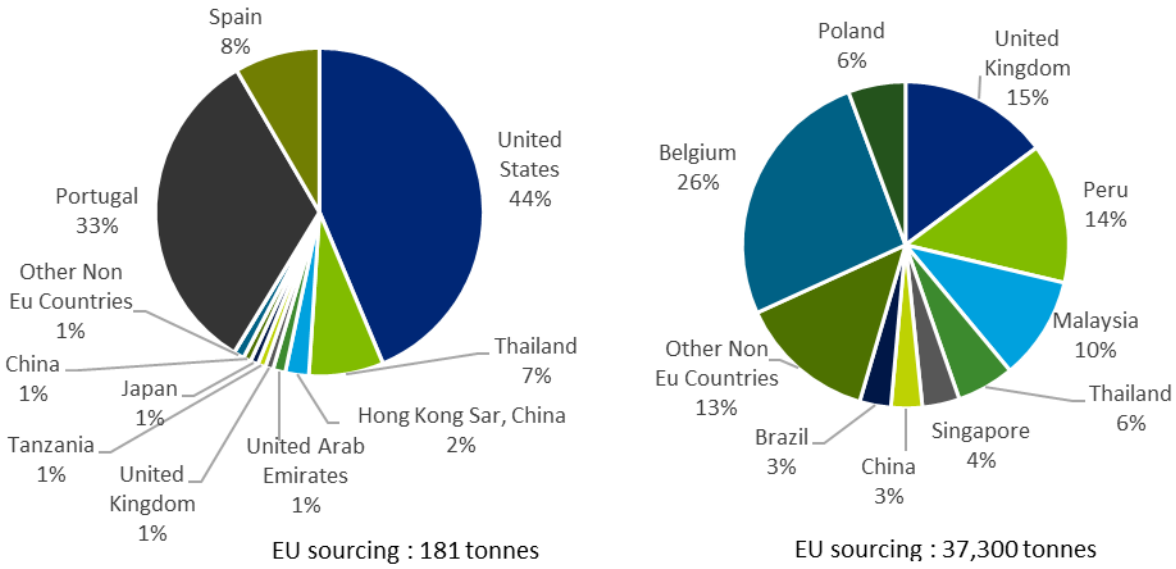


Figure 289: EU Sourcing (domestic production + imports) of (A) ores and concentrates, and of (B) refined tin, with average absolute values for the period 2012-2016 (BGS, 2018; Eurostat, 2019)

In the past, Europe was an important supplier also of tin ores and concentrates. Western and central-eastern Europe host an outstanding tin-tungsten mineral belt. Deposits of this belt were intensely used in the past until, however, in the meantime most of these tin mines were closed, mainly before the 1980s when tin prices went very low. To counteract that

development and to exploit the full tin mining potential in Europe, the project iTARG3T[172] was funded by the EIT on Raw Materials[173], running from 2019 to 2020. It is deployed in Spain and looks at the whole value chain of Sn-W-Ta in Europe, addressing the various problems arising during the early and advanced stages of W-Sn-(Ta-Li) exploration, effective ore targeting, and ore processing. iTARG3T estimates that based on the methods proposed, around ten new mines can be developed and opened, reaching the European self-production on a mid-term time scale.

33.4.2Supply from primary materials

33.4.2.1 Geology, resources and reserves of tin

Geological occurrence: The estimated abundance of tin in the upper continental crust is 2.1 ppm (Rudnick, 2003), which is low compared to other industrial metals.

Tin is invariably found in association with granitic rocks, either in situ or as alluvial or eluvial deposits resulting from the weathering of the original tin-bearing rock. Cassiterite (SnO_2) is by far the most important tin ore. Small quantities of tin have also been recovered from complex sulphide minerals such as stannite (Cu_2FeSnS_4).

Primary deposits can occur within the granite or within pegmatities or aplites associated with the granite. Deposits occur also in rocks surrounding the margins of the intrusions as veins, disseminations, skarns or carbonate replacements generated by tin bearing fluids derived from the granite magmas.

Secondary deposits also known as placers result from the weathering and erosion of primary tin deposits. Cassiterite is chemically resistant, heavy and readily forms residual concentrations. Deposits in oceanic submerged river channels are important sources of tin. More than half of the world's tin production come from this type of deposits which aremostly located in Malaysia, Indonesia and Thailand (Geoscience Australia, 2016; Thompson, 2001).

Global resources and reserves[174]:Global reserves of tin at the end of 2018 were estimated at around 4,700,000 tonnes (USGS, 2019), with China accounting for a quarter of the global total, followed by Indonesia and Brazil (Table 162).

[172] https://eitrawmaterials.eu/project/itarg3t/

[173] European Institute of Innovation and Technology: EIT Raw Materials: https://eitrawmaterials.eu/

[174] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of tin in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template.[174], which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

Table 162: Global reserves of Tin in 2018 (USGS, 2019)

Country	Estimated Tin Reserves (tonnes)
China	1,100,000
Indonesia	800,000
Brazil	700,000
Bolivia	400,000
Australia[175]	370,000
Russia	350,000
Malaysia	250,000
Thailand	170,000
Congo D.R.	150,000
Burma	110,000
Peru	110,000
Vietnam	11,000
Nigeria	n/a
Rwanda	n/a
Other countries	180,000
World Total (rounded)	4,700,000

According to the International Tin Association (2016), the world's reported tin resources at the end of 2015 totalled some 11,700,000 tonnes, including 2,200,000 tonnes of reserves i.e. about half of the USGS estimate.

EU resources and reserves[176]: Resource data for some countries in Europe are available at the European Minerals Yearbook (Minerals4EU 2019) but cannot be summed as they are partial and they do not use the same reporting code. Tin resources have identified in Czech Republic, Finland, France, Germany, Spain and Sweden (see Table 163).

In Spain, exploration for tin is active since 2010. The Oropesa Tin Project in Andalucia has a JORC measured and indicated resource of 9,340,000 tonnes (0.55% tin), and JORC inferred resource of 3,200,000 tonnes (0.52% tin, at 0.15% tin cut-off); for a total contained JORC resource of 67,520 tonnes of tin (Elementos, 2019). ITA indicated higher resources for the Czech Republic (278,000 tonnes, 0.04% tin).

[175] For Australia, Joint Ore Reserves Committee-compliant reserves were about 260,000 tonnes.

[176] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for tin. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for tin, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for tin the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019). Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However a very solid estimation can be done by experts.

Table 163: Resource data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2019)

Country	Reporting code	Quantity	Unit	Grade	Code Resource Type
Czech Republic	National reporting code	164,299	tonnes	0.22%	*Potentially economic*
Finland	None	0.11	Mt	0.32%	Historic Resource Estimate
France	None	47,341	tonnes	Metal content	Historic Resource Estimates
Portugal	None	101.137	Mt	0.11%	Historic Resource Estimates
Sweden	None	0.6	Mt	0.07 %	Historic Resource Estimates

33.4.2.2 World and EU mine production

During the period 2012-2016, 305,000 tonnes of tin were mined on average annually, in the world. China was the main producer and accounted for 35% of the global mine production, followed by Indonesia (27%) and Myanmar (10%) (Figure 290). Experts noted that there is tin smuggling taking place between Myanmar and China, which hampers the quality of the related trade data. Nearly all Myanmar output, which soared from 5,000 tonnes in 2012 to 57,000 tonnes in 2016, is further processed in China. Indonesian production, in contrast, has plummeted by a third since the government banned exports of unprocessed tin concentrates in 2014.

With an annual average production of 75 tonnes, the EU accounted for less than 1% of global tin ore production. In the period 2012-2016, average annual tin extraction was in Portugal (59 tonnes per year, 80% of EU production) and a smaller output in Spain (15 tonnes per year, 20%) (see Figure 290), from the W-Sn San Finx mine in Galicia, and the Lousame, La Coruña, mine. Experts considered the production figures as uncertain.

Two mines are expected to start soon tin extraction in Europe. First, the Cinovec mine extending across the Czech-German border hosts one of the worldwide largest undeveloped tin resources. Second, the South Crofty mine in Cornwall, UK, is located in an ancient tin mining region and awaits permission for the dewatering before it can be reopened.

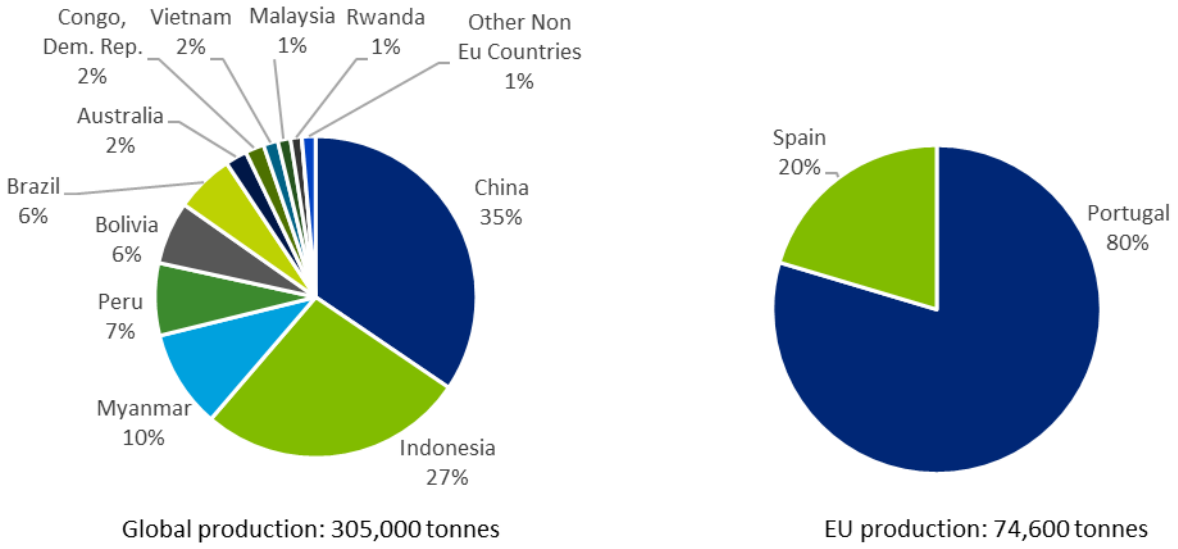


Figure 290: (A) Global and (B) EU mine production of tin ores in tonnes and percentage. Average for the period 2012-2016 (BGS, 2018)

33.4.3Supply from secondary materials/recycling

33.4.3.1 Post-consumer recycling (old scrap)

End-of-life recycling rate depends on the applications, with tinplate in food and beverages cans having the highest (around 65%), followed by solders in electronics (40%). The End-of-Life Recycling Input Rate (EoL-RIR) of tin, including refined and unrefined forms, was calculated as 30.7% in 2016, down from 31.4% in 2015, with re-refined tin contributing approximately 16% (ITRI, 2016; ITRI, 2017).

33.4.4Processing of tin

The recovery of an impure cassiterite concentrate leads to further concentration by gravity methods which involve passing the concentrate in a stream of water over equipment such as jigs, spirals, or shaking tables. This separates the heavy cassiterite from the lighter minerals such as quartz. Magnetic or electrostatic separation removes the heavy mineral impurities. It results in the production of a cassiterite concentrate containing about 70% tin (Geoscience Australia, 2016). Although cassiterite is the main mineral, tin is also mined through other minerals.

The next step is smelting. The objective is to reduce cassiterite into tin by heating it with carbon at 1,200-1,300 °C in reverberatory furnaces together with a carbon-reducing agent, limestone and silica fluxes. Smelting takes 10-12 h. The molten batch is tapped into a settler from which the slag overflows into pots. The molten tin from the bottom of the settler is cast into slabs or pigs (of about 34 kg) for refining, and the cooled slag, which contains 10-25% tin, is crushed and re-smelted.

Before the tin is put on the market, refining is necessary to remove metallic impurities contained after smelting. As there is not a great demand for tin of extremely high-purity (typically 99.85%-99.9%) pyrometallurgical techniques are the most widely used (Geoscience Australia, 2016). In this process, tin slabs are heated to a temperature slightly above the

melting point of pure tin but below the one of the impurities. The "pure" tin melts and flows into a kettle, leaving impurities in the residue or slag. Some of these slags contain other valuable elements such as tantalum, niobium or REEs and can be re-processed specifically. Primary tin metal grading 99.85% tin is cast and sold as bars, ingots, pigs and slabs. High-purity tin with up to 99.999% purity may also be produced using electrolytic refining.

World refined tin metal production amounted to 361,000 tonnes per year on average during the period 2012-2016 (BGS, 2018). China was the world leading supplier with 47% (169,000 tonnes per year) of the global production, followed by Indonesia contributing 68,000 tonnes per year, and Malaysia (32,000 tonnes per year). The world top 3 refined tin producers are Yunnan Tin in China, PT Timah in Indonesai and Malaysia Smelting Corp in Malaysia.

The EU produced at an annual average for the period 2012-2016 around 12,000 tonnes, by refineries in Belgium (10,000 tonnes) and Poland (2,000 tonnes) from primary and secondary material (BGS, 2019). The tin production in Belgium declined by 25% from 2012 to 2016, whereas the Polish production more than doubled.

The International Tin Association (International Tin Association 2019b) reports higher EU production of 14,100 tonnes per year (Belgium 9,300 tonnes, Poland 3,800 tonnes and Spain 1,000 tonnes).

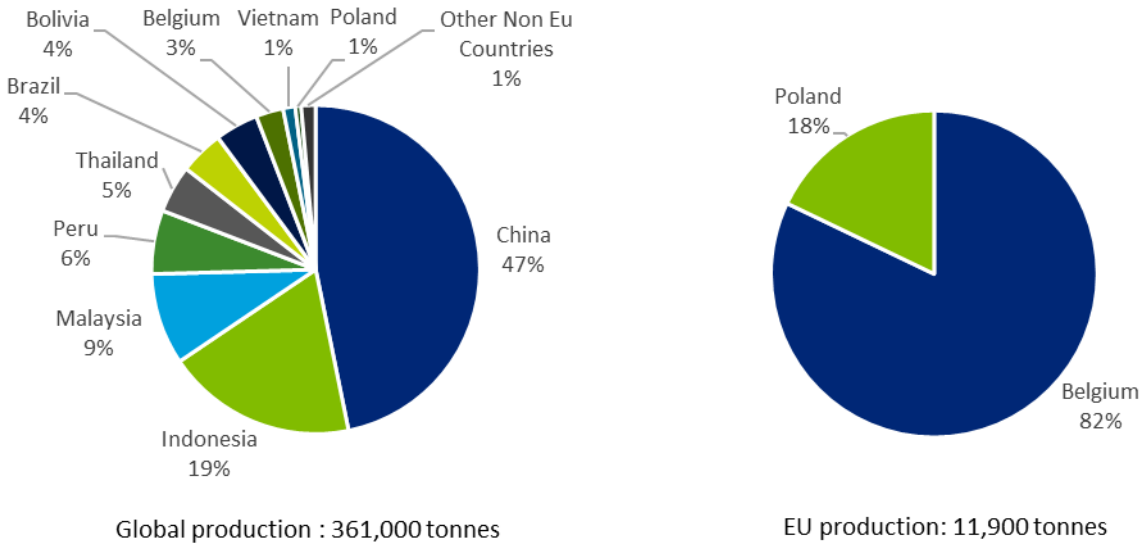


Figure 291: Global (A) and EU (B) refined tin production. Average for the years 2012-2016. (BGS, 2018)

33.5Other considerations

33.5.1Environmental and health and safety issues

EU occupational safety and health (OSH) requirements exist to protect workers' health and safety. Employers need to identify which hazardous substances they use at the workplace, carry out a risk assessment and introduce appropriate, proportionate and effective risk

management measures to eliminate or control exposure, to consult with the workers who should receive training and, as appropriate, health surveillance[177].

At EU level, occupational exposure limit values[178] (OELs) are set for platinum to prevent occupational diseases or other adverse effects in workers exposed to platinum in the workplace. Workers' and employers organisations should be kept informed by member states about the indicative occupational exposure limit values[179] (IOELVs) (Skowroń 2017), which is set for tin (inorganic compounds) at Community level[180] by Directive 91/322/EEC: 2 mg/m^3 (measured or calculated in relation to a reference period of eight hours)[181].

No specific environmental restriction is known for tin.

33.5.2Socio-economic issues

Tin falls under the scope of The Regulation (EU) 2017/821 (sometimes referred to as "Conflict Minerals Regulation").

The Regulation sets out legally binding due diligence requirements for EU importers of tin, tantalum, tungsten and gold that will apply as of 1 January 2021. The main objective of the Regulation is to break the link between the trade in these minerals and metals and armed conflict and associated human rights abuses. The Conflict Minerals Regulation will also provide transparency and certainty as regards the supply practices of EU importers sourcing from conflict-affected and high-risk areas.

The Regulation's due diligence requirements are aligned with the 5-step framework for risk-based due diligence developed by the Organisation for Economic Co-operation and Development (OECD) -'Due Diligence Guidance for Responsible Supply Chains from Conflict-Affected and High-Risk Areas' (OECD Guidance).

33.6Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. Supply risk has been analysed at both mine and processing stages.

The results of this and earlier assessments are shown in Table 164. The economic importance has been decreasing since 2014, first it dropped from 2014 to 2017 and since then decreased only slightly. The supply risk, however, was stable below 1, with a slight decrease in 2017.

[177] https://ec.europa.eu/social/main.jsp?catId=148

[178] "OEL means the limit of the time-weighted average of the concentration of a chemical agent in the air within the breathing zone of a worker in relation to a specified reference period" (Skowroń 2017)

[179] as set out by Council Directive 98/24/EC

[180] IOELVs from Directive 91/322/EEC, which was based on an earlier legal framework (Directive 80/1107/EEC), are being scientifically reviewed, as foreseen in art. 3 of the abovementioned Directive 98/24/EC.

[181] Existing scientific data on health effects appear to be particularly limited.

Table 164: Economic importance and supply risk results for tin in the assessments of 2011, 2014, 2017, 2020 (European Commission, 2011; European Commission, 2014; European Commission, 2017)

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Tin	Not assessed		6.7	0.9	4.4	0.8	4.2	0.90

33.7Data sources

For the supply of ores/concentrates and tin metal, the World Mineral Production dataset was used (BGS 2019). For trade, the Eurostat Comext database has been used (Eurostat 2019). The sector data for Europe was getting outdated, and as there are no reliable data available on application shares of tin in Europe, global data of the International Zinc Association was accessed (ITA 2019b).

33.7.1Data sources used in the factsheet

British Geological Survey (2019). World Mineral Production, 24/4/2019

Buchholz P., Wellmer F.W., Bastian D., Liedtke M. (2019). Leaning against the wind: Low price benchmarks for acting anticyclically in the metal markets. Mineral Economics. https://doi.org/10.1007/s13563-019-00199-y

Coherent Market Insights (2019). Global tin chemical market insights. [online] Available at: https://www.coherentmarketinsights.com/market-insight/tin-chemicals-market-2574

CRU (2018). Estaño - Caracterización y análisis de mercado internacional de minerales en el corto, mediano, y largo plazo con vigencia al año 2035. http://www1.upme.gov.co/simco/Cifras-Sectoriales/Datos/mercado-inter/Producto3_Estano_FINAL_11Dic2018.pdf

Elementos (2019). The Oropesa Tin Project. [online] Available at: https://www.elementos.com.au/oropesa-tin-project/

EU (2017). 791 Regulation (EU) 2017/821 of the European Parliament and of the Council of 17 May 2017 laying down supply chain due diligence obligations for Union importers of tin, tantalum and tungsten, their ores, and gold originating from conflict-affected and high-risk areas.

Eurostat (2019). Comext database, accessed at 24/4/2019

Geoscience Australia (2019). https://www.ga.gov.au/

International Tin Association (2019a). Tin in lithium-ion batteries could represent significant new use. [online] Available at: https://www.internationaltin.org/tin-in-lithium-ion-batteries-could-represent-significant-new-use/

International Tin Association (2019b). Contribution to the criticality assessment of tin. pers. comm. (email of ITA, 20.09.2019)

ITRI (2016). Tin usage patterns by region, tin production and recycling www.itri.co.uk

ITRI (2017a). Future of China tin export duty uncertain [online] Available at: https://www.itri.co.uk/market-analysis/news-2/future-of-china-tin-export-duty-uncertain

ITRI (2017b). Lead-Acid Batteries Technical Report 2017: Impact on future tin use. 2017. [online] Available at: https://www.internationaltin.org/wp-content/uploads/2018/03/ITRI-Report-Tin-in-Lead-Acid-Batteries-260318.pdf

OECD (2016). OECD Export restrictions on Industrial Raw Materials database. [online] Available at: http://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

Roskill (2015). The World Market for Tin to 2024. 9th Edition. Roskill Information Services Ltd., London, UK. pp.286.

Rudnick, R.L., Gao., S. (2003). Composition of the Continental Crust. In: Treatise on Geochemistry, Volume 3. Editor: Roberta L. Rudnick. Executive Editors: Heinrich D. Holland and Karl K. Turekian. pp. 659. ISBN 0-08-043751-6. Elsevier, p.1-64.

Thompson, M. (2001). Base Metals Handbook. Woodhead Publishing Ltd.

UNEP (2011). Recycling Rates of Metals. A Status Report, A Report of the Working Group on the Global Metal Flows to the International Resource Panel; United Nations Environment Programme, [online] Available at: http://web.unep.org/publications/

USGS (2019). Anderson C.S. Tin - Mineral Commodity Summaries. United States Geological Survey. Ed., Washington DC.

33.7.2Data sources used in the criticality assessment

Battery University (2019). Types of Lithium-ion. BU-205. https://batteryuniversity.com/learn/article/types_of_lithium_ion, accessed at 24/4/2019

BGS (2019). World Mineral Production, 24/4/2019

Canmaker (2019). Canmaker FAQ, available at: https://www.canmaker.com/online/frequently-asked-questions/, accessed at 24/4/2019

Copper alliance (2019). Copper alloys, https://copperalliance.org.uk/about-copper/copper-alloys/, accessed at 24/4/2019.

Cosper, A. (2019). Tinplate and Aluminum Cosmetic Containers - Sustainability Considerations. Desjardin Metal Packaging, https://www.desjardin.fr/en/blog/tinplate-and-aluminum-cosmetic-containers-sustainability-considerations, accessed at 24/4/2019.

Cova scientific (2019). Electrically Conductive Epoxy vs. Solder. Available at: https://www.covascientific.com/blog/electrically-conductive-epoxy-vs.-solder

Earthsci (2019). http://earthsci.org/mineral/mindep/tin/tin.html, accessed at 24/4/2019.

ECHA (2019). Analysis of Alternatives. Available at: https://echa.europa.eu/documents/10162/7983363c-ff2d-4eeb-8587-2fcf024fcb0c, accessed at 24/4/2019.

European Commission (2017). Study on the Review of the List of Critical Raw Materials. EC Raw Materials Supply Group, June 2017, 24/4/2019.

European Commission (2019). DG Trade website "Agreements". http://ec.europa.eu/trade/policy/countries-and-regions/agreements/, accessed at 24/4/2019.

European Stabilisers Producers Association (2017) Carolina, SUSIN. 'PVC Stabilisers: A 15 Year-Journey on the Sustainability Road', 2017, 21. https://www.stabilisers.eu/wp-content/uploads/2017/06/SUSIN-CAVALLERO-Brighton_20170425-V2-pdf.pdf , 16/4/2019.

European Stabilisers Producers Association (2019), https://www.stabilisers.eu/stabilisers accessed at 16/4/2019.

Eurostat (2019). Comext database, accessed at 24/4/2019.

Infomine (2019a). Aluminum. https://www.infomine.com/investment/metal-prices/aluminum/, accessed at 24/4/2019.

Infomine (2019b). Zinc. https://www.infomine.com/investment/metal-prices/zinc/, accessed at 24/4/2019.

International Tin Association (2019a). Tin information on selected topics. personal communication (email of ITA, 20.09.2019).

International Tin Association (2019b). https://www.internationaltin.org/ita-survey-weaker-tin-use-growth-2018/, accessed at 15/4/2019.

International Tin Association (2019c). Tin users see weaker markets. Available at website of International Tin Association: https://www.internationaltin.org/tin-users-see-weaker-markets, accessed at 19/10/2019 (last update 16.10.2019).

Koons, E.S.K. (2019). How Aluminium and Tinplate are Better Than Plastic Packages. Desjardin Metal Packaging, available at: https://www.desjardin.fr/en/blog/how-aluminium-and-tinplate-are-better-than-plastic-packages, accessed at 24/4/2019

Masterbond (2019). Conductive Epoxy Replaces Lead Soldering. Available at: https://www.masterbond.com/techtips/conductive-epoxy-replaces-lead-soldering accessed at 24/4/2019

Mizu, M., Mitsudera, T., Sengoku, T., Iwanami, K., Yukino, T., Nishimura, H., Weiler, R.G. (2010). Non-Tin Heat Stabilizers for Clear Rigid PVC Applications. 16/4/2019

OECD (2019). Export restrictions on Industrial Raw Materials database. http://qdd.oecd.org/table.aspx?Subject=ExportRestrictions_IndustrialRawMaterials, accessed at 4/4/2019

Petersen, J. (2019). https://seekingalpha.com/article/4152035-battery-chemistry-assumptions-distort-nickel-cobalt-demand-forecasts, accessed at 24/5/2019.

Pillot, C. (2019). The Worldwide rechargeable Battery Market 2016-2025. Avicenne, 24/4/2019

Total Materia (2019). Solder Alloys. Website available at: https://www.totalmateria.com/page.aspx?ID=CheckArticle&LN=EN&site=ktn&NM=229, accessed at 15.04.2019.

USGS (2019). https://minerals.usgs.gov/minerals/pubs/mcs/, 24/4/2019.

33.8Acknowledgments

This Factsheet was prepared by JRC in collaboration with the French Geological Survey (BRGM).

The authors thank the Ad Hoc Working Group on Critical Raw Materials, in particular Corina Hebestreit (Euromines), as well as experts participating in the tin session of the SCRREEN workshop for their valuable contribution and feedback, notably Jonathan Rickwood (International Tin Association).

34. ZINC

34.1 Overview

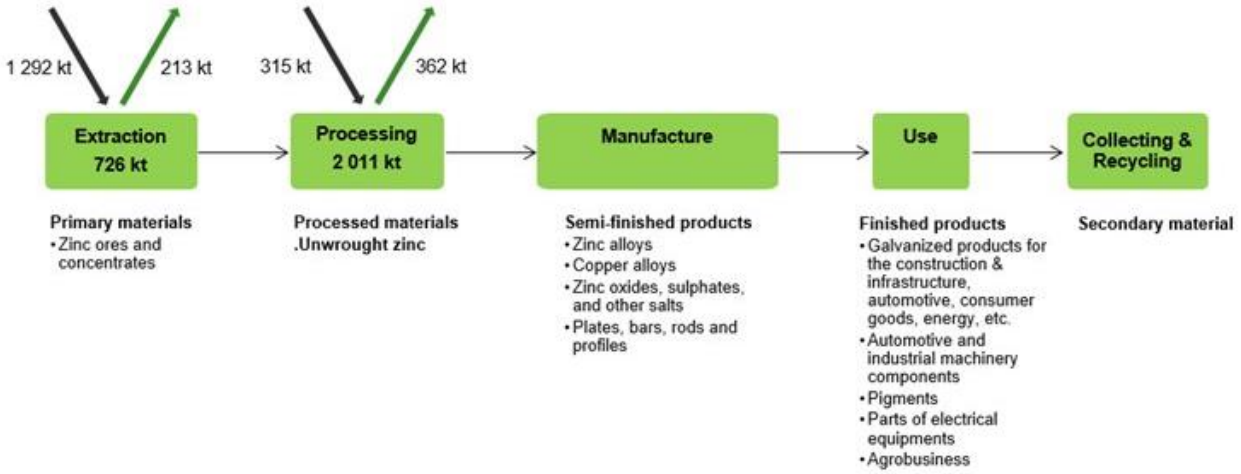
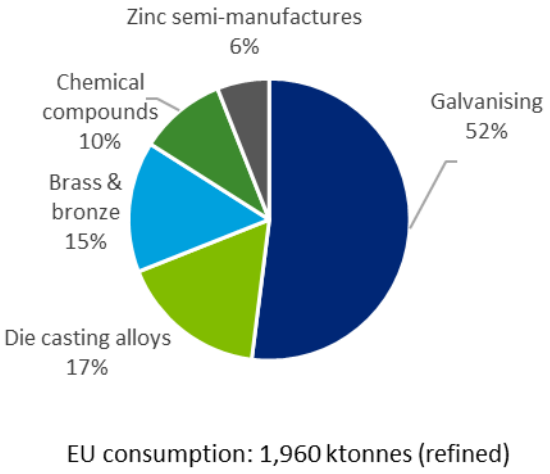


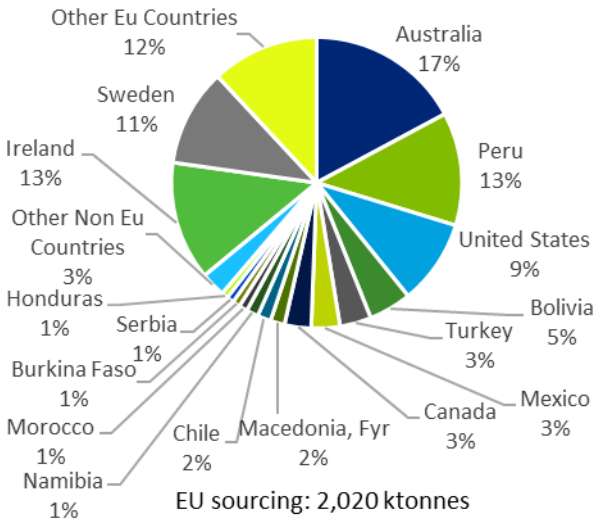
Figure 292: Simplified value chain for zinc for the EU, average 2012 to 2016[182]

Zinc (chemical symbol Zn) is the fourth most used nonferrous metal, after iron, aluminum and copper. Zinc has a specific weight of 7.13 g/cm^3 and its melting and boiling points are 419 °C and 906 °C, respectively. It alloys readily with other metals and is chemically active. Zinc is an essential element for the growth of living organisms.

For the purpose of this assessment zinc is analysed at both extraction and processing stages. Mine production is expressed in terms of metal content. Primary zinc metal is recovered as slab which usually contains more than 98% zinc.



EU consumption: 1,960 ktonnes (refined)



EU sourcing: 2,020 ktonnes

[182] JRC elaboration on multiple sources (see next sections).

Figure 293: End uses of zinc in the EU, 2015 (ILZSG 2017) (left) and EU sourcing of zinc concentrates (right) Average 2012-2016 (BGS, 2018; Eurostat, 2019)

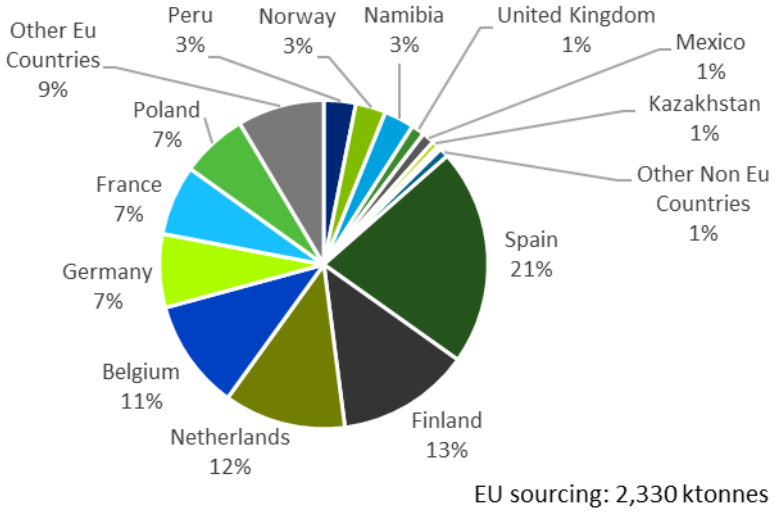


Figure 294: EU sourcing of zinc metal, average 2012-2016 (BGS, 2018; Eurostat, 2019)

Trade data is analysed using CN codes 2608 00 00 which is labelled "zinc ores and concentrates" (55% zinc) and 7901 "Unwrought zinc, not alloyed" which includes 7901 11 00 (zinc ≥ 99.99%), 7901 12 10 (99.95% ≤ zinc < 99.99%), 7901 12 30 (98.5% ≤ zinc < 99.95%) and 7901 12 90 (97.5% ≤ zinc < 98.5%). (Eurostat Comext, 2019)

Global usage of refined zinc metal amounted to 14,100 ktonnes in 2016 and is expected to reach 16,300 ktonnes in 2020 (Nexa resources, 2018). The London Metal Exchange (LME) trades a contract on ingots of zinc that is at least 99.995% pure. Each contract represents 25 tonnes of zinc and is quoted in U.S. dollars.

Average yearly LME prices increased 8% from US$1,946 per tonne to US$2,095 per tonne during the period 2012-2016.

The EU consumption of zinc concentrates between 2012 and 2016 was 1,800 ktonnes per year which were sourced through domestic production (726 kt), mainly in Ireland (266 kt; 13%) and Sweden (218 kt; 11%). Imports, mostly from Australia (346 kt; 27%) and Peru (253 kt; 20%).

The EU consumption of zinc metal was almost 2,000 ktonnes per year averaged over 2012-2016, mostly supplied by domestic production in Spain (496 ktonnes per year; 25%), Finland (305 ktonnes per year; 16%), the Netherlands (279 ktonnes per year; 14%) and Belgium (252 ktonnes per year; 13%).

About one-half of the zinc that is produced in the EU is used in steel galvanising to protect steel from corrosion. It is also used to produce die-castings, in alloys such as brass and bronze and chemical compounds. About two-third of zinc containing materials are used in the construction and infrastructure sectors. For the purpose of corrosion protection, zinc is substituted by aluminium alloys, paint and plastic coatings.

Renewable energy technologies need zinc for the galvanisation of the steel used in wind turbines, solar panel frames, power distribution poles, and hydro-electric plants. As a recyclable and durable metal, zinc contributes to the construction of sustainable buildings.

New, large rechargeable zinc battery types ensure constant power supply from non-constant sources, such as solar and wind power.

Identified world zinc resources were approximately 1,900 Mtonnes (metal content) (USGS 2019). World known reserves of zinc are estimated at around 230 Mtonnes (USGS 2019). Australia has the world's largest zinc reserves (28%), followed by China (19%). According to USGS, the largest zinc reserves and resources in the EU are located in Sweden (1%). Further countries with significant reserves are Portugal, Ireland, Kosovo, and Spain (Minerals4EU, 2019).

The world production of zinc concentrates was 13,300 ktonnes per year on average for the period 2012-2016, with China accounting for 37% of the total production, followed by Australia (11 %) and Peru (10 %). The EU domestic production (726 ktonnes per year) was in average 5% of the global production for the period 2012-2016. Ireland and Sweden were major contributors of the domestic production: Ireland with 266 ktonnes per year (37%) and Sweden with 218 ktonnes per year (30%) together contributed 67% of the EU production (BGS, 2018). According to the World Lead and Zinc Statistics, the EU production rose by 4% between 2016 and 2018 to 713 ktonnes (International Lead and Zinc Study Group, 2019).

World refined zinc metal production amounted to 13,300 ktonnes (BGS 2018). China was the world leading supplier with 42% (5,700 ktonnes per year) of the global production. The EU produced on average 2,000 ktonnes per year of refined zinc, i.e. 15% of the global production, with Spain accounting for 25% (496 kt) of the production. According to the World Lead and Zinc Statistics, the EU production rose by 4% between 2016 and 2018 to 2,075 kttonnes (International Lead and Zinc Study Group, 2019).

World zinc production from secondary raw materials in zinc smelters amounted to around 820 ktonnes per year, with the EU accounting for 34% of this production (283 ktonnes per year) (ILZSG, 2017). A further 700 ktonnes per year of zinc were recycled annually in the EU from scrap, wastes and by-products without passing through the zinc slab stage (IZA, 2019).

China applies an export tax of 30% on zinc concentrates.

34.2Market analysis, trade and prices

34.2.1Global market analysis and outlook

World zinc demand of refined metal increased steadily between 2012 and 2016 from 12,400 ktonnes per year to 13,900 ktonnes per year (ILZSG, 2017). The market was in surplus in 2012 and 2015 and fell to deficit in 2013, 2014 and 2016.

Peru is the largest world exporter of zinc concentrates followed by Australia, Bolivia and the United States. Glencore was the largest producer of zinc concentrates with a production of about 1,100 ktonnes of zinc in 2016, followed by Vedanta Resources and Teck Resources. Boliden was the main EU producer in 2016.

The growing need for galvanised steel is the major factor that will drive zinc market growth. Zinc demand will stay reliably strong as urbanization continues to expand and new sources of final demand, such as offshore wind energy structures, solar panel frames, electric vehicles[183]

[183] Although conventional vehicles use zinc, electric vehicles are estimated to use up to 70% more per vehicle ("World Bank")

and zinc products for the agribusiness, have a greater market impact. A significant rise in demand is also expected According to Nexa Resources (2018), demand will register a stable growth of 2.2% from 2018 to 2023.

Over the period 2019-2022, global zinc supply is expected to grow at a compound annual growth rate of about 4%, to 15,700 ktonnes in 2022 (Mining Technology, 2019). The market, which is currently in defict, is forecast to move into a surplus in 2022 due to new projects commencing operations between 2019 and 2022. However, ongoing environmental checks might constrain China smelting capacity that could restrict refined metal output (World Bank, 2019).

Table 165: Qualitative forecast of supply and demand of zinc

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Zinc		x	+	+	+	++	+	+

34.2.2EU trade

EU zinc concentrates imports amounted to 1,292 ktonnes per year on average over the period 2012-2016. Around a quarter of the ores imported to the EU came from Australia (27%). Peru was another major supplier (20%), followed by the United States (15%) (Eurostat, 2019). The EU industry reliance on imports of zinc concentrates was 60%. China has put a tax of 30% on zinc concentrates exports (OECD, 2016).

The EU exported 213 ktonnes per year of zinc concentrates on average between 2012 and 2016, mostly to Norway (62%) and China (28%).

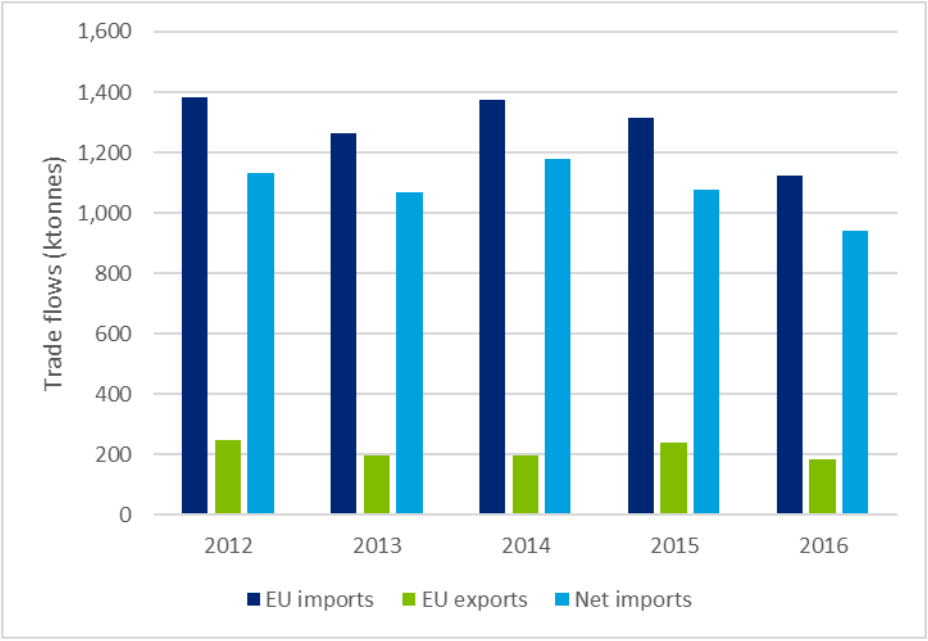


Figure 295: EU trade flows for zinc concentrates, 2012-2016 (Eurostat, 2019)

Currently there are EU free trade agreements in place with Peru, Turkey, North Macedonia, Canada, Mexico, Chile, Namibia, Morocco, Serbia and Honduras (European Commission, 2016).

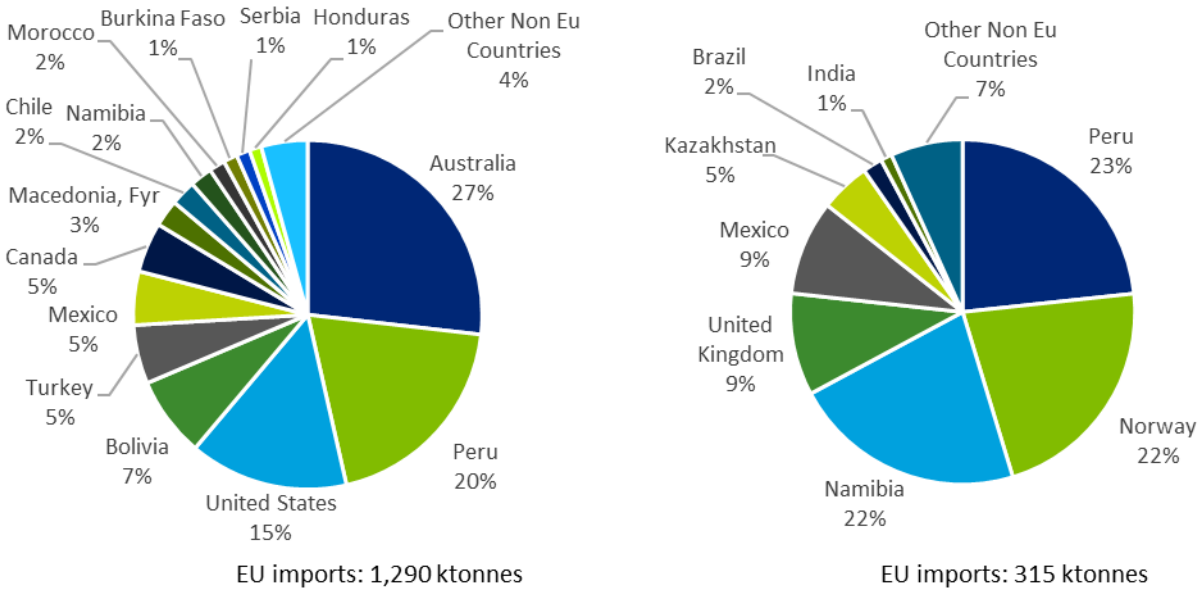


Figure 296: EU imports of zinc concentrates (left) and refined zinc (right), average 2012-2016 (Eurostat, 2019)

The EU imported 315 ktonnes per year of refined zinc on average between 2012 and 2016, mainly coming from Peru (23%), Norway (22%) and Namibia (22%). The EU was a net exporter of refined zinc over the period 2012-2016, with exports reaching a maximum in 2016 (361 ktonnes per year). (Eurostat, 2019)

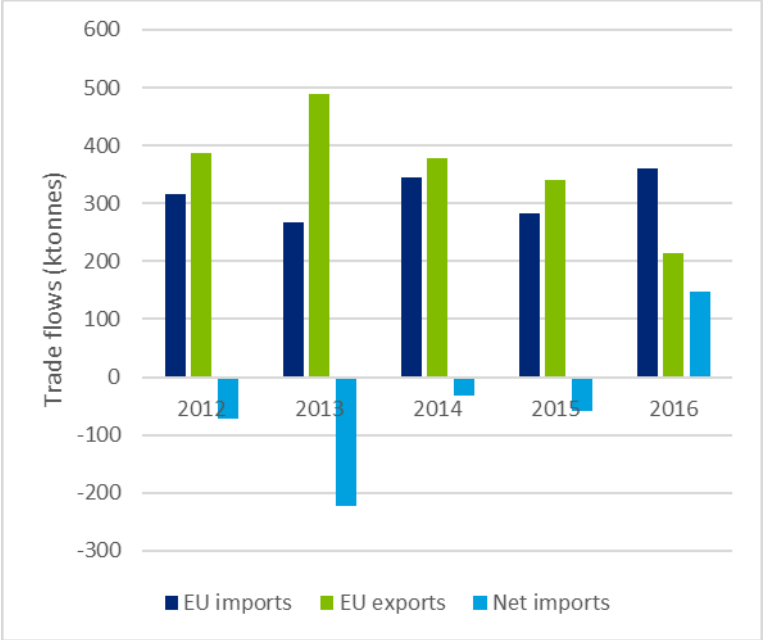


Figure 297: EU trade flows for refined zinc, 2012-2016 (Eurostat, 2019)

34.2.3 Prices and price volatility

Zinc is traded on the major exchanges around the world including the London Metals Exchange (LME) and the Shanghai Metal Exchange (SHME). The LME trades a contract on ingots of zinc that at least are 99.995% pure. Each contract represents 25 tonnes of zinc and is quoted in U.S. dollars.

Average yearly LME prices incresead 8% from US$1,946 per tonne to US$2,095 per tonne during the period 2012-2016. Supply curtailments due to the closure of major mines such as Century in Australia and Lisheen in Ireland and suspensions of other operations saw zinc prices rise 60% and 29% in 2016 and 2017, respectively, before reaching a high point at US$3,618 per tonne in February 2018 (Figure 298). Zinc lost around 25% of its value through 2018, from its starting point of US$3,377 per tonne to close the year at US$2,542 per tonne as market became better supplied and on increasing uncertainty amid the trade tensions between the United States and China. Galvanised sheet trade has been directly affected by US Section 232 tariffs on steel products (Mineralinfo, 2018; INN, 2019, SA, 2019).

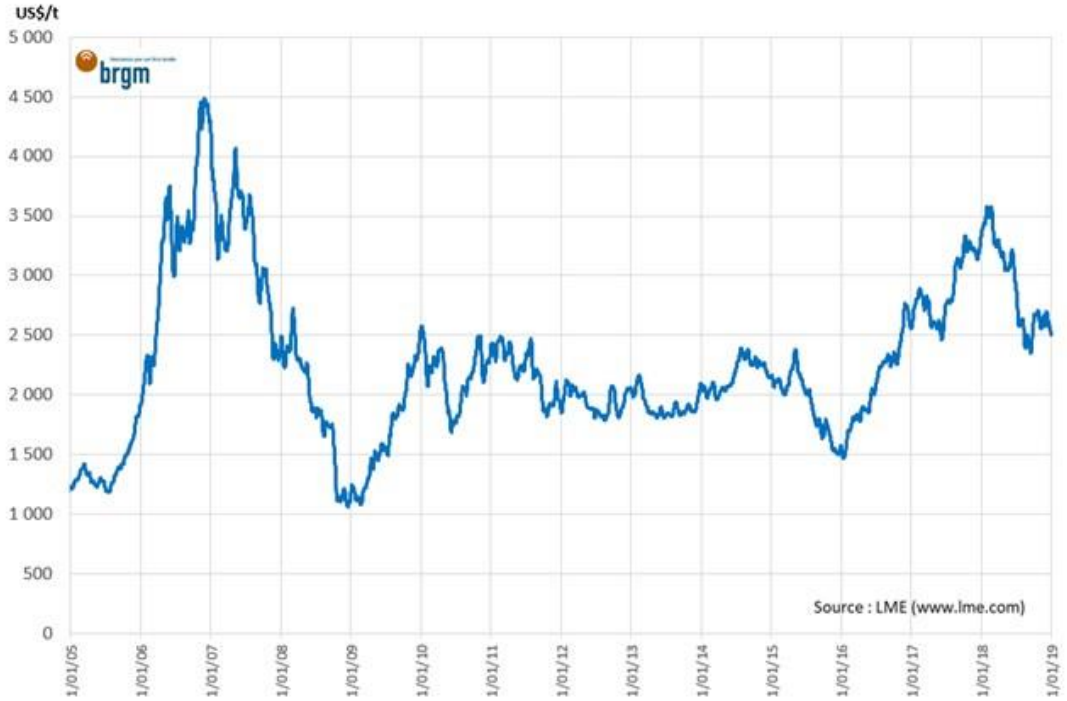


Figure 298: EU Refined zinc prices (US$/t, 7–day moving average), 2005-2018 (LME, 2019)

The long-term prices of zinc are shown in Figure 299. The price curve shows real prices.



Figure 299: Zinc prices in US$ per tonne. Vertical dashed lines indicate breaks in price specification.(Buchholz *et al.*, 2019)

34.3EU demand

34.3.1EU demand and consumption

The average annual EU apparent consumption between 2012 and 2016 was 1,804 ktonnes per year of zinc concentrates, and 1,964 ktonnes per year of processed zinc.

34.3.2Uses and end uses of zinc in the EU

Figure 300 presents the main uses of zinc in the EU in 2015 and the average EU consumption in the period 2012-2016.

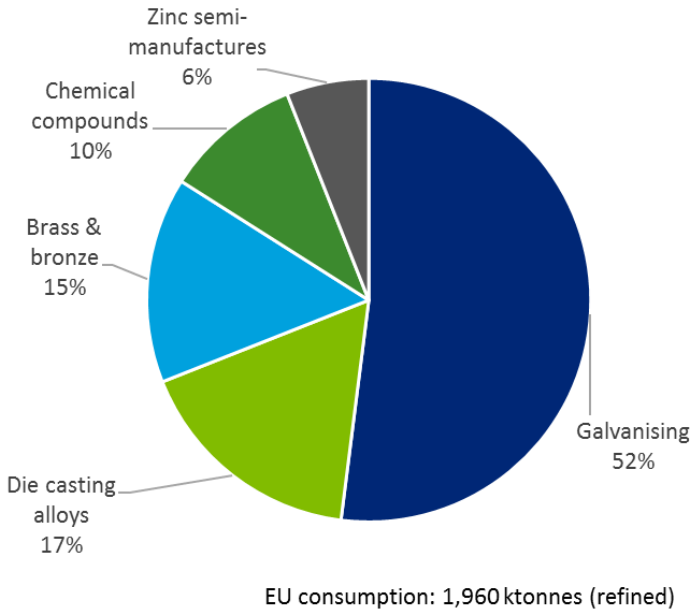


Figure 300: Europe end uses of zinc in 2015 (ILZSG, 2017)

At present, galvanisation – general and continuous galvanising – accounts for 52% of all zinc consumption in Europe (including Turkey) (ILZSG, 2017). Galvanisation is primarily used in surface coatings on steel structures (e.g. galvanised sheet) for construction (metal frames, staircases etc.), automobiles, shipbuilding, energy generation and transmission (pylons and towers), infrastructures (lights, security fences etc.) and some other industries.

Zinc alloys are widely used in the production of die-casting components (17%) in automobile manufacturing, in the mechanical industry, for electrical and electronic goods, for household appliances, toys, furniture, and buildings. Zinc is alloyed to copper, aluminium, magnesium, chromium and titanium for die casting process.

Brass and Bronze production uses 15% of the world total refined demand. Brass contains between 5% and 45% of zinc, whereas bronze only contains maximum 1% of zinc.

Zinc compounds or zinc chemicals such as zinc oxide are found in many common commercial products, including fertilisers, paints, plastics, rubber products, food supplements and additives for animals and humans, medicines, cosmetics, etc. Zinc sulfate is used in electrolytes for zinc plating. Metallic zinc powder is used as an anode material in zinc air button batteries.

In terms of end products, 66% of the zinc is used by the construction and infrastructure sectors, 28% by the automotive and industrial machinery industry, 5% by the consumer goods and the remaining by other industries such as agribusiness (Nexa, 2018).

Relevant industry sectors are described using the NACE sector codes (Eurostat, 2019).

Table 166: Zinc applications, 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2019)

Applications	2-digit NACE sector	Value added of NACE 2 sector (M€)	4-digit NACE sectors
Galvanising	C25 - Manufacture of fabricated metal products, except machinery and equipment	148,351	25.61 - Treatment and coating services of metals
Zinc alloys	C24 - Manufacture of basic metals	55,426	24.43 - Semi-finished products of lead, zinc and tin or their alloys 24.54 - Casting services of other non-ferrous metals
Brass and bronze	C24 - Manufacture of basic metals	55,426	24.44 - Semi-finished products of copper or copper alloys
Chemical compounds	C20 - Manufacture of chemicals and chemical products	105,514,	20.30 - Paints, varnishes and similar coatings, printing ink and mastics; 20.15 - Fertilisers and nitrogen compounds
Zinc semi-manufactures	C25 - Manufacture of fabricated metal products, except machinery and equipment	148,351	24.43 - Zinc bars, rods, profiles and wire; zinc plates, sheets, strip and foil

34.3.3Substitution

For the purpose of corrosion protection zinc coating is substituted by aluminium alloys (less effective), cadmium, paint and plastic coatings (less durable). Galvanised plates, e.g. in automobiles, can be replaced by aluminium, steel or plastics. Aluminium, magnesium as well as their alloys, and plastics are major competitors for parts of zinc-based die-casting alloys (USGS, 2019). Aluminum is commonly employed in die-casting, but is prone to cracking or shrinking at high temperatures. Magnesium has a high strength-to-weight ratio despite being a relatively light alloy, and it is useful for die-casting operations that require thin-structured walls and close precision. Zinc can be alloyed with aluminium, magnesium, and copper to further improve its qualities (FisherCast, 2008; IZA, 2019). Many elements are substitutes for zinc in chemical, electronic, and pigment uses (USGS, 2019).

Especially in thin film using industries, such as for solar panels, zinc oxide (ZnO) can substitute an II-VI compound semiconductor. Emerging amorphous transparent conductive oxides, like gallium-indium-zinc-oxide (IGZO/IZGO), indium-zinc-oxide (IZO) and zinc-tin-oxide promise properties equal or better than indium-tin-oxides, but are estimated to take at least 5 years to commercialization.

34.4Supply

34.4.1EU supply chain

Zinc ore is extracted and processed in the EU. The EU extracted 726 ktonnes per year of zinc in concentrates over the period 2012-2016 (BGS, 2018) making up in average 5% of the global production for the period 2012-2016. Ireland and Sweden were major contributors of the domestic production:. Ireland with 266 ktonnes per year (37%) and Sweden with 218 ktonnes per year (30%) together contributed 67% of the EU production (BGS, 2018). A major mine closed in 2015 in Ireland (Lisheen Mine), taking more than 150 ktonnes per year out of the market. The EU was dependant on its foreign imports, with an import reliance of 60% (average 2012-2016).

The domestic production of refined zinc averaged over the period 2012-2016 to 2,000 ktonnes per year with Spain accounting for almost a quarter of this production (496 ktonnes per year). The secondary slab production represents 15% of the metal output. Finland (305 ktonnes per year, 15%), the Netherlands (279 ktonnes per year, 14%) and Belgium (252 ktonnes per year, 13%) are further main producers. The EU produces enough zinc metal for its domestic consumption.

An additional average of about 700 ktonnes per year of zinc are produced from recycling materials (scrap, residues, by-products and specific products (e.g. brass) going directly to zinc use sectors without passing through the smelters.

34.4.2Supply from primary materials

34.4.2.1 Geology, resources and reserves of fluorspar

Geological occurrence:

The average zinc concentration in the Earth continental upper crust is estimated to be 67 ppm (Rudnick & Gao, 2014).

Zinc is extracted from two main types of deposits hosted in sedimentary rocks: sedimentary-exhalative (SEDEX) and Carbonate hosted deposits, which include Mississippi-valley type (MVT) and Irish type carbonate lead zinc deposits. Zinc occurs in the form of sphalerite (ZnS). Carbonate replacement deposits (CRD), Zn-Pb skarn deposits and volcanogenic massive sulphide deposits (VMS) are also important sources of zinc.

- *SEDEX deposits* are hosted in fine grained clastic sediments, mainly shales. They form from warm brines (~100-200 °C) discharged on or just below the seafloor, in sedimentary basins in continental rift settings. They include some of the largest Pb-Zn deposits in the world, such as McArthur River in Australia and Red Dog in the USA.
- *MVT deposits* are epigenetic stratabound deposits hosted mainly by dolomites and limestones. They form from warm brines with temperatures in the range of 75-200 °C (the Irish style tend to have higher temperatures with some data indicating up to 240°C) in carbonate platforms adjacent to cratonic sedimentary basins (e.g. Viburnum trend, USA; Silesia, Poland). The mineralization occurs as replacement of the carbonate rocks and as open-space fill (Paradis *et al.*, 2007; Leach *et al.*, 2010).
- *Carbonate-replacement deposits (CRD) and Zn-Pb skarn* deposits (e.g. Groundhog, USA; Bismark, Mexico) are hosted by carbonate rocks (limestones, dolomites, calcareous clastic sediments). They form by reaction of high temperature hydrothermal fluids (»250 °C) with the carbonate rocks, in the vicinity of igneous intrusions. CRD

deposits occur as massive lenses, pods, and pipes (mantos or chimneys) (Hammarstrom, 2002).

- *Volcanogenic Massive Sulphide Deposits (VMS)* are hosted either in volcanic or in sedimentary rocks and occur as lenses of polymetallic massive sulphide. VMS deposits form on, and immediately below the seafloor, by the discharge of a high temperature, hydrothermal fluids in submarine volcanic environments. They also are significant sources for cobalt, tin, selenium, manganese, cadmium, indium, bismuth, tellurium, gallium, and germanium.

Global resources and reserves[184]: The USGS estimated the world identified zinc resources at about 1,900 million tonnes (USGS, 2019). A recent study assessing the world zinc mineral resources (Mudd *et al.*, 2017) indicates that at least 610 Mtonnes are present within 851 individual mineral deposits and mine waste projects from 67 countries, at an average zinc grade of 1.2%.

At the end of 2018, global reserves of zinc were estimated at around 230 Mtonnes (USGS, 2019), with Australia and China accounting for almost half of the global total (47%) (Table 167).

Table 167: Global reserves of zinc in 2018 (USGS 2019)

Country	Estimated zinc reserves (Mtonnes)
Australia[185]	64.0
China	44.0
Peru	21.0
Mexico	20.0
Kazakhstan	13.0
United States	11.0
India	10.0
Bolivia	4.8
Canada	3.0
Sweden	1.4
Other countries	33.0
World total (rounded)	230.0

[184] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of zinc in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template.[184], which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

[185] For Australia, Joint Ore Reserves Committee-compliant reserves were about 24 Mtonnes (USGS 2019)

EU resources and reserves[186]:

Resource data for some countries in Europe are available in the Minerals4EU website (see Table 168) (Minerals4EU, 2019) but cannot be summed up as they are partial and do not use the same reporting code.

Table 168: Reserve data for the EU compiled in the European Minerals Yearbook (Minerals4EU, 2019) (rounded values)

Country	Reporting code	Quantity	Unit	Grade	Code Reserve Type
Portugal	NI43-101	16.5	Mt	5.83%	Proven
Ireland	JORC	14.8	Mt	7.39%	Proven & Probable
Finland	NI43-101	7.4	Mt	1.8%	Proven
	JORC	2.4	Mt	0.68%	Proved
Sweden	NI43-101	12.3	Mt	6.69%	Proven
	FRB-standard	17.2	Mt	5.2%	Proven
Italy	None	3.4	Mt	24.6%	Estimated
Poland	Nat. rep. code	8.2	Mt	–	total
Ukraine	Russian Classification	723.746	kt	–	C1
Slovakia	None	0.049	Mt	2.78%	Probable (Z2)
Kosovo	Nat. rep. code	13,247	kt	3.17%	(RUS)A
Turkey	NI43-101	4.49	Mt	3.19%	Proven

34.4.2.2 World and EU mine production

Zinc is usually extracted as a co-product with lead and copper. During the period 2012-2016, 13,300 ktonnes of zinc (metal content in ore) were mined annually on average in the world. The output increased by 10% from 2012 to 2016 to reach 13,788 ktonnes (metal content) in

[186] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for zinc. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for zinc, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for zinc the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019). Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However a very solid estimation can be done by experts.

2016. China was the leading producer over the period 2012 to 2016 and accounted for 37% of the global mine production, followed by Australia (11%) and Peru (10%) (BGS, 2018).

With an annual average production of 726 ktonnes in the period 2012-2016, the EU accounted for 5% of the world production. Ireland (266 ktonnes per year, 37%) and Sweden (218 ktonnes per year, 30%) together contributed 67 % of the EU production. Zinc was also mined in Poland (62 ktonnes), Portugal (56 ktonnes) and Spain (42 ktonnes)(see Figure 301). From 2012 to 2016, the EU production decreased by 9% due to the decline of Lisheen Mine output in Ireland, until its closure in November 2015, after 17 years of operation. Tara Mine in Ireland is the largest zinc mine in Europe with a production of 148 ktonnes in 2016. In Sweden, three deposits are currently being mined: Garpenberg, Zinkgruvan and the Boliden area.

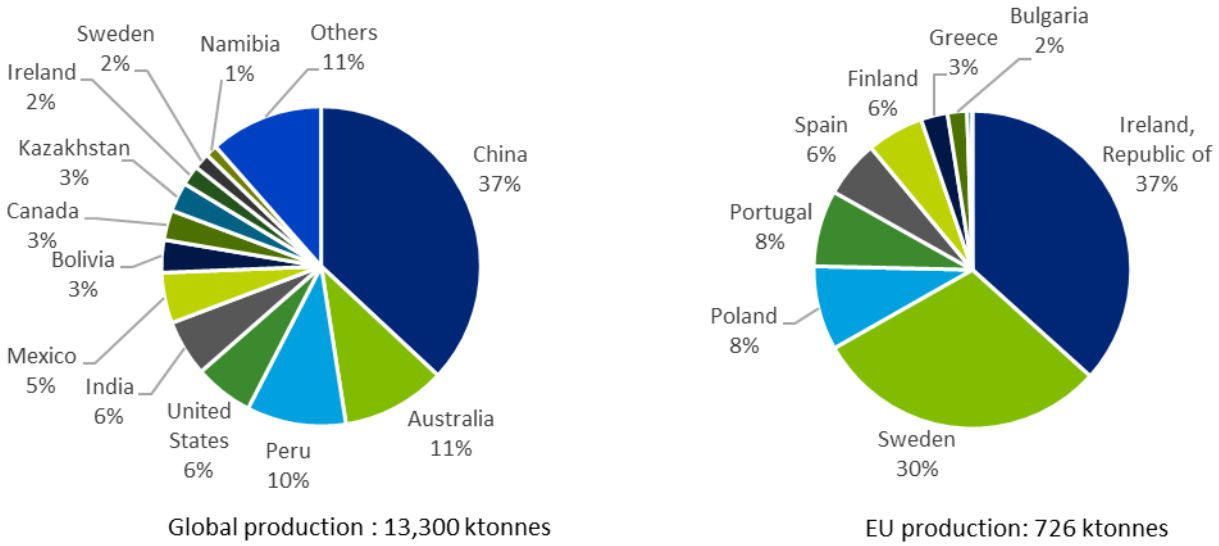


Figure 301: Global and (left) EU mine production (right) of zinc in tonnes and percentage, average 2012-2016 (BGS 2018)

34.4.3Supply from secondary materials/recycling

34.4.3.1 Post-consumer recycling (old scrap)

In addition to ore concentrate, zinc smelters feed an average of 10-15% secondary raw materials into their processes. These are predominantly crude oxides (waelz oxides), which are enriched zinc containing flue dusts from production of galvanized steel. In some cases, the recycled zinc content in the smelter feed can be higher – in specific cases up to 100%. These recycled tonnages are included in the primary zinc production data in the previous chapter.

An additional (global) tonnage of 4,000-5,000 ktonnes of zinc was recycled annually in re-melt processes, in the copper or the zinc compound industry, without passing through the zinc smelters (about 700 ktonnes in the EU). Different from many other metals, there is not a single technology for recycling, but instead tailor made recycling technologies for the most important zinc uses are well established:

- Zinc sheet and zinc die casted parts are re-melted. Over 95% of zinc sheet scrap is recycled in Europe. Re-melting zinc requires only 5% of the energy that is needed to produce primary zinc from ores.

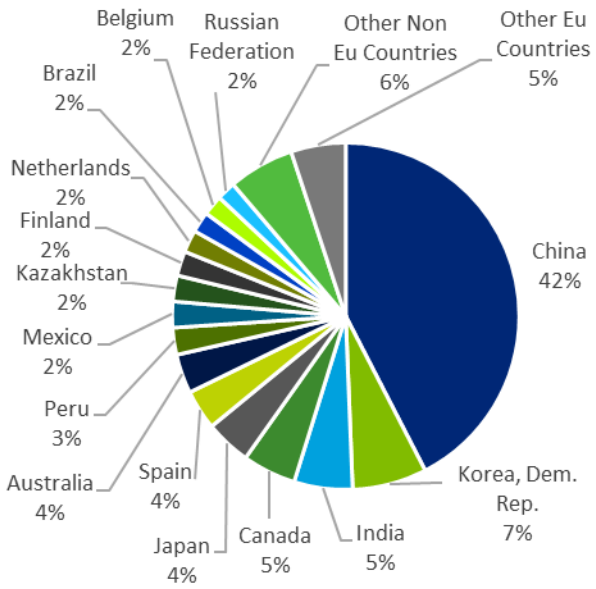
- Galvanized steel is re-melted in the steel industry e.g. electric arc furnace. Zinc ends up in the flue dust (EAF dust) and is further concentrated in the Waelz process. The Waelz/crude oxide is a welcome raw material for primary zinc production at less costs than concentrates supply, its use often being limited by the available tonnage. Other potential technologies for zinc recycling from galvanized steel are being tested at pilot plant or conceptual phase. 11% of steel scrap from building and construction is reused e.g. in Germany, while 88% are recycled in the steel industry. All EAF dusts that are produced in Europe are recycled. With the emerging markets for galvanized steel a significant growth at global scale is expected.
- Zinc as an alloying element in brass is recycled by the copper industry. There it is used for brass production or alternatively returned to the zinc industry.
- Various technologies are applied to recycle zinc from residues, wastes and by-products. Often zinc in these recycling loops is directly used to produce zinc compounds without passing through zinc smelters, thus saving costs, energy and raw materials (Grund *et al.*, 2019).

34.4.4Processing of zinc

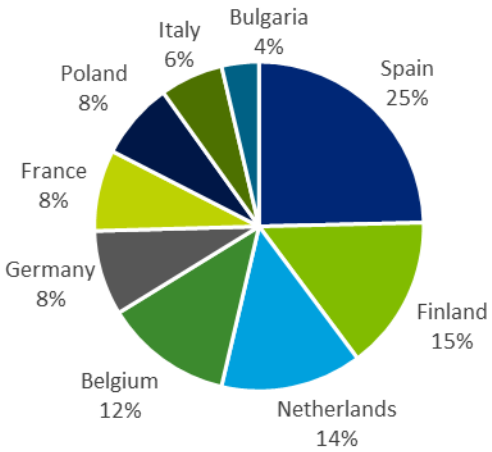
Zinc is recovered from zinc ores, and as by-product of other non-ferrous metals, by using either hydrometallurgical or pyrometallurgical techniques after removing the sulfur in the concentrates by roasting or sintering.

World refined zinc metal production amounted to 13,300 ktonnes per year on average during the period 2012-2016 (BGS, 2018). China was the world leading supplier with a share of 42% (5,700 ktonnes per year) of the global production, followed by South Korea with 7% (900 ktonnes per year), and India (5%, 700 ktonnes per year) (see Figure 302).

The EU produced on average 2,000 ktonnes per year (15 %) of the global production of refined metal over the period 2012-2016, from ores produced within the EU and imported ores. Spain was the main producer with 496 ktonnes per year (25% of the EU production), followed by Finland (305 ktonnes per year, 15%), Netherlands (279 ktonnes per year, 14%) and Belgium (252 ktonnes per year, 12%).



Global production : 13,330 ktonnes



EU production : 2,010 ktonnes

Figure 302: (left) Global and (right) EU refined zinc production, average 2012-2016. (BGS, 2018)

34.5Other considerations

34.5.1Environmental and health and safety issues

An overview is available of the effects of zinc exploitation on human health and environment as a result of industrial processes (mining and smelting) in China, referencing also to activities in the U.S. and the EU during the period from the eighteenth to the twentieth century (Zhang et al. 2012) when industrialisation and intensive mining peaked. The low concentrations of zinc in combination with the dissipative nature of some applications of zinc require consistent monitoring, but no effects were found that urgently require the current regulation of the use of zinc to be expanded.

Classification, Labelling and Packaging

The C&L Inventory, as published on ECHA's website, contains the following zinc substances:

- zinc powder – zinc dust (pyrophoric)[187]: Catches fire spontaneously if exposed to air (H250). In contact with water releases flammable gases, which may ignite spontaneously (H260). Very toxic to aquatic life (with long lasting effects) (H400, H410);
- zinc powder – zinc dust (stabilised)[188]: Very toxic to aquatic life (with long lasting effects) (H400, H410).

Occupational safety and health (OSH)

EU OSH requirements exist to protect workers' health and safety. Employers need to identify which hazardous substances they use at the workplace, carry out a risk assessment and introduce appropriate, proportionate and effective risk management measures to eliminate or control exposure, to consult with the workers who should receive training and, as appropriate, health surveillance[189].

34.6Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. Supply risk (SR) has been analysed at both mine and processing stages. The higher supply risk is at the mine stage.

The results of this and earlier assessments are shown in Table 169. Both economic importance (EI) and supply risk have decreased since 2011.

[187] EC ECHA List no.: 231-175-3; Harmonised Classification and Labelling index number (Annex VI of CPL Regulation ((EC) No 1272/2008): 030-001-00-1. In brackets, the Hazard Statement Code(s) are given.
[188] EC ECHA List no.: 231-175-3; Harmonised Classification and Labelling index number (Annex VI of CPL Regulation ((EC) No 1272/2008): 030-001-01-9
[189] https://ec.europa.eu/social/main.jsp?catId=148

Table 169: Economic importance and supply risk results for zinc in the assessments 2011, 2014, 2017, 2020 (European Commission, 2011; European Commission, 2014; European Commission, 2017)

Assessment	2011			2014			2017			2020	
Indicator	EI	SR		EI	SR		EI	SR		EI	SR
Zinc	9.4	0.4		8.7	0.45		4.5	0.3		5.4	0.34

It should be noted that the EI in 2020 might be impacted by the adaptation of the reference area of the end uses (application shares), from global to EU. In addition, the shift from EU-28 to EU-27 (without UK) might also impact the assessment.

34.7Data sources

34.7.1Data sources used in the factsheet

Buchholz P., Wellmer F.W., Bastian D., Liedtke M. (2019) Leaning against the wind: Low price benchmarks for acting anticyclically in the metal markets. Mineral Economics. https://doi.org/10.1007/s13563-019-00199-y

Eurometaux (2019). The metals industry's 2050 vision for a Sustainable Europe. Available at: https://eurometaux.eu/media/1523/full-lt-sustainability-framework-document-approved-1.pdf

Eurostat (2019). Comext database. Available at http://epp.eurostat.ec.europa.eu/newxtweb/

Grund, S., Genderen, E., van Leeuwen, M. (2019). Circular Economy – Recycling at All Costs? Zinc: Unleashing Valuable Resources. 10th European Metallurgical Conference (EMC), At Düsseldorf, Germany.

Gu *et al.*, 2017. Rechargeable zinc-air batteries: A promising way to green energy. Journal of Materials Chemistry A, Issue 17, pp. 7633-8134. DOI: 10.1039/c7ta01693j

INN (2019). Investing News Network website. Available at: investingnews.com

International Lead and Zinc Study Group (2016). ILZSG Monthly bulletins (available to members only).

International Lead and Zinc Study Group (2017a). ILZSG Monthly bulletins (available to members only).

International Lead and Zinc Study Group (2017b). Lead and zinc first uses in Europe. (available to members only).

International Lead and Zinc Study Group (2018). ILZSG Monthly bulletins (available to members only).

International Zinc Association (IZA) (2019). Expert review.

London Metal Exchange (2019). https://www.lme.com/

Mineralinfo (2018). Zinc: un marché fortement déficitaire en 2017. Available at: http://www.mineralinfo.fr/ecomine/zinc-marche-fortement-deficitaire-en-2017

Mining Technology (2019). Global zinc market to grow at 3.8% in 2022. Available at: https://www.mining-technology.com/comment/zinc-outlook-2019/

Mudd, G.M., Jowitt, S.M., Timothy T.T., Werner, T.T. (2017). The world's lead-zinc mineral resources: Scarcity, data, issues and opportunities. Ore Geology Reviews 80, pp. 1160–1190.

Nexa resources (2018). Zinc Market Overview. Nexa Investor Meeting, October 2018. Available at: https://ri.nexaresources.com/

Rudnick, R.L., Gao, S. (2014) Composition of the Continental Crust. Treatise On Geochemistry. Heinrich D. Holland and Karl K. Turekian(ed), 2nd edn. Elsevier, Oxford, pp 1–51.

SA (2019). Seeking Alpha website. Available at: seekingalpha.com

Thomas (2019). Common Processes and Alloys Used In Die Castings. Available at: https://www.thomasnet.com/articles/custom-manufacturing-fabricating/die-casting-alloys

USGS (2019). Mineral Commodity Summaries: Zinc. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/zinc/mcs-2019-zinc.pdf

World Bank (2019). Commodity Markets Outlook, April 2019. Available at: http://documents.worldbank.org/curated/en/992831556034429620/Commodity-Markets-Outlook-April-2019

World Health Organization (WHO) (2004). Manganese and its compounds: Environmental aspects. Concise International Chemical Assessment Document 63. Corrigenda published by 12 April 2005 incorporated, WHO, Geneva

Zhang, X1., Yang, L., Li, Y., Li, H., Wang, W., Ye, B. (2012) Impacts of lead/zinc mining and smelting on the environment and human health in China. Environ Monit Assess. Vol. 184, N°4, pp.2261-73. doi: 10.1007/s10661-011-2115-6.

34.7.2Data sources used in the criticality assessment

Aalberts Surface Treatment GmbH. Available at: https://www.aalberts-st.com/en/surface-treatment/processes/polymer-coatings

Anatech USA. Metal coating. Available at: http://www.anatechusa.com/metal-coating

Australian Government. Available at http://www.npi.gov.au/resource/zinc-and-compounds

BGS (2018). World Mineral Production. 2012-2016.

European Commission (EC) (2017) Study on the review of the list of Critical Raw Materials - Critical Raw Materials Factsheets & Non-critical Raw Materials Factsheets.

European Commission, DG Trade website "Agreements" Available at http://ec.europa.eu/trade/policy/countries-and-regions/agreements/

Eurostat (2018).-Contribution of recycled materials to raw materials demand- End-of-life recycling input rates (EOL-RIR). Available at: https://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=cei_srm010&plugin=1

Eurostat (2019). Comext database. Available at http://epp.eurostat.ec.europa.eu/newxtweb/

FisherCast (2008). Composition and Properties of Zinc Alloys and Comparative Data for Other Materials. Available at: http://www.fishercast.com/downloads/Composition_and_Properties_of_Zinc_2008.pdf

International Lead and Zinc Study Group (2017). Lead and Zinc First Uses in Europe. An Oakdene Hollins presentation commissioned by the ILZSG.

Mineralinfo. http://www.mineralinfo.fr/

Nyrstar (2009). Introduction to Zinc and Lead Smelting Business. Available at: https://www.nyrstar.com/~/media/Files/N/Nyrstar/results-reports-and-presentations/english/2009/zincleadsmelting.pdf

OECD (2019). Export restrictions on Industrial Raw Materials database. Available at: http://qdd.oecd.org/table.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

Thebalance.com (2019). Available at: https://www.thebalance.com/brass-alloy-additives-2340107. Updated June 25, 2019.

ThoughtCo (2019). Brass Alloys and Their Chemical Compositions. Brass Alloys and Their Chemical Compositions. Available at: https://www.thoughtco.com/common-brass-alloys-and-their-uses-603706 (updated January 2019).

WorldSteelprices. https://worldsteelprices.com/

34.8Acknowledgments

This factsheet was prepared by JRC in collaboration with the French Geological Survey (BRGM).

The authors thank the Ad Hoc Working Group on Critical Raw Materials, in particular Kamila Slupek and Laura Fazio Bellacchio (Eurometaux), Sabina Grund, (International Zinc Association), Corina Hebestreit (Euromines), as well as experts participating in the zinc session of the SCRREEN workshop for their valuable contribution and feedback, notably Nikolaos Arvanitidis (SGU).

35. ZIRCONIUM

35.1 Overview

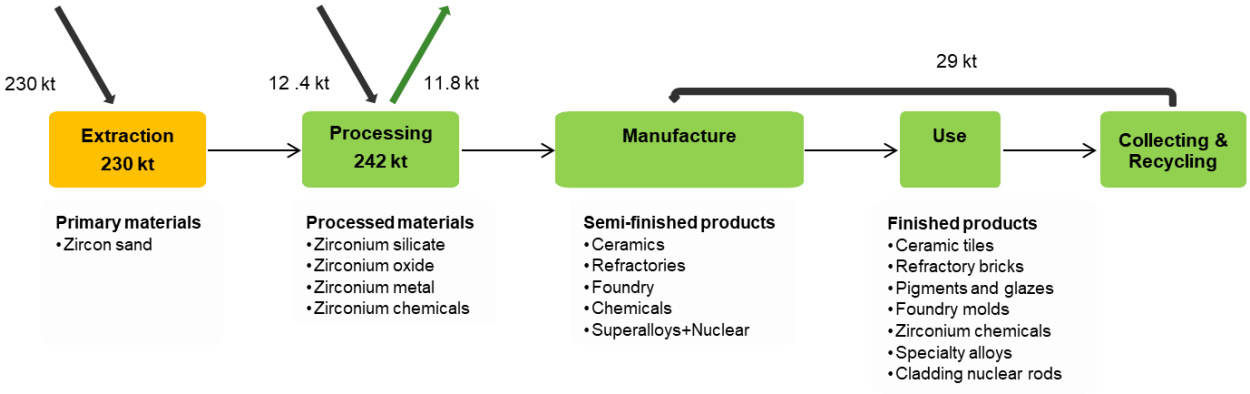


Figure 303: Simplified value chain for zirconium for the EU[190], averaged over 2012-2016

Zirconium (chemical symbol Zr) is a metal recovered from zircon (zirconium silicate, $ZrSiO_4$) and baddeleyite (zirconium oxide, ZrO_2), which are extracted from mineral sands and alkaline complexes, respectively. Approximately 75% of zirconium ore is directly used as zircon, while the remaining is transformed in zirconium oxide and other chemicals, including zirconium metal. The criticality of zirconium was not assessed in 2011, 2014, and 2017.

For the purpose of this assessment, zirconium is analysed essentially at the extraction stage, as processing into zirconium metal entails about2% of the total amount of ore. At mine stage, zirconium is considered as zircon or baddeleyite ore ("zirconium ores and concentrates", CN8 code 26151000). Quantities are given as zircon content ($ZrSiO_4$); this means that baddeleyite (ZrO_2) production figures have been multipled by a factor 1.5 to account for the different zirconium content in $ZrSiO_4$ and ZrO_2. At processing stage, "unwrought zirconium"; "zirconium powders" (CN8 code 81092000) are considered and expressed in zirconium content.

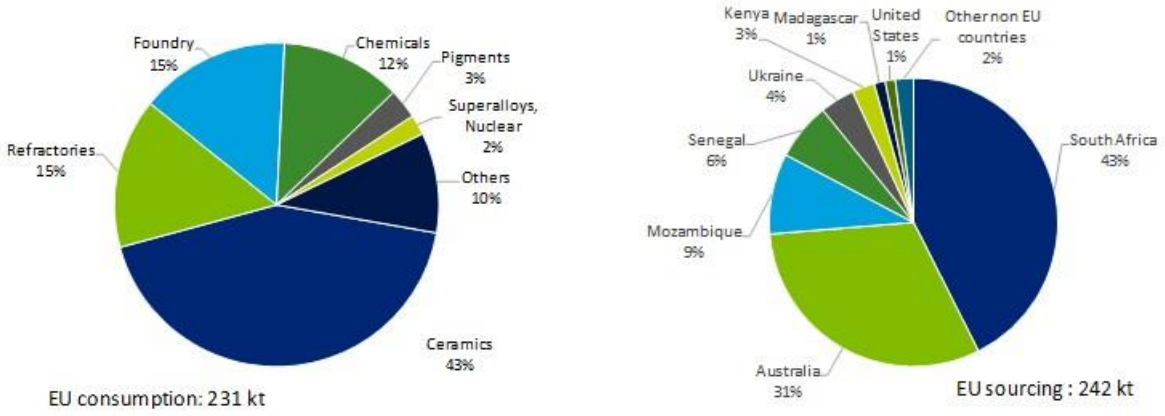


Figure 304: End uses (Zircon Industry Association, 2015) and EU sourcing (Eurostat, 2019) of zirconium ore (2012-16).

[190] JRC elaboration on multiple sources (see next sections)

The world market of zirconium was about 1,423 thousand t (average 2012-2016) growing to about 1,524 thousand t in 2018 (WMD, 2019). The zircon market is worth about 2,000 million Euro, expected to keep steady by 2020. The growth in the global demand of zirconium ore till 2020, forecast on 2012 basis, did not come true (DERA, 2013). Zircon sands are both traded on annual contracts and sold on the open market.

According to DERA, zircon prices turned steady after a sudden increase (occurred since February to April 2018) from ~970 to ~1,300 €/t. In the last decade, zircon prices had a considerable upward trend (+47% from ~880 €/t in 2009) with a shocking peak to ~2,200 €/t in 2011-2012. According to DERA raw materials volatility monitor (DERA, 2019) zircon prices suffered a certain volatility (17-18%).

The EU consumption of zircon is around 230 kt per year (average 2012-2016), which are entirely imported, since no sources of zirconium ore exist in the EU. The main consumers are Spain (~124 kt), Italy (~51 kt) France (~21 kt) and Germany (~16 kt) which account for over 90% of the EU total (Eurostat, 2019). Zircon sand is imported mainly from South Africa, Australia, Senegal and Mozambique. Import reliance of zircon is 100%. The share of zirconium metal consumed annually in the EU averaged 3,200 t between 2012-2016.

Europe is a net importer of processed Zirconium metal: around 3,550 t (average 2017-2018). The EU annual consumption is approximately 3,200 t (average 2017-2018) with France accounting for ~86%, followed by Romania (~5%), Italy (~3%) and Belgium (~2.5%). The import of zirconium metal to the EU comes from the United States (~1300 t, 37%), China (~1278 t, 36%), and the United Kingdom (~534 t, 15%), plus minor contribution from South Korea, Canada and Russia. The EU exports about 343 t per year (average 2017-2018) mostly by Germany (~94%).

Zirconium is used in ceramics (43%), refractories (15%), foundry (15%), chemicals (12%), pigments (3%), superalloys and nuclear (2%) (Zircon Industry Association, 2015). Possible substitutes are often raw materials with higher price and/or lower production with respect to zirconium, as the case of wollastonite, tin, diamond, vanadium, or cobalt (ceramics) and niobium or tantalum for metallurgical application . Alumina, tungsten, and magnesium compounds (dolomite, spinel, chromite, olivine) seem to be affordable substitutes in technical ceramics, foundry and refractories.

The resources of zirconium ore are essentially concentrated in stable cratons along long lived shorelines, where sands enriched in heavy minerals are found. Such deposits are primarily exploited for titanium ore; this circumstance makes zircon output and price somewhat dependent on the demand of titania. Large resources are known in Australia, Africa (South Africa, Kenya, Mozambique and Senegal) and Canada. The resources of zirconium ore in the EU are negligible. The world reserves of zirconium are thought to be around 73 million t, as ZrO_2 content (WMD, 2019; BGS, 2019) that corresponds to about 110 Mt of zircon sand. The largest reserves of zircon sand are in Australia (63 Mt) and Africa (32 Mt). The potential of Canada (as byproduct of the exploitation of Athabasca oil sands) is still unexpressed.

The world annual production of zirconium ore is about 1,520 kt with one third of production in Australia, 23% in South Africa and 10% in China (WMD, 2019). No production is registered in the EU. Zirconium is to a good extent recycled in the foundry industry, while in other sectors the use is dissipative and recycling is impracticable. Overall recycling rate, considering each application share, could be indicated around 12% of zirconium concentrates.

There are no major health and regulatory issues about zircon sands, which are considered Naturally Occurring Radioactive Materials (NORM) due to their very small uranium and thorium content (usually 100 ppm). The radioactivity of zircon is low and the risk is minimal. However,

safe handling of the material is necessary, since higher radioactivity levels can result during processing and particularly storage of big amounts of zircon sand. There are no trade restrictions for zircon sand, but only export taxes (below 25%) applied in China and Vietnam (OECD, 2019).

35.2Market analysis, trade and prices

35.2.1Global market analysis and outlook

Availability and price of zirconium ore depend principally on two main factors (ILUKA, 2014; Zircon Industry Association, 2015): firstly, any change in the manufacture of ceramics, refractories and foundry molds, which account for 76% of the global demand of zircon sand. Secondly, the market trends of titanium ore, which is the main target of the exploitation of heavy mineral sands, directly influence the production and value of zirconium silicate. This circumstance reflects on the saw tooth shape trend in production and price of zircon sand in the last decade. Any forecast is difficult because market fluctuations are only partially linked to economic geology or technological issues concerning zirconium end-use.

The outlook for ceramic ware is of continuous growth of global production, by now driven by demographic pressure in transition and developing countries. However, the growth rate is expected to slow down in the next years, as already observed sectors like ceramic tiles, which is the major consumer of zirconium silicate in absolute terms. The conversion to digital decoration has been reducing the fraction of zircon used in ceramic tilemaking, because of lower amounts of glazes, pigments and opacifiers applied on tiles. Trends in other industrial sectors suggest a moderate increase of the demand of zirconium ore in the next years (Table 170).

New countries joined the list of zirconium ore producers in the last decade, especially from Africa (Kenya, Madagascar, Mozambique, Senegal, Sierra Leone). By this way, the offer was substantially expanded beyond the bottleneck in zircon supply occurred in the 2000s (WMD, 2019; USGS, 2019a-b; BGS, 2016). These new sources now ensure about 25% of the EU demand and this share is trending upward. Eventual starting of zircon recovery from large-scale operations on oil sands in Canada can play a destabilizing impact on the market, even though it is hard to be quantified now.

Present situation depicts an almost steady demand to 2025 for zirconium due to limited changes in the consumption by the main end-users, primarily ceramics, refractories and foundry (USGS,2017-2019b; ILUKA, 2014; Zircon Industry Association, 2015). However, this picture might be modified by oversupply (e.g., new entries and/or increasing output from existing suppliers).

Table 170: Qualitative forecast of supply and demand of zircon sand

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Zircon sand		X	=	+	?	=	+	?

35.2.2EU trade

The EU is a net importer of zirconium ore with about 242 kt per year (average 2012-2016). Import was twenty times higher than export in the same period (Eurostat, 2019). Export is about 11 kt per year.

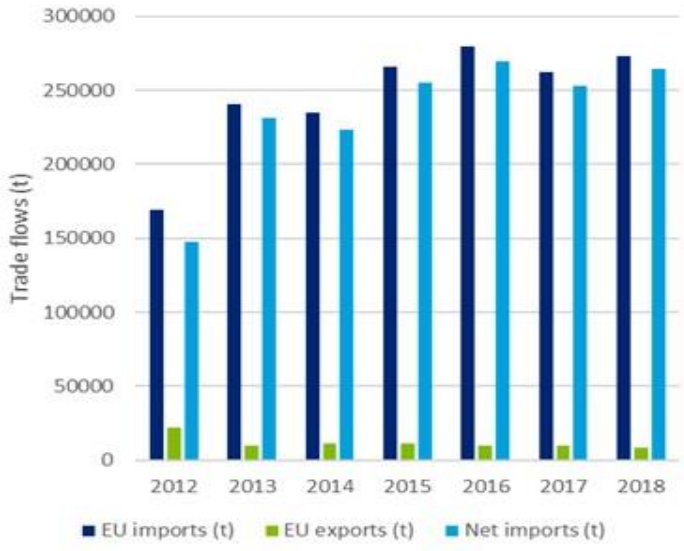


Figure 305: EU trade flows[191] for zircon sand (Eurostat, 2019).

The main suppliers between 2012 and 2016, ensuring on the whole 97% of the EU demand, are (Eurostat, 2019): South Africa (~110 kt), Australia (~84 kt), Mozambique (~27 kt), Senegal (~24 kt), Kenya (~8 kt), Ukraine (~6 kt), Madagascar (~4 kt) and the United States (~3 kt). African suppliers address to the EU from 30% to 40% of their zirconium output. The imports of Zirconium metal amount to 3.5 kt, coming mainly from China and the United States.

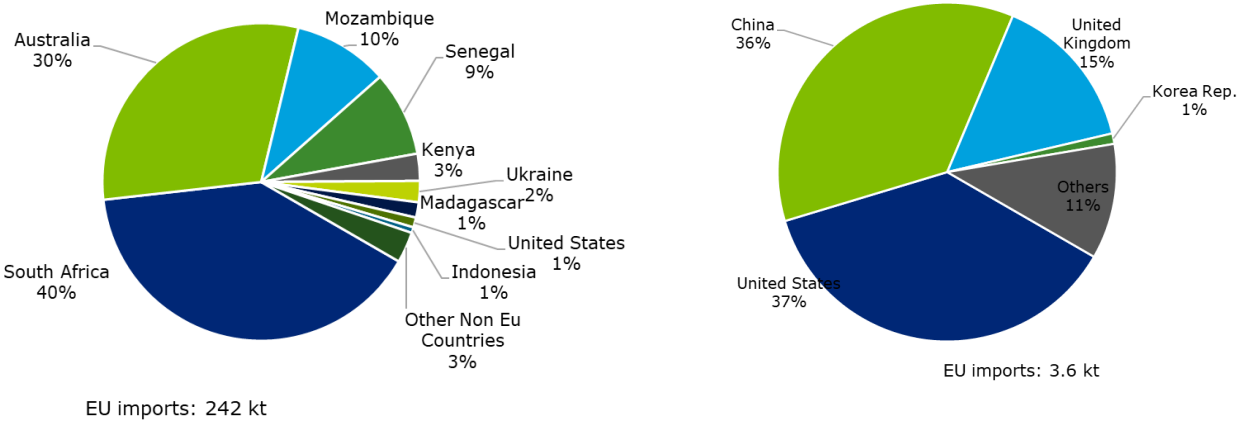


Figure 306: EU imports of (left) zircon sand and (right) Zr metal, 2012-2016 (Eurostat, 2019).

[191] 2017 and 2018 data not used in the criticality assessment

At the time of the assessment there are EU free trade agreements in place with South Africa and Ukraine (bilateral agreement) as well as with Mozambique and Madagascar (Economic Partnership Agreements); a Market Access Regulation concerns Kenya (European Commission, 2019). There are no exports quotas or prohibition in place between the EU and its suppliers (OECD, 2019). An export prohibition from Indonesia took place in 2014, but apparently it was not applied, as exports from the country to the EU continued. Export taxes (below 25%) are applied in China and Vietnam.

35.2.3Prices and price volatility

Zircon sand is apparently traded on both annual contracts and sold on the open market. In the last decade, zircon prices alternated long periods of substantial stability or slight increasing with sudden booms, as those occurred in 2011-2012 and 2018. In the last decade, zircon prices were characterised by a considerable upward trend (+47% from ~880 €/t in 2009 to ~1,300 €/t in 2018) with a shocking peak to ~2,200 €/t in 2011-2012. According to DERA raw materials volatility monitor, zircon prices suffered a certain volatility (17-18%) in the latest years (DERA, 2019).

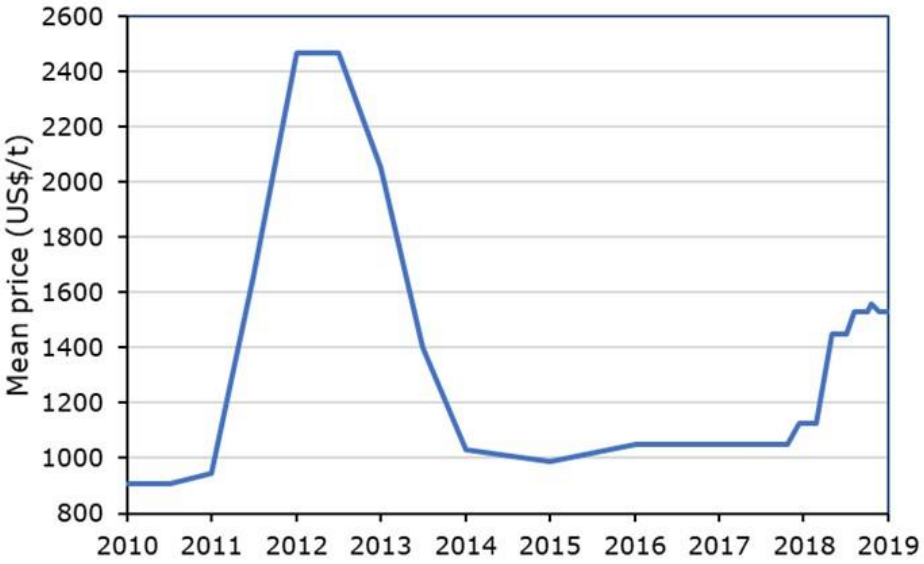


Figure 307: Prices of zircon sand (USD per tonne) from 2010 to 2019 (WMD, 2019; USGS, 2019b).

35.3EU demand

The world market of zirconium is about 1,423 kt (average 2012-2016) (WMD, 2019) for a total value around 2,000 million Euro. These figures grew to about 1,524 kt in 2018, value that is expected to keep steady by 2020. The EU demand is averaged 242kt per year, corresponding to a share of 17% of the global market between 2012 and 2016.

35.3.1EU demand and consumption

The EU consumption of zirconium compounds is in the following sectors (USGS, 2019b; Zircon Industry Association, 2015): ceramics (43%), refractories (15%), foundry (15%), chemicals (12%), pigments (3%), superalloys and nuclear (2%) and others (10%). The EU consumption of zircon is around 230,000 t, which are entirely imported, since no sources of zirconium ore exist in the EU (Eurostat, 2019). The main consumers are Spain (~124 kt), Italy (~51 kt), France (~21 kt) and Germany (~15 kt) (average 2012-2016). Zircon sand is imported mainly from South Africa, Australia, Senegal and Mozambique. Import reliance is 100%. The share of zirconium metal consumed annually in the EU is around 3,200 t.

35.3.2Uses and end-uses of Zirconium in the EU

Figure 308 presents the main uses of zirconium in the EU.

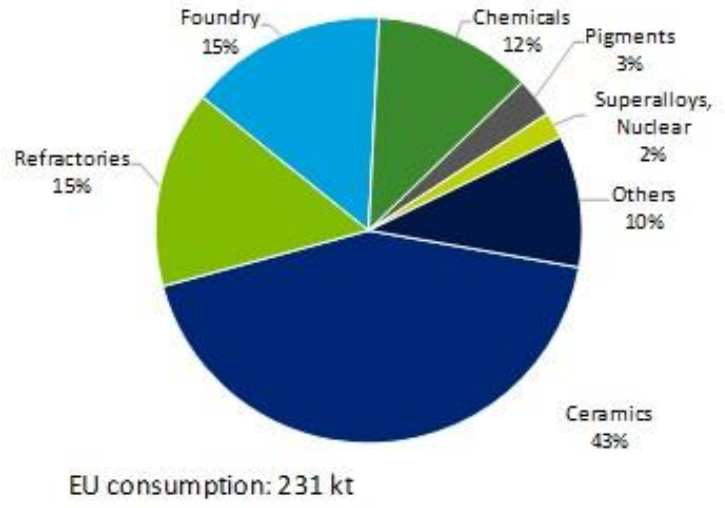


Figure 308: EU end uses of zirconium (Zircon Industry Association, 2015). Average figures for 2012-2016.

The main applications in ceramics are in the manufacture of floor and wall tiles, sanitaryware, tableware, frit and glazes, technical ceramics (including abrasives and dentistry). In the refractories sector, zircon bricks are used in furnaces for molten metals and fused mullite-zirconia-based refractories for glass tank furnaces. In the foundry industry, zircon is utilized mostly as facing and surface coating of molds. Zirconium chemicals encompass zirconium oxychloride, boride, nitride, sulfate, carbonate, hydride (among others) used in several application fields. In the pigment industry, zirconium is used for ceramic pigments, inks, paper coatings, paint driers, etc. Zirconium metal enters in superalloys in two distinct forms: Hafnium-bearing zirconium metal is used in specialty alloys and in corrosive environments, while Hf-free zirconium metal is used as cladding for nuclear fuel rods and for structural materials in nuclear reactors. In addition, there are miscellaneous applications, including glasses, sensors, catalysts, materials for electronics and fuel cells (Zircon Industry Association, 2015).

Relevant industry sectors are described using the NACE sector codes.

Table 171: Zirconium applications (Zircon Industry Association, 2015), 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2019)

Applications	2-digit NACE sector	Value added of NACE 2 sector (M€)	4-digit NACE sectors
Ceramics	C23 - Manufacture of other non-metallic mineral products	57,255	23.31, 23.42, 23.41, 23.44, 23.91
Refractories	C23 - Manufacture of other non-metallic mineral products	57,255	23.20
Foundry	C24 - Manufacture of basic metals	55,426	24.54
Chemicals	C20 - Manufacture of chemicals and chemical products	105,514	20.13
Pigments	C20 - Manufacture of chemicals and chemical products	105,514	20.12.1
Superalloys, Nuclear	C24 - Manufacture of basic metals	55,426	24.45.30
Others	C26 - Manufacture of computer, electronic and optical products	65,703	

35.3.3Substitution

Zirconium compounds find special applications in the manufacturing sector that makes substitution difficult, also because in most cases the alternatives are raw materials with higher price and/or lower production (ILUKA, 2014; Zircon Industry Association, 2015; Kogel, 2006; European Commission, 2017b). In the ceramic field, zircon can be substituted mainly by alumina, wollastonite, and tin dioxide in coatings for tiles, sanitaryware, and tableware. Alumina, tungsten (tungsten carbide) and diamond are valid alternatives in abrasives and some technical ceramics. In some cases, the substitution of zirconia, as in dentistry, would imply a step behind to old technologies (using porcelain, hence kaolin-silica-feldspar). In the refractories industry, zirconium silicate can be replaced by magnesium compounds, namely dolomite or spinel. However, zirconium oxide cannot find any prompt substitution in fused alumina-zirconia refracatories for the lining of glass furnaces. In foundry, surrogates for zircon used in molds are represented by chromite and olivine. In the pigment manufacture, zirconium is hardly replaceable, even though tin oxide doped with vanadium may substitute yellow zircon (doped with praseodymium) as well as cobalt aluminate might substitute turquoise zircon (doped with vanadium). Regarding zirconium metal, niobium and tantalum are the alternatives in superalloys and nuclear applications. About chemicals and further sectors, there are several possible substitutes in a range of small-scale applications.

35.4Supply

35.4.1EU supply chain

No production of zirconium ore is registered in the EU.

The EU demand of zircon averaged over 2012-2016 (~230,000 t) was entirely met by importation (Eurostat, 2019). The main consumers are Spain (~124 kt), Italy (~51 kt), France (~21 kt) and Germany (~15 kt). Zircon sand is imported mainly from South Africa, Australia, Senegal and Mozambique. Import reliance is 100%.

The zirconium metal consumed annually in the EU was 3,200 t (average 2012-2016), with France accounting for ~86%, followed by Romania (~5%), Italy (~3%) and Belgium (~2.5%). The import of zirconium metal to the EU comes from the United States (~1300 t, 37%), China (~1278 t, 36%), and the United Kingdom (~534 t, 15%), plus minor contribution from South Korea, Canada and Russia (Eurostat, 2019). The EU exports about 343 t per year (average 2017-2018) mostly by Germany (~94%).

35.4.2Supply from primary materials

35.4.2.1 Geology, resources and reserves of zirconium

Geological occurrence: Zirconium deposits exploit concentrations of zircon ($ZrSiO_4$) or baddeleyite (ZrO_2) of economic importance (USGS, 2017; Minerals4EU, 2019). Other zirconium minerals (e.g., eudyalite, zirkelite, vlasovite, etc) are rare and never reach a concentration high enough to be commercially significant. Zircon is a common accessory mineral in most igneous rocks, especially in granitic suites and corresponding metamorphics, where it is usually present in small amount. Nevertheless, being highly resistant to weathering and physical degradation, zircon tends to be enriched in some sedimentary rocks, particularly in river and beach sands, where it can be found in the heavy minerals fraction (together with tourmaline, rutile, ilmenite, leucoxene, etc). Such placer deposits are essentially located along coastlines of stable cratons, where the action of the waves for long time gave rise to sands enriched in heavy minerals (up to 10-20%). Both strand line (active or fossil beaches) and aeolian dune deposits are exploited. In these deposits, zircon is always associated to titanium minerals, which represent the main target of mining operations. The zircon-to-rutile ratio is on average 1:5, even though it can be sometimes higher, up to 2:1 (ILUKA, 2014). Deposits in operation are along the coasts of Australia, Africa, southern Asia and the Americas. Baddeleyite deposits are very rare and found only in peculiar alkaline igneous complexes (USGS, 2017; Murphy, 2006): Kovdor in the Kola peninsula (Russia), Poço de Caldas, Minas Gerais (Brazil), and Phalaborwa (South Africa).

Global resources and reserve[192]: Identified world zirconium resources mostly consist of zircon placers and major deposits are preferentially distributed in the Austral hemisphere (Australia, South Africa, Brazil) and southern Asia (India, China). World known reserves of zircon sand are estimated at approximately 150 million tonnes, corresponding to about 100 million tonnes of ZrO_2 (USGS, 2019a). Australia has the world's largest zirconium reserves, followed by India and South Africa; these three countries account for 80% of global reserves.

Table 172: Global reserves of zircon sand (USGS, 2017; USGS, 2019a)

Country	Zircon Reserves (million tonnes)	Share of reserves (% of World total)
Australia	63.0	42.5%
India	35.8	24.1%
South Africa	21.0	14.2%
Kenya	5.4	3.6%

[192] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of zircon sand in different geographic areas of the EU or globally

Mozambique	2.7	1.8%
Brazil	2.4	1.6%
China	0.8	0.5%
USA	0.8	0.5%
Ukraine	0.5	0.3%
Others	15.9	10.7%
World total	148.2	100.0%

EU resources and reserves[193]: Some zirconium resources are known in the EU from the Minerals4EU website: zircon placers and alkaline or felsic igneous rocks, along with bauxite deposits and polymetallic mineralizations (e.g., U-Zr). However, further occurrences surely exist in other countries, not covered by this database. In most cases, we are dealing with occurrences, as just the zircon sand placers are classified as deposits. Overall, these resources cannot be summed because no quantitative estimation is available for reserves (Minerals4EU, 2019).

Table 173: Resource data for the EU and surrounding countries compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2019)

Deposit group (type)		Country	Area	Resource number	Commodity Minerals
Placer (paleoplacer)	D	France	Bretagne, Normandie	65	Ti, Zr (zircon)
		non-EU	Ukraine, Greenland	4	
Alkaline igneous rocks (syenite, alkali granite)	O	Finland	Sokli, Katajakangas	3	REE, Nb, Ta, Zr (eudyalite), P, U, etc.
		Sweden	Norra Kärr	1	
		non-EU	Greenland	8	
Residual (bauxite)	O	Greece	Macedonia, Thrace	9	Al, Cr, Fe, Ni, Zr, REE, etc.
Felsic-intermediate igneous rocks (granite, pegmatite)	O	Sweden	Näverån, Björkråmyran	2	REE, U, Th, Y, Zr (zircon)
		France	Squiffiec	1	Zr (zircon)
		Greece	Pagoni Rachi	1	Cu, Mo, Nb, Zr
		non-EU	Norway (Høgtuva)	1	REE, Be, U, Zr
Others (epithermal, metasomatics)	O	Sweden	Tunbyholm, etc.	3	Nb, Ta, U, V, Zr
D = deposit; O = occurrence.					

35.4.2.2 World and EU mine production

The production of zirconium comes essentially from deposits of heavy mineral sands, which are primarily exploited for titanium ore and secondarily for zircon (monazite and further minerals).

[193] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for zirconium sources. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for zirconium minerals, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets.

This circumstance makes zircon output and price somewhat dependent on the demand of titania. The world annual production of zirconium ore is about 1,423 kt, averaged over 2012-2016 (WMD, 2019). One third of the global production is from Australia, 23% from South Africa and 10% from China. In the last decade, new countries joined the list of zircon sand producers, especially in Africa (Kenya, Mozambique, Senegal, Madagascar, Nigeria and Sierra Leone) and their contribution summed up to 8% of the World output (WMD, 2019; USGS, 2019a-b; BGS, 2016).

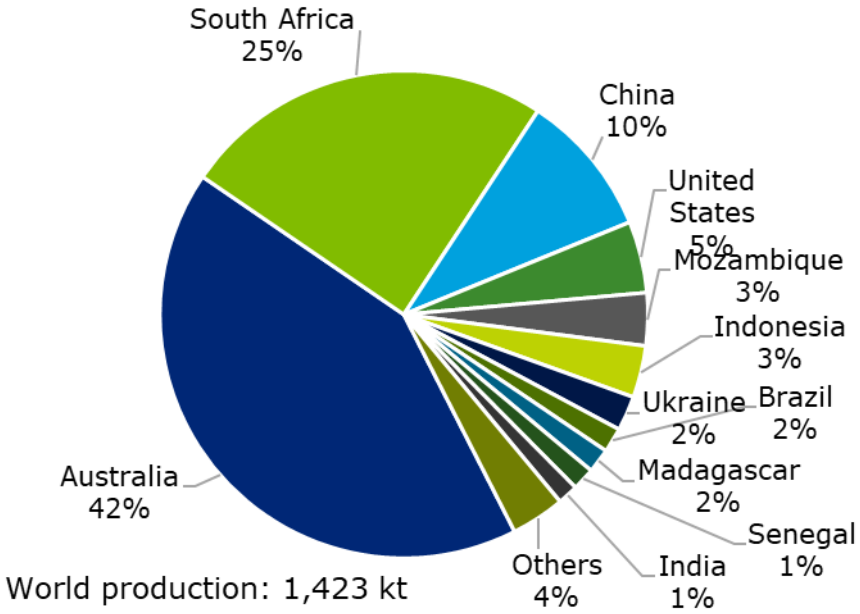


Figure 309: Global mine production of zircon. Average for the years 2012-2016 (WMD, 2019).

35.4.3Supply from secondary materials/recycling

35.4.3.1 Post-consumer recycling (old scrap)

Zirconium included in ceramics, refractories, pigments and alloys cannot be recovered as zirconium compounds. Hoewever, when refactories and steel alloys are recycled the zirconium remains in the recycled product. Therefore these recycling rates are applicable also for the zirconium which would results in estimate rate of 70% of zirconium utilized. Overall end-of life recycling input rate (EoL-RIR), considering each application share, could be indicated around 12% (SCRREEN workshops, 2019).

35.4.3.2 Industrial recycling (new scrap)

Recycling of zirconium during processing is close to 100%, but quantities are small (SCRREEN workshops, 2019).

35.4.4Processing of Zirconium

Heavy minerals sands contain both zircon and titanium minerals (commonly in the 1-10% range by weight). Mining by dredging or dry mining techniques (Murphy, 2006) is followed by washing the sand, then concentrates containing 90-95% heavy minerals are separated from

the silica sand by wet gravity concentration techniques. Specific processes are employed to get zircon sand: electrostatic separation (typically used for separating zircon from rutile); magnetic separation (zircon from leucoxene, monazite and ilmenite), gravity separation (zircon from kyanite, feldspars and quartz). Iron and aluminum oxide coatings at the surface of zircon grains are removed by hot acid leaching. In some cases, the final product is calcined at approximately 900°C to render the zircon whiter.

35.5Other considerations

35.5.1Environmental and health and safety issues

There are no major health and regulatory issues about zircon sands. However, zircon is listed among Naturally Occurring Radioactive Materials (NORM) due to its very small, but not negligible content of uranium and thorium (usually 100 ppm). Higher concentrations of radioactive isotopes can occur for some sources, like baddeleyite deposit in Russia. The radioactivity of zircon is low and the risk is considered minimal. Nontheless, safe handling of the material is necessary, since higher radioactivity levels can result during processing and particularly storage of big amounts of zircon sand (Righi, 2005).

35.5.2Socio-economic issues

Zirconium supply is not linked to any particular socio-economic issues. However, it is used in alloys as a corrosion protection and therefore contrihuteds to the longer life-span of products and higher resource efficiency.

35.6Comparison with previous EU assessments

Zirconium was not previously assessed, so it did not appear in the 2011, 2014, and 2017 lists. Supply risk has been analysed for the mine stage only.

Table 174: Economic importance and supply risk results for Zirconium in the assessments of 2011, 2014, 2017, 2020 (European Commission, 2011-2014-2017)

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Zirconium	NA	NA	NA	NA	NA	NA	3.19	0.83

35.7Data sources

Data for the production of zirconium present slight differences from one source to another. Quantities are given as zircon content ($ZrSiO_4$); this means that baddeleyite (ZrO_2) production figures have been multipled by a factor 1.5 to account for the different zirconium content in $ZrSiO_4$ and ZrO_2.

35.7.1Data sources used in the factsheet

BGS (2016). World Mineral Production 2011-15, Brown, T.J., Idoine, N.E., Raycraft, E.R., Shaw R.A., Deady, E.A., Hobbs, S.F. & Bide T., Keyworth, 96 p.

DERA (2013). Zircon – insufficient supply in the future?, Elsner, H. Deutsche Rohstoffagentur, in Bundesanstalt für Geowissenschaften und Rohstoffe, Berlin, 290 p.

DERA (2019). Commodity prices: Commodity Price List, Volatility monitoring. German Mineral Resources Agency (DERA) and Federal Institute for Geosciences and Natural Resources (BGR), 2019.

European Commission (2011). Materials. Critical raw materials for the EU, Report of the Ad-hoc Working Group on defining critical raw materials.

European Commission (2014). Communication On the Review of the List of Critical Raw Materials for the EU and the Implementation of the Raw Materials Initiative, COM(2014)297final. Brussels.

European Commission (2017a). Communication on the List of Critical Raw Materials 2017, COM(2017) 490 Final. Brussels.

European Commission (2017b). Study on the review of the list of Critical Raw Materials – Non-critical raw materials factsheets. DG Internal Market, Industry, Entrepreneurship and SMEs (Deloitte Sust., BGS, BRGM, TNO), 476 p.

European Commission (2019). DG Trade. Agreements [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/.

Eurostat (2019). Eurostat's Reference database for detailed statistics on international trade in goods, (Comext).

ILUKA (2014). Mineral Sands Industry – Fact Book, 25 p.

Kogel, J.E., Trivedi, N.C., Barker, J.M. & Krukowski, S.T. (eds.) (2006). Industrial Minerals and Rocks: Commodities, Markets and Uses, Littleton, Colorado, Society of Mining, Metallurgy and Exploration, 1565 p.

Minerals4EU (2019) European Minerals Knowledge Data Platform (EU-MKDP), www.minerals4eu.eu.

Murphy, Ph., Frick, L., (2006). Zirconium and Hafnium, in Industrial Minerals and Rocks: Commodities, Markets and Uses (Kogel, J.E., Trivedi, N.C., Barker, J.M. & Krukowski, S.T., eds.). Littleton, Colorado, Society of Mining, Metallurgy and Exploration, 1065-1071.

OECD (2019). OECD Export restrictions on Industrial Raw Materials database. [online] Available at: http://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

Righi, S., Andretta, M., Bruzzi, L. (2005). Assessment of the radiological impacts of a zircon sand processing plant. Journal Environmental Radioactivity, 82, 237-250.

SCRREEN CRM validation workhop (2019). Expert’s comment, Brussels, 11 Sep. 2019.

USGS (2017)., Zirconium and hafnium, chap. Jones, J.V., III, Piatak, N.M., and Bedinger, G.M., Critical mineral resources of the United States—Economic and environmental geology and prospects for future supply: U.S. Geol. Surv. Prof. Paper 1802, p. V1– V26.

USGS (2019a). Mineral Commodity Summaries, U. S. Geological Survey, 204 p.

USGS (2019b). Zirconium and Hafnium, in 2015 Minerals Yearbook, 2017, 86 (7 pp) and in Mineral Commodity Summaries, Bedinger, G.M., 193-194, U. S. Geological Survey.

WMD (2019) World Mining Data 2019, Reichl, C.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian

Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

Zircon Industry Association (2015). Technical handbook on zirconium and zirconium compounds. Densley Tingley, D., Serrenho, A.C., (second edition), 127 p.

35.7.2Data sources used in the criticality assessment

Densley Tingley, D., Serrenho, A.C. Technical handbook on zirconium and zirconium compounds. Zircon Industry Association, 2015 (second edition), 127 p.

Murphy, Ph., Frick, L., Zirconium and Hafnium, in Industrial Minerals and Rocks: Commodities, Markets and Uses (Kogel, J.E., Trivedi, N.C., Barker, J.M. & Krukowski, S.T., eds.). Littleton, Colorado, Society of Mining, Metallurgy and Exploration, 2006, 1065-1071.

Bedinger, G.M., Zirconium and Hafnium, in 2015 Minerals Yearbook, 2017, 86 (7 pp) and in Mineral Commodity Summaries, 2019, 193-194, U. S. Geological Survey.

Brown, T.J., Hobbs, S.F., Idoine, N.E., Mills, A.J., Wrighton, C.E. & Raycraft, E.R. European Mineral Statistics 2010-2014, British Geological Survey, 2016, Keyworth, 378 p.

Brown, T.J., Idoine, N.E., Raycraft, E.R., Shaw R.A., Deady, E.A., Hobbs, S.F. & Bide T., World Mineral Production 2011-15, British Geological Survey, 2016, Keyworth, 96 p.

Elsner, H. Zircon – insufficient supply in the future? Deutsche Rohstoffagentur (DERA) in Bundesanstalt für Geowissenschaften und Rohstoffe, Berlin, 2013, 290 p.

Mineral Sands Industry – Fact Book. ILUKA, 2014, 25 p.

Industrial Minerals and Rocks: Commodities, Markets and Uses, Kogel, J.E., Trivedi, N.C., Barker, J.M. & Krukowski, S.T. (eds.) Littleton, Colorado, Society of Mining, Metallurgy and Exploration, 2006, 1565 p.

Mineral Commodity Summaries, 2019, U. S. Geological Survey, 204 p.

DG Internal Market, Industry, Entrepreneurship and SMEs (Deloitte Sust., BGS, BRGM, TNO), Study on the review of the list of Critical Raw Materials – Executive summary. European Commission, 2017, 9 p.

Eurostat's Reference database for detailed statistics on international trade in goods (Comext)

DG Internal Market, Industry, Entrepreneurship and SMEs (Deloitte Sust., BGS, BRGM, TNO), Study on the review of the list of Critical Raw Materials – Non-critical raw materials factsheets. European Commission, 2017, 476 p. 13/09/2017

Jones, J.V., III, Piatak, N.M., and Bedinger, G.M., 2017, Zirconium and hafnium, chap. V of Schulz, K.J., DeYoung, J.H., Jr.,Seal, R.R., II, and Bradley, D.C., eds., Critical mineral resources of the United States—Economic and environmental geology and prospects for future supply: U.S. Geological Survey Professional Paper 1802, p. V1– V26.

WMD (2019) World Mining Data 2019, Reichl, c.; Schatz, M; Zsak, G. Iron and Ferro Alloy Metals, non Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels, Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx.

35.8Acknowledgments

This factsheet was prepared by the JRC in collaboration with Mr. Michele Dondi (CNR-ISTEC, Faenza, Italy). The authors would like to thank the Ad Hoc Working Group on Critical Raw Materials, in particular Euromines, as well as experts participating in SCRREEN workshops for their valuable contribution and feedback.

GETTING IN TOUCH WITH THE EU

In person

All over the European Union there are hundreds of Europe Direct information centres. You can find the address of the centre nearest you at: http://europa.eu/contact

On the phone or by email

Europe Direct is a service that answers your questions about the European Union. You can contact this service:
– by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),
– at the following standard number: +32 22999696 or
– by email via: http://europa.eu/contact

Finding information about the EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website at: http://europa.eu

EU publications

You can download or order free and priced EU publications from EU Bookshop at: http://publications.europa.eu/eubookshop. Multiple copies of free publications may be obtained by contacting Europe Direct or your local information centre (see http://europa.eu/contact).

EU law and related documents

For access to legal information from the EU, including all EU law since 1951 in all the official language versions, go to EUR-Lex at: http://eur-lex.europa.eu

Open data from the EU

The EU Open Data Portal (http://data.europa.eu/euodp) provides access to datasets from the EU. Data can be downloaded and reused for free, both for commercial and non-commercial purposes.

ET-03-20-529-EN-N



doi: 10.2873/587825
ISBN 978-92-76-21051-1