Study on the review of the list of Critical Raw Materials

Non-critical Raw Materials Factsheets

EUROPEAN COMMISSION

Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs
Directorate Industrial Transformation and Advanced Value Chains
Unit C.2 — Resource Efficiency and Raw Materials

Contact: Lidia Godlewska and Milan Grohol

E-mail: grow-c2@ec.europa.eu

European Commission
B-1049 Brussels

EUROPEAN COMMISSION

Study on the review of the list of Critical Raw Materials

Non-critical Raw Materials Factsheets

Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs
Raw Materials

2017

LEGAL NOTICE

Luxembourg: Publications Office of the European Union, 2017

ISBN 978-92-79-72118-2
doi:10.2873/49178

CONTENTS

1. Aggregates 6
2. Aluminium and Bauxite 16
3. Bentonite 37
4. Chromium 51
5. Coking coal 66
6. Copper 77
7. Diatomite 93
8. Feldspar 104
9. Gold 115
10. Gypsum 132
11. Iron Ore 149
12. Kaolin 171
13. Lead 182
14. Limestone 197
15. Lithium 213
16. Magnesite 226
17. Manganese 245
18. Molybdenum 258
19. Natural cork 273
20. Natural Teak wood 282
21. Nickel 292
22. Perlite 308
23. Potash 323
24. Rhenium 335
25. Sapele wood 346
26. Selenium 355
27. Silica sand 371
28. Silver 384
29. Sulphur 397
30. Talc 408
31. Tellurium 420
32. Tin 435
33. Titanium 449
34. Zinc 462

1. AGGREGATES

Key facts and figures

Material name	Aggregates (crushed stone, gravel, granules, pebbles, sand)	EU production (tonnes)[1]	2,354,391,031
Parent group (where applicable)	N/A	EU import reliance[1]	0%
Life cycle stage assessed	Extraction	Substitution index for supply risk [SI(SR)][1]	0.9
Economic importance score (EI)(2017)	2.3	Substitution Index for economic importance [SI(EI)][1]	0.9
Supply risk (SR)(2017)	0.2	End of life recycling input rate	8%
Abiotic or biotic	Abiotic	Major end use in the EU[1]	Construction (100%)
Main product, co-product or by-product	Main product	Major EU producers[1]	Germany (19%), France (14%), Poland (9%)
Criticality results	2011	2014	2017
	Not assessed	Not assessed	Not critical

[1] Average for 2010-2014, unless otherwise stated.

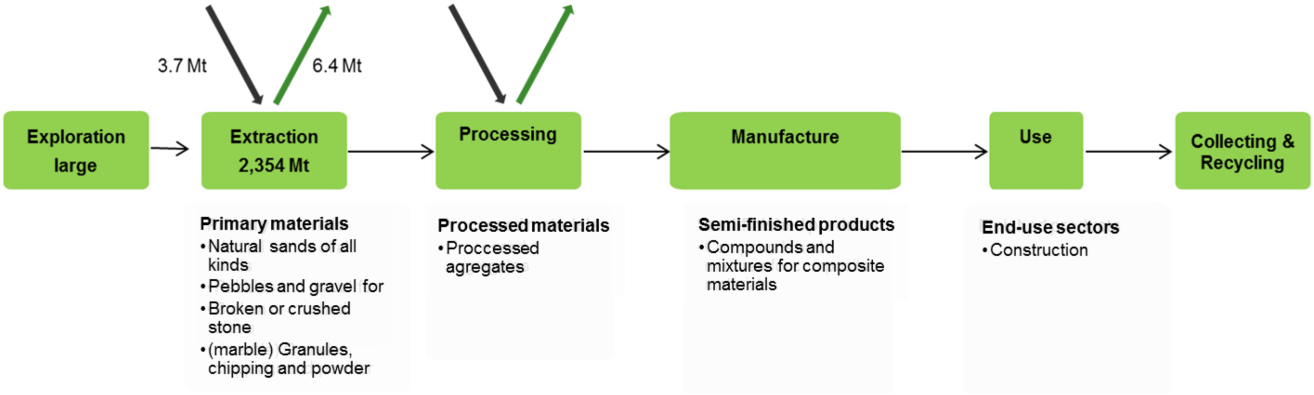


Figure 1: Simplified value chain for aggregates

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU. EU reserves are displayed in the exploration box.

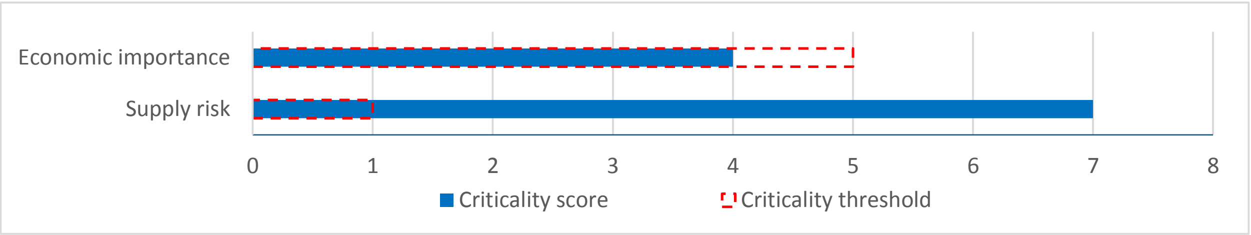


Figure 2: Economic importance and supply risk scores for aggregates

1.1 Introduction

Aggregates are a granular material used in construction. The most common natural aggregates of mineral origin are sand, gravel and crushed rock. This also includes marine or fluvial dredged aggregates. However, aggregates are mainly produced from natural sources extracted from quarries and gravel pits.

Aggregates are extracted all over the world. They are transported over relatively small distances, given the low value/weight ratio. The total volume of aggregates extraction exceeds the total tonnage of all other minerals produced in the EU (BGS., 2016). This results in a conflicting message about the occurrence and supply of aggregates. On one hand it is among the most abundant resources extracted from the earth’s crust, on the other hand do the annual volumes raise concern about the sustainability of supply.

1.2 Supply

1.2.1 Supply from primary materials

1.2.1.1 Geological occurrence/exploration

Stone resources of the world are very large (USGS, 2016).

1.2.1.2 Processing

Mechanical feeders deliver the material to a series of crushers and screens. Crushers of various types such as compression, impact, and shear crushers reduce the raw material to the required size and shape. Often, multiple crushers are used to reduce and shape the raw material in primary, secondary, and tertiary stages, with crushers in the later stages commonly operating in a closed circuit. Multiple vibrating mechanical screens sort the materials into specific product sizes and remove undesirable material sizes. Sometimes recirculating water or air is used to help remove contaminants and excess fine material (Holcim, 2015).

1.2.1.3 EU production

The production of aggregates in the EU between 2010 and 2014 was an annual 2,354Mt on average. Surprisingly, production of Marine Aggregates declined to only 58Mt in 2014 compared to 82Mt in 2009. Production of Manufactured Aggregates declined also to 61Mt in 2014 and demonstrated an irregular trend (UEPG, 2016b).

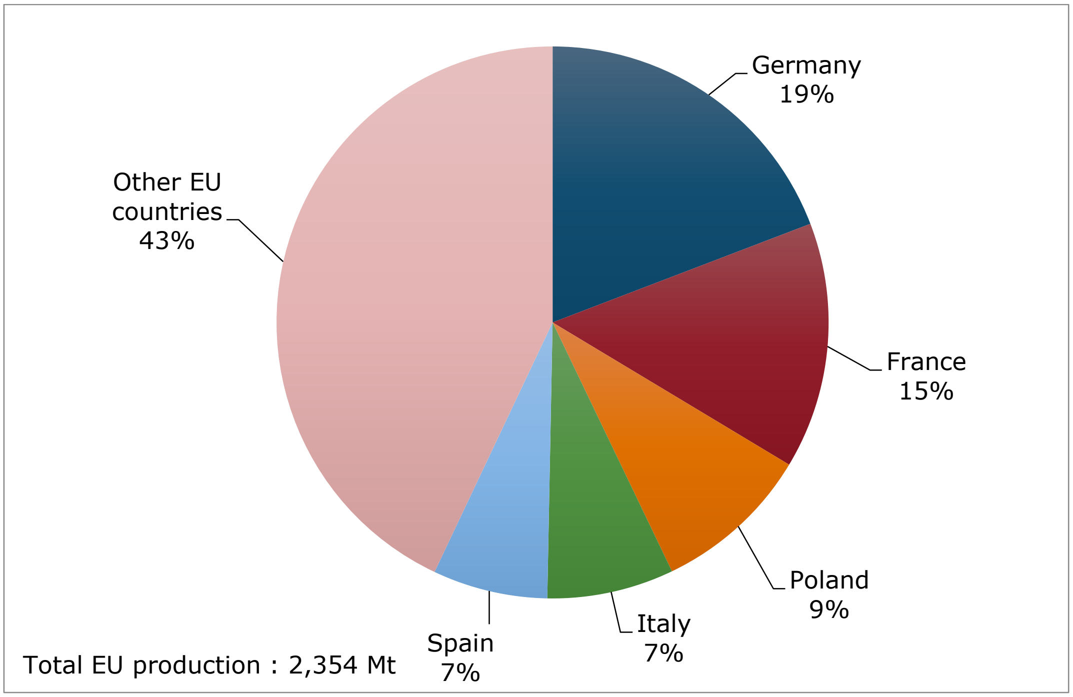


Figure 3: Extraction in the EU of aggregates, average 2010–2014 (Data from BGS World Mineral Statistics database).

1.2.2 Supply from secondary materials

End of life recycling input rate for aggregates is estimated to be 8%.

This value is based on the fact that around 8% of the aggregates themselves are essentially secondary materials (fly ash, slag, Construction & Demolition Waste/CDW). Secondary aggregates are usually by-products from other industrial processes, like blast or electric furnace slags or china clay residues. Recycled aggregates derive from reprocessing materials previously used in construction, including construction, demolition residues (UEPG, 2016a).

The potential of aggregates to be recycled is significantly higher than 8%, but this is not the current practice given the market prices for extraction, transportation and collection. Supply of aggregates from secondary minerals will become increasingly important (BGS, 2016).

1.2.3 EU trade

The traded volumes of aggregates are relatively small compared to the domestic production of several member states (MS). The total annual imports between 2010 and 2014 were on average 3.7Mt, the total annual exports between 2010 and 2014 on average amounted to 6.4 Mt. Prospect, EFTA and Eastern Partnership countries are the trading partners; Norway is very dominant, countries such as Ukraine and Bosnia Herzegovina have a minor share. The imports and exports of aggregates are heavily influenced by the relatively low value/weight ratio of aggregates; hence trade relations are chiefly with neighbouring states. See Figure 4 and Figure 5.

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.

No export restrictions were reported for the 2010-2014 period (OECD, 2016). Some EU free trade agreement exist with suppliers such as Norway, Switzerland, Bosnia, Turkey, Andorra, Morocco, Serbia and Montenegro (European Commission, 2016).

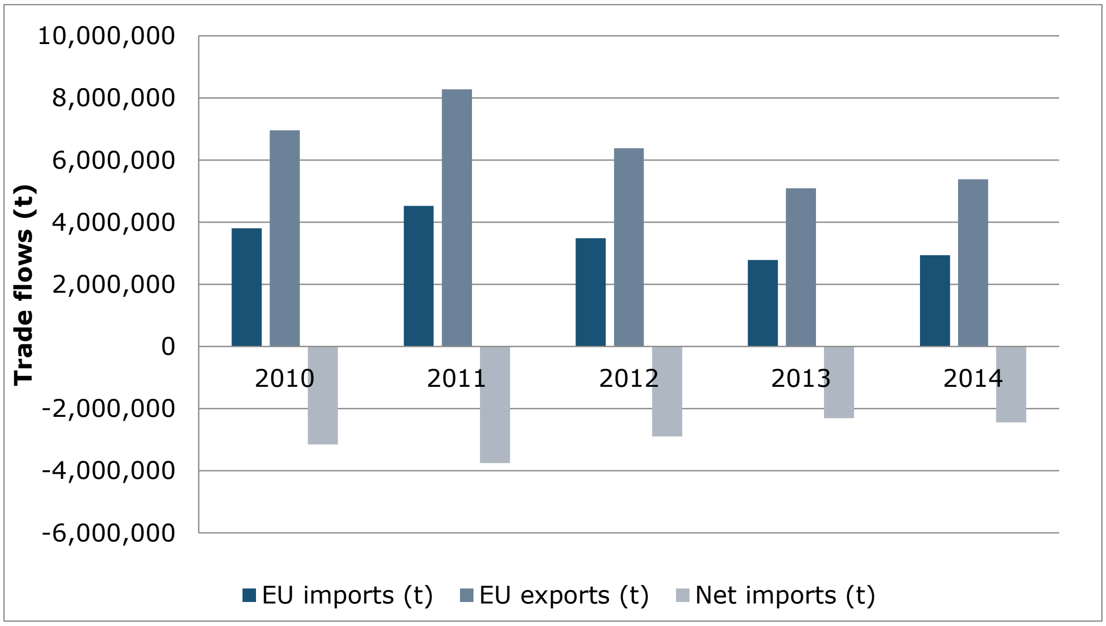


Figure 4: EU trade flows for aggregates (Data from Comext - Eurostat, 2016a)

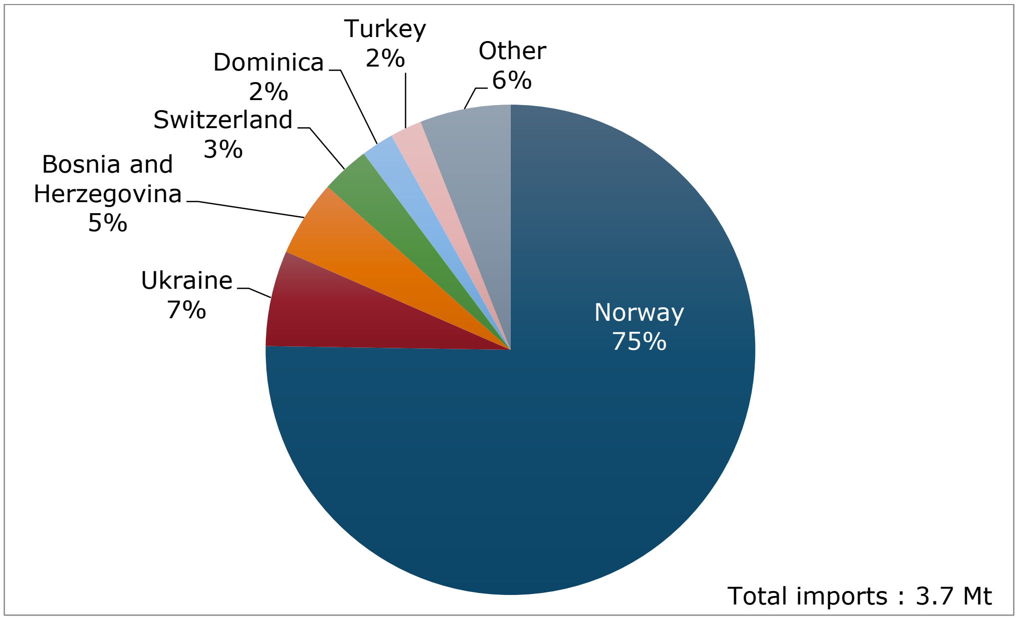


Figure 5: EU imports of aggregates, average 2010-2014 (Data from Comext - Eurostat, 2016a).

1.2.4 EU supply chain

The supply chains of aggregates are basic in general terms. Extraction delivers directly to the construction sector or construction materials sector. The specific chains can be highly specialized on a corporate level given on the particular application of aggregates. Moreover, the application of aggregates in construction works is relatively local given the different characteristics of aggregates per region. This is especially true for secondary aggregates (UEPG, 2006).

The EU is not relying on non-EU countries for its supply of aggregates, and is in fact a net exporter of them. The Figure 6 presents the EU sourcing (domestic production + imports) of aggregates, totally dominated by EU supply.

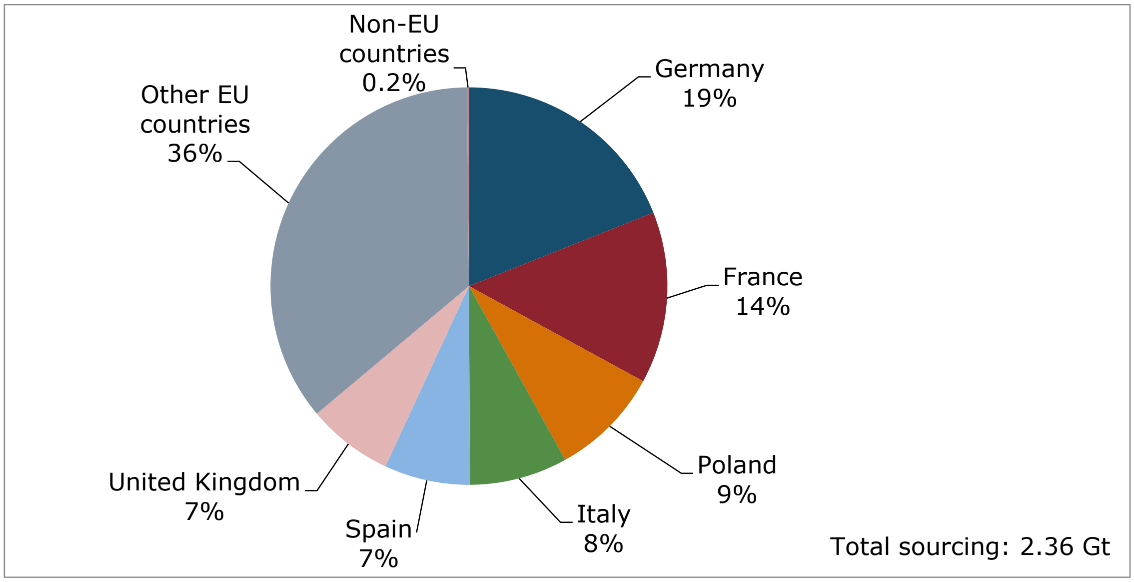


Figure 6: EU sourcing (domestic production +imports) of aggregates, average 2010-2014 (Data from Comext (Eurostat, 2016a; BGS, 2016)).

1.3 Demand

1.3.1 EU consumption

The annual EU consumption (based on the average between 2010 and 2014) of aggregates is estimated to be around 2,400 Mt. Aggregate sales have been depressed since the onset of the recession in 2008, reflecting the significant decline in construction markets, but have started to recover since mid-2013. (MPA, 2016)

1.3.2 Applications / End uses

The use of aggregates takes place in construction. This entails all kinds of construction, utility buildings, homes, civil engineering and specialized construction.

Every different application requires a different technical specification of aggregates, some with extremely demanding requirements in respect of shape, durability, abrasion, frost resistance and other factors (UEPG, 2016b).

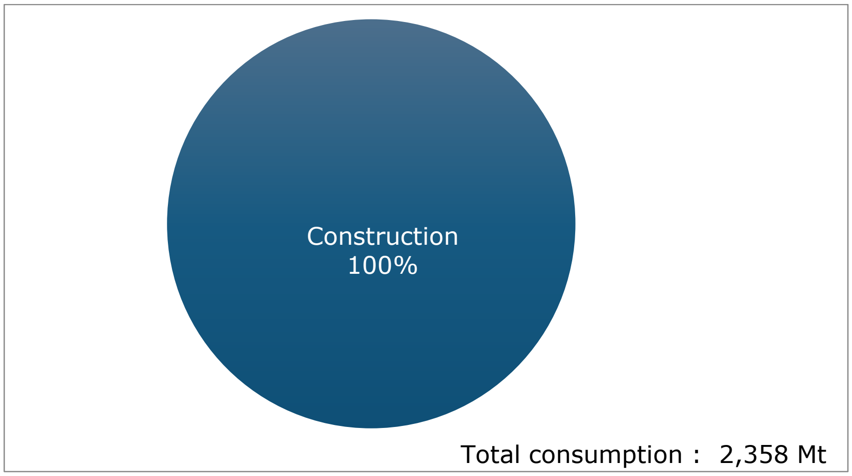


Figure 7: End uses of aggregates. Average figures for 2010-2014 (Data from UEPG, 2016b).

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 1). The value added data correspond to 2013 figures.

Table 1: Aggregate applications, 2-digit NACE sectors, associated 4-digit NACE sectors and value added per sector (Data from the Eurostat database - Eurostat, 2016c).

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (millions €)
Construction	C23 - Manufacture of other non-metallic mineral products	2363 - Manufacture of ready-mixed concrete	59,166.0

1.3.3 Prices

The price of aggregates is relatively low, as well as stable, compared to other minerals and metals. It is also very stable, hence the depiction of prices since 2004 only. The value of sand and gravel on US (a value that is comparable to the global market price), expressed in 1998 EUR to exclude the influence of inflation, shown in Figure 8.

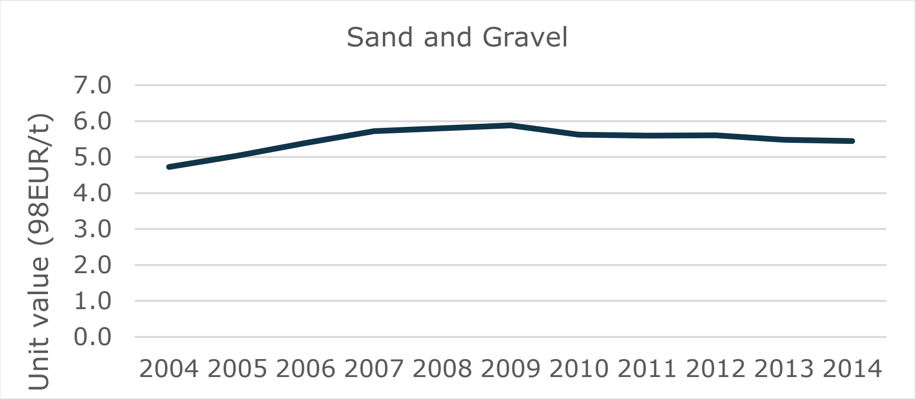


Figure 8: Illustration of developments in price of sand and gravel (Data from USGS, 2016).

1.4 Substitution

Aggregates is a material that has the most existing substitute materials. Given the heterogeneous nature of aggregates, it is possible to substitute one type of aggregate with another. But even if we disregard that option, it is reported that the large volumes of construction and demolition waste can already account for 28% of certain MS aggregates markets (MPA, 2016). Limestone, mortar and asphalt are other substitutes. The value of the substitute material is the limiting factor. So even though the substitution options are diverse in terms of technical requirements, economic constraints are particularly relevant given the high volumes of aggregate applications.

In theory, the primary aggregate in concrete can almost completely be replaced by recycled concrete aggregate (for example upgraded by thermal or other separation techniques) and to a large extent mixed stone-like secondary aggregates from CDW (i.e. crushed concrete and masonry) with over 50% of crushed concrete (Mulder et al., 2002; Mulder et al., 2003). The potential replacement levels are higher than currently done in most countries, reasons being amongst other mismatch between the availability of secondary aggregates from CDW and new construction volumes and restrictive regulations. Recent developments have, for example in the EU Horizon 2020 project SUSCON (Visser et al., 2015), explored the feasibility of secondary aggregates (including rigid polyurethane foams, shredded tire rubber and mixed plastic scraps) from other sources for light weight concretes.

1.5 Discussion of the criticality assessment

1.5.1 Data sources

The following CN product groups are used to analyses the international trade of aggregates.

- 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)
- 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
- 2517 10 20, Broken or crushed dolomite and limestone flux, for concrete aggregates, for road metalling or for railway or other ballast
- 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)
- 2517 41 00, Marble granules, chippings and powder, whether or not heat-treated
- 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 long list exemplifies the heterogeneous nature of aggregates when they are considered a single raw material. Aggregates suffer from incompleteness of production data and incompatibility of countries' statistics (BGS, 2016).

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.

1.5.2 Calculation of Economic Importance and Supply Risk indicators

Extraction or refining usually take place in close proximity of each other. The main bottlenecks for aggregates are competition of land use and transport costs (BGR, 2016). The extraction phase was chose for the analysis.

The world production of non-European countries is not analysed in the criticality assessment. This could not be considered a problem given the strong regional focus of aggregates. This also explains the large share of "other EU countries" in European Supply, which basically means that all EU MS are supplying the EU. The SR indicator is therefore calculated using the EU-HHI only.

The supply risk was assessed for aggregates used only the EU-28 HHI, given only the EU production was taken into account in the criticality assessment.

1.5.3 Comparison with previous EU assessments

Aggregates was not assessed in 2011 or in 2014. Therefore, aggregates are being assessed for the first time in 2017 with the EI and SR presented below in Table 2.

Table 2: Economic importance and supply risk results for aggregates in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

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

1.6 Other considerations

1.6.1 Forward look for supply and demand

The estimations for the outlook for supply and demand are shown in Table 3. The implication of long term replenishment rates below 100% is that shortages of supply may become apparent (MPA, 2016).

Table 3: Qualitative forecast of supply and demand of aggregates

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
Aggregates		x	+	+	?	+	+	0

1.6.2 Environmental and regulatory issues

The European Innovation Partnership "European Network for Sustainable Quarrying and Mining" illustrates the need for aggregate extraction operations to consider land-use competition and interference with natural habitats. It is in some areas still a challenge to ensure compatibility of extraction with Natura 2000 and the corresponding environmental management. There is a difference in interpretation per MS of Directives that relate to Natura 2000 that is reported to thwart the EU single market in some cases.

Aggregates producers in many European countries are facing the negative consequences of unfair competition. This includes: illegal extraction, extraction as part of civil works, illegal landfilling, illegal backfilling and dumping of waste, poor environmental performance, unsafe and unhealthy working conditions, grey/black/informal markets and employment, late payments, non-compliance with accounting, overloading and exceeding working times and low quality aggregates. (UEPG, 2016).

1.6.3 Supply market organization

The 2011 EU Regulation (No 305/2011), which replaced the Construction Product Directive, was designed to simplify and clarify the existing framework for placing construction products on the market.

1.7 Data sources

1.7.1 Data sources used in the factsheet

BGR (2016) Expert consultation from A. Wittenberg.

BGS (2016). World Mineral Production 2010–2014. Keyworth, Nottingham: British Geological Survey, p. 81. Available at: http://www.bgs.ac.uk/mineralsuk/statistics/worldStatistics.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/

Eurostat (2016)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

Holcim (20150 How are aggregates produced? Available at: http://www.holcim.com/en/aggregates-production.html

Minerals4EU (2014). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

Mulder, E., Blaakmeer, J., Tamboer, L., Nijland, T.G., (2002). A closed material cycle for concrete, as part of an integrated process for the reuse of the total flow of C&D waste. In: Dhir, R.K., Dyer, T.D. & Halliday, J.E., eds., Sustainable concrete construction. Thomas Telford, 555-562.

Mulder, E., Blaakmeer, J., Van Dijk, K., Nijland, T.G., (2003). Closed material cycles for concrete and masonry, as part of an integrated process for the reuse of the total flow of C&D waste. In: Ortiz de Urbina, G. & Goumans, J.J.J.M., eds., Proceedings of the 5th International Conference on the Environmental and Technical Implications of Construction with Alternative Materials, San Sebastián, 219-229.

UEPG (2006). Aggregates from construction & Demolition Waste in Europe. Special edition. Available at: http://www.uepg.eu/uploads/Modules/Publications/uepg_recycling-study.pdf.pdf

UEPG (2016a) What are aggregates [online] Available at: http://www.uepg.eu/what-are-aggregates

UEPG (2016b) Annual review 2015-2016. Available at: http://www.uepg.eu/uploads/Modules/Publications/uepg-ar2016-17_32pages_v04_small.pdf

USGS (2016) J. C. Willet 2014 Minerals Yearbook. U.S. Geological Survey. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/stone_crushed/myb1-2014-stonc.pdf

Visser, J., Couto, S., Gupta, A., Larraza Alvarez, I., Chozas Ligero, V., Sotto Mayor, T., Vinai, R., Pipilikaki, P., Largo, A., Attanasio, A., Chaolung Huang, M. & Soutsos, M., 2015. Sustainable concrete: Design and testing. Heron 60:59-92. Available at: http://www.sus-con.eu/deliverables

1.7.2 Data sources used in the criticality assessment

BIO by Deloitte (2015). Study on Data for a Raw Material System Analysis: Roadmap and Test of the Fully Operational MSA for Raw Materials. Prepared for the European Commission, DG GROW. Availeble at: https://ec.europa.eu/growth/tools-databases/msa/sites/default/files/deliverables/MSA_Final_Report.pdf

BGS (2016). World Mineral Production 2010–2014. Keyworth, Nottingham: British Geological Survey, p. 81. Available at: http://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 (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

MPA (2016) The Mineral Products Industry at a Glance. Available at: http://www.mineralproducts.org/documents/Mineral_Products_Industry_At_A_Glance_2016.pdf

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

1.8 Acknowledgments

This Factsheet was prepared by the Netherlands Organisation for Applied Scientific Research (TNO). The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this factsheet.

2. ALUMINIUM AND BAUXITE

Key facts and figures

<table>
<tr><td>Material name and Element symbol/ Formula</td><td colspan="3">Aluminium,
Al</td><td colspan="3">Bauxite,
Variable</td></tr>
<tr><td>Parent group (where applicable)</td><td colspan="3">n/a</td><td colspan="3">n/a</td></tr>
<tr><td>Life cycle stage/material assessed</td><td colspan="3">Refined metal</td><td colspan="3">Ores and concentrates</td></tr>
<tr><td>Economic importance score EI (2017)</td><td colspan="3">6.5</td><td colspan="3">2.6</td></tr>
<tr><td>Supply risk SR (2017)</td><td colspan="3">0.5</td><td colspan="3">2.0</td></tr>
<tr><td>Abiotic or biotic</td><td colspan="3">Abiotic</td><td colspan="3">Abiotic</td></tr>
<tr><td>Main product, co-product or by-product</td><td colspan="3">Main product</td><td colspan="3">Main product</td></tr>
<tr><td>World/EU production (million tonnes)[1]</td><td colspan="3">World:47
EU: 2.2</td><td colspan="3">World:258
EU: 2.2</td></tr>
<tr><td>EU import reliance[1]</td><td colspan="3">64%</td><td colspan="3">85%</td></tr>
<tr><td>Substitution index for supply risk [SI (SR)]</td><td colspan="3">0.88</td><td colspan="3">1.00</td></tr>
<tr><td>Substitution Index for economic importance [SI(EI)]</td><td colspan="3">0.80</td><td colspan="3">1.00</td></tr>
<tr><td>End of life recycling input rate (EOL-RIR) [2]</td><td colspan="3">12%</td><td colspan="3">0%</td></tr>
<tr><td>Major end uses in EU[1]</td><td colspan="3">Mobility (transport and automotive) (39%), Construction (24%), Packaging (17%)</td><td colspan="3">Refining to alumina (90%), Refractories (3%), Cement (3%)</td></tr>
<tr><td>Major world producers[1]</td><td colspan="3">China (45%), Russia (8%), Canada (6%)</td><td colspan="3">Australia (29%), China (18%), Brazil (13%)</td></tr>
<tr><td rowspan="2">Criticality results</td><td>2011</td><td>2014</td><td>2017</td><td>2011</td><td>2014</td><td>2017</td></tr>
<tr><td>Not critical</td><td>Not critical</td><td>Not critical</td><td>Not critical</td><td>Not critical</td><td>Not critical</td></tr>
</table>

[1] average for 2010-2014 [2] EOL-RIR based on global data

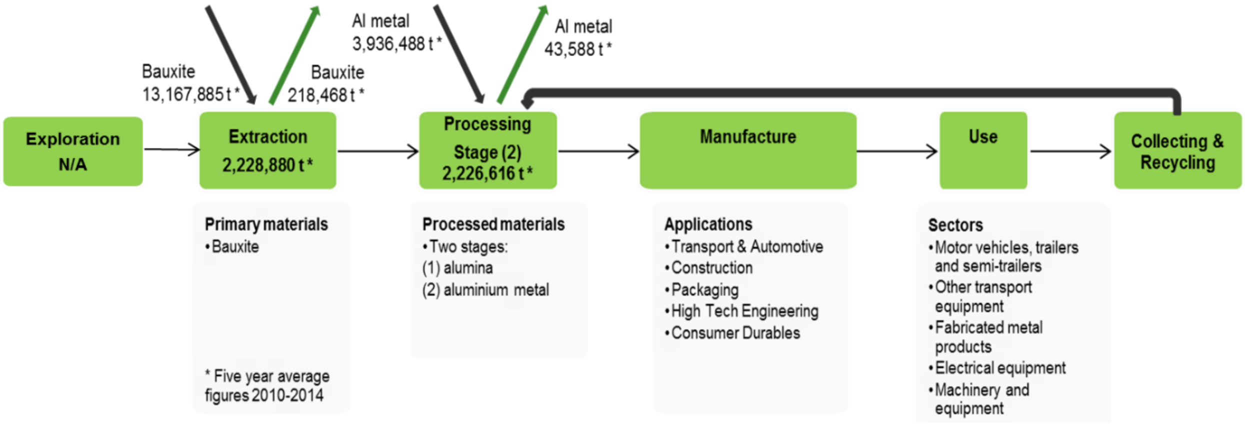


Figure 9: Simplified value chain for bauxite and aluminium

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU. A quantitative figure on recycling is not included as the EOL-RIR is below 70%. EU reserves are displayed in the exploration box.

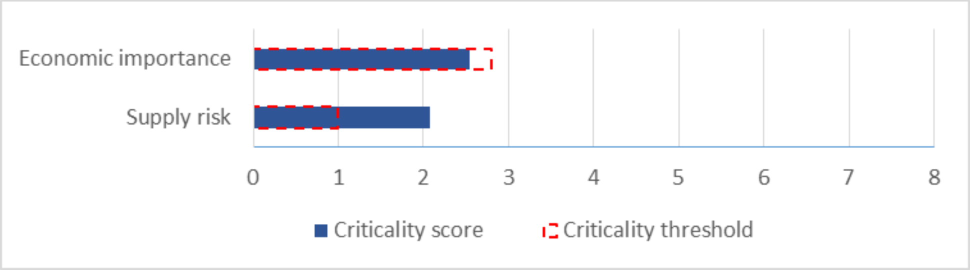


Figure 10: Economic importance and supply risk scores for bauxite

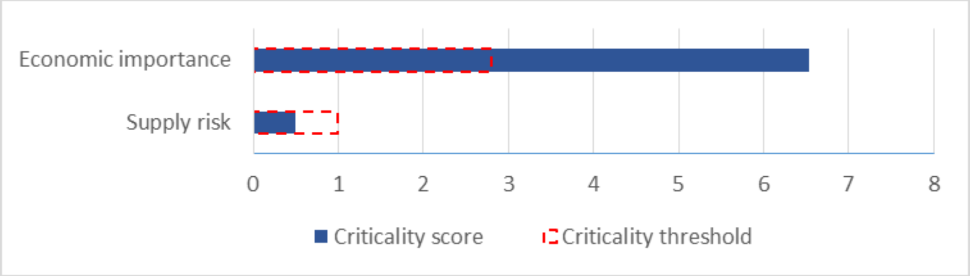


Figure 11: Economic importance and supply risk scores for aluminium

2.1 Introduction

Bauxite is the main ore of aluminium. It is a heterogeneous material composed primarily of the minerals gibbsite, boehmite and diaspore with varying quantities of silica, iron oxide, titanite, aluminosilicate and other associated minerals; and contains more than 40% of Al_2O_3. It typically occurs in shades of brown, red-brown or yellow-brown but it can be white, grey or mottled depending on the impurities contained within the rock. Deposits of bauxite are residual accumulations caused by intense lateritic weathering. Approximately 90% of bauxite mined in the world is converted to alumina (aluminium oxide) using the Bayer Process and 80–90% of the world's alumina is smelted to aluminium using the Hall-Herout Process. The typical bauxite grade useable in the Bayer process consists of 50 - 55 % Al_2O_3, up to 30% of Fe_2O_3, and up to 1.5% of SiO_2. Bauxite is also used in refractories, cement, abrasives, chemicals and other minor uses.

Aluminium (chemical symbol Al) is a lightweight, malleable, silver-grey metal with a density of 2.70 g/cm^3 at 20°C and a hardness of 2.75 on Mohs scale. It has a thermal conductivity of 235 $W\ m^{-1}\ K^{-1}$ and a melting point of 660 °C (933 K). Aluminium is the most abundant metal in the Earth's crust (8.1%) and is the third most abundant element after oxygen and silicon. In the upper crust, the abundance of Al_2O_3 is 15.4 wt% (Rudnick, 2003). Although it occurs in a wide range of minerals (mainly oxides and silicates) it rarely occurs in native form. It is difficult and therefore expensive to extract aluminium from most of the minerals in which it is present and almost all aluminium production is from bauxite. Aluminium is the second most widely used metal (after iron) and readily forms alloys. Its main uses are in transportation (aircraft, vehicles, trains, boats, spacecraft, etc.), construction (windows, doors, cladding, curtain walls, etc.), packaging (cans, foil, food trays, boxes, etc.), high-tech engineering (electrical transmission lines, ladders, cylinder blocks, pistons, pulleys, etc.) and consumer durables (domestic appliances, cooking utensils, cutlery, paint, coins, etc.).

Within the EU, bauxite is currently mined in 4 countries but the combined output from these countries represents less than 1% of the world’s total production of bauxite. There are alumina refineries in 7 countries and aluminium smelters in 11 countries in Europe, contributing 5% each to the respective global production totals.

2.2 Supply

2.2.1 Supply from primary materials: bauxite

2.2.1.1 Geological occurrence of bauxite

Most bauxite deposits can be classified into two categories: those developed over carbonate rocks, sometimes known as ‘karst bauxite’; and those developed over other types of rocks which are known as ‘lateritic bauxite’. The majority of the world’s production comes from the latter group. Intense and sustained weathering processes, often in tropical or sub-tropical regions where both temperatures and rainfall are high, remove the more mobile elements, e.g. silica, and leave behind a residual deposit. If the original source rock was suitable, e.g. a volcanic ash rich in aluminous minerals or felsic igneous rocks such as rhyolite or granite, this residual deposit may be formed of bauxite. Further details of the conditions required for bauxite formation are available in Gow & Lozej (1993).

Major deposits of bauxite tend to be grouped into a series of ‘provinces’. Hill & Sehnke (2006) identify four karst bauxite provinces and four lateritic bauxite provinces as follows:

Karst bauxite provinces

- Caribbean – extends from Jamaica, through Haiti and the Dominican Republic to Puerto Rico.
- Mediterranean – extends from Turkey, through Greece, Albania, Serbia, Montenegro, Bosnia and Herzegovina, Croatia, Hungary, Italy and into parts of France. There are also smaller associated deposits in Spain and Austria.
- Central Urals and Kazakhstan – including deposits in the Ural mountains and east of St Petersburg in Russia, and deposits in Kazakhstan and Ukraine.
- China – extends from the Liaoning Province in northern China, southwest to Guangxi Province in the south and also into Vietnam.

Lateritic bauxite provinces

- African – comprising the Guinea and Cameroon shields. The former extends from Guinea Bissau to Ghana and north into Mali; the latter extends southeast from Cameroon to Malawi and Mozambique.
- South Asia-Australia – includes sub-provinces in Australia, India and south-east Asia, particularly Malaysia and Indonesia.
- North American – mostly located in south-east U.S.A.
- South American – extends from Columbia, through Venezuela, Guyana, Suriname and French Guiana and into Brazil.

2.2.1.2 Exploration for bauxite

During the Minerals4EU project it was identified that in 2013 exploration for bauxite undertaken by Geological Surveys was not known to be taking place in any of the European countries that responded to the survey. However, exploration for bauxite may have taken place in other countries where no information was provided (Minerals4EU, 2015). Indeed, bauxite mining companies never stop conducting near-mine exploration.

2.2.1.3 Resources and reserves of bauxite

There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of bauxite 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[1], 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.

For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for bauxite. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for bauxite, 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 bauxite at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU, 2015).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.

Globally, the United States Geological Survey (USGS) estimate that resources of bauxite are in the range of 55–75 billion tonnes, in Africa (32%), Oceania (23%), South America and the Caribbean (21%), Asia (18%), and elsewhere (6%) (USGS, 2016). The USGS notes that because the aluminium element is so abundant across the world there are "essentially inexhaustible" quantities in materials other than bauxite (USGS, 2016). However, these are currently not economic to extract and therefore should not be included in any estimates of resources.

Estimated global reserves reported by the USGS amounts about 28 billion tonnes and the breakdown per counties is shown in Table 4. These are not necessarily reported in accordance with any internationally recognised system of reporting.

Table 4: Global reserves of bauxite in year 2015 (Data from USGS, 2016)

Country	Bauxite Reserves (thousand tonnes)	Percentage of total (%)
Guinea	7,400,000	26
Australia	6,200,000	22
Brazil	2,600,000	9
Vietnam	2,100,000	8
Jamaica	2,000,000	7
Indonesia	1,000,000	4
Guyana	850,000	3
China	830,000	3
India	590,000	2
Suriname	580,000	2
Venezuela	320,000	1
Greece	250,000	1
Russia	200,000	1

---

[1] www.crirsco.com

Country	Bauxite Reserves (thousand tonnes)	Percentage of total (%)
Kazakhstan	160,000	1
Malaysia	40,000	0
U.S.A.	20,000	0
Other countries (unspecified)	2,400,000	9
World total (rounded)	*28,000,000*	*100*

During the Minerals4EU project, bauxite resources were reported as being present in the following countries: Albania, Bosnia & Herzegovina, Bulgaria, France, Germany, Greece, Hungary, Italy, Kosovo, Montenegro, Romania, Serbia, Turkey and Ukraine. Of these, only Romania reported statistical data in compliance with the United Nations Framework Classification (UNFC) system of reporting. That country reported 97 million tonnes in category 333. Of the countries listed, no statistical data was available from Bulgaria, Montenegro and Germany. Resources data for Germany, in particular, are not reported because data collection in that country is the responsibility of sub-national level authorities. Resources may exist in Croatia or Luxembourg but no information is available. All the other European countries covered by the survey do not have any known resources of bauxite (Minerals4EU, 2015).

During the Minerals4EU project, bauxite reserves were reported as being present in Italy, Kosovo, Romania and Ukraine but again only Romania reported statistical data in compliance with the UNFC system of reporting. Reserves of bauxite in Romania amount to 2.5 million tonnes in category 121. There are no known reserves in Austria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Greece, Ireland, Macedonia, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland or the United Kingdom. No information was available for other European countries (Minerals4EU, 2015).

2.2.1.4 World mine production of bauxite

Globally bauxite was mined in 31 countries in 2014 with total production averaged over the 2010–2014 period amounting to more than 258 million tonnes per year. The largest producers are shown in Figure 12. Within the EU, bauxite is mined in Greece (0.8% of global total), Hungary, France and Croatia (<0. 1% each) (BGS, 2016). The EU annual production of bauxite (average 2010-2014) is about 2.2 million tonnes.

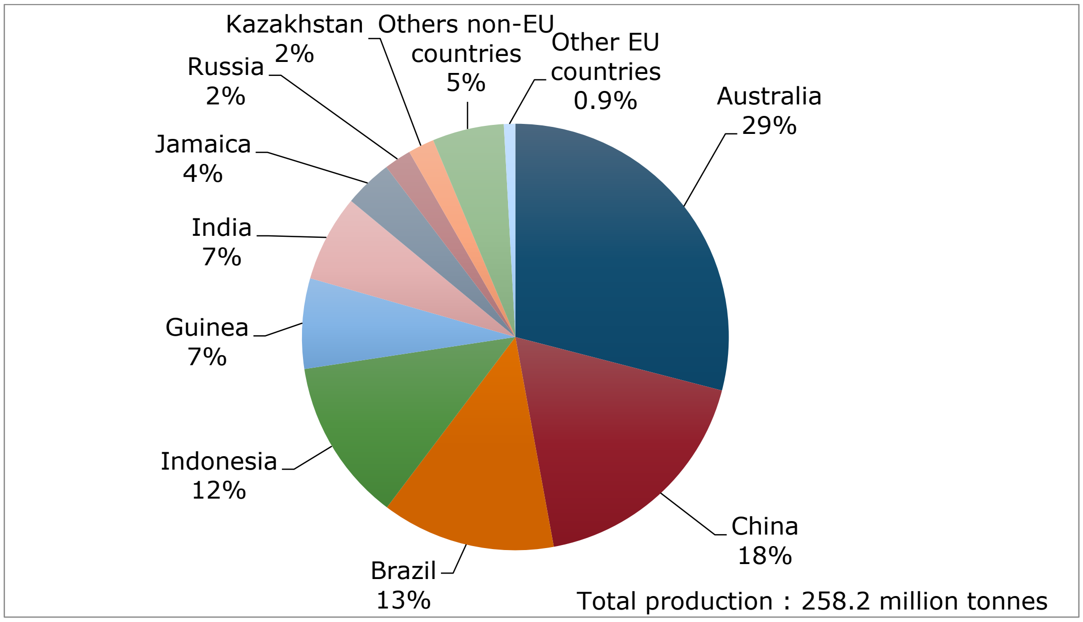


Figure 12: Global mine production of bauxite, average 2010–2014 (Data from BGS World Mineral Statistics database - BGS, 2016)

2.2.1.5 Mining, processing and extractive metallurgy: from bauxite to primary aluminium

Most bauxite deposits are shallow and are therefore worked by typical surface mining techniques. First the soil and any existing overburden is removed and stored for later reinstatement work. The bauxite is then extracted using drilling and blasting or ripping using a large bulldozer, depending on how consolidated the deposit is, and transported to a processing plant by dumptruck, railway or conveyor. In general bauxite does not need complicated beneficiation stages because the ore grade is usually already sufficient but there may be crushing, washing and screening processes to remove clay (International Aluminium Institute, 2016a).

Of all bauxite mined, approximately 85% is converted to alumina for the production of aluminum metal, and an additional 10% is converted to various forms of specialty aluminas for nonmetal uses. The remaining 5% is used directly for nonmetallurgical bauxite applications. The bulk of world bauxite production is used, therefore, as feed for the manufacture of alumina via a wet chemical caustic leach process known as the Bayer process. Typically two or three tonnes of bauxite are required to produce one tonne of alumina (aluminium oxide, Al_2O_3). At the refinery, the bauxite is washed and milled to reduce the particle size and any excessive silica is removed. Hot caustic soda is added to dissolve the aluminium-bearing minerals (gibbsite, boehmite and diaspore) to form a saturated solution within a digester at temperatures of between 140°C and 280°C depending on the type of ore. The slurry is then rapidly cooled in a series of flash tanks to around 106°C and a chemical flocculant added to assist in the sedimentation of the solid bauxite residue so that it can be removed from the saturated solution in settling tanks and filters. Next the saturated solution is progressively cooled under controlled conditions and aluminium trihydroxite precipitates as crystals (with a chemical formula of $Al(OH)_3$ this is also known as 'alumina hydrate'). These crystals are separated from the remaining liquor using vacuum filtration and calcined at 1100°C to form alumina (International Aluminum Institute, 2016b).

Alumina is smelted to form primary aluminium metal using the Hall-Héroult process. This involves passing an electrical current (direct current at 600,000 amps) into a line of electrolytic cells, or 'pots', connected in a series known as a 'potline'. Each pot is a large carbon-lined container, which forms the negative electrode (or cathode) of the cell. Inside the pot is an electrolytic bath of molten cryolite at a temperature of 960–980°C into which the alumina powder is dissolved. Aluminium fluoride is added to the solution to optimise the chemistry. Carbon blocks are suspended in the solution to serve as the positive electrode (or anode). The electrical current is passed from the anode via the electrolytic bath to the cathode and then on to the anode of the next pot in the series. As it passes through the bath the dissolved alumina is split into molten aluminium and oxygen. The molten aluminum metal sinks to the bottom of the pot from where it is siphoned every day or two in a process known as 'tapping' (International Aluminium Institute, 2016c). Typically 1.9 tonnes of alumina (aluminium oxide, Al_2O_3) are required to produce one tonne of aluminium metal.

2.2.1.6 World production of primary aluminium

Alumina (aluminium oxide) was produced in 24 countries in 2014 and global production amounted to more than 107 million tonnes. The largest producer was China (with 47% of the global total in 2014), followed by Australia (19%) and Brazil (10%). Within the EU there are alumina refineries in France, Germany, Greece, Hungary, Ireland, Romania and Spain, with a combined total that amounts to just 5% of the global total in 2014 (BGS, 2016).

Primary aluminium metal was produced in 42 countries in 2014, with the total global production over the 2010–2014 period amounting to an average of nearly 47 million tonnes per year. The largest global producers are shown in Figure 13. Within the EU for the 2010-2014, there were aluminium smelters in Germany, France, Spain, Romania, Slovakia, Greece, Netherlands, Sweden, United Kingdom, Italy and Slovenia. These contributed a total of 2.2 million tonnes of aluminium, or 4%, to the global total (based on figures averaged over 2010–2014) (BGS, 2016). Since 2012, the Italian smelter is closed.

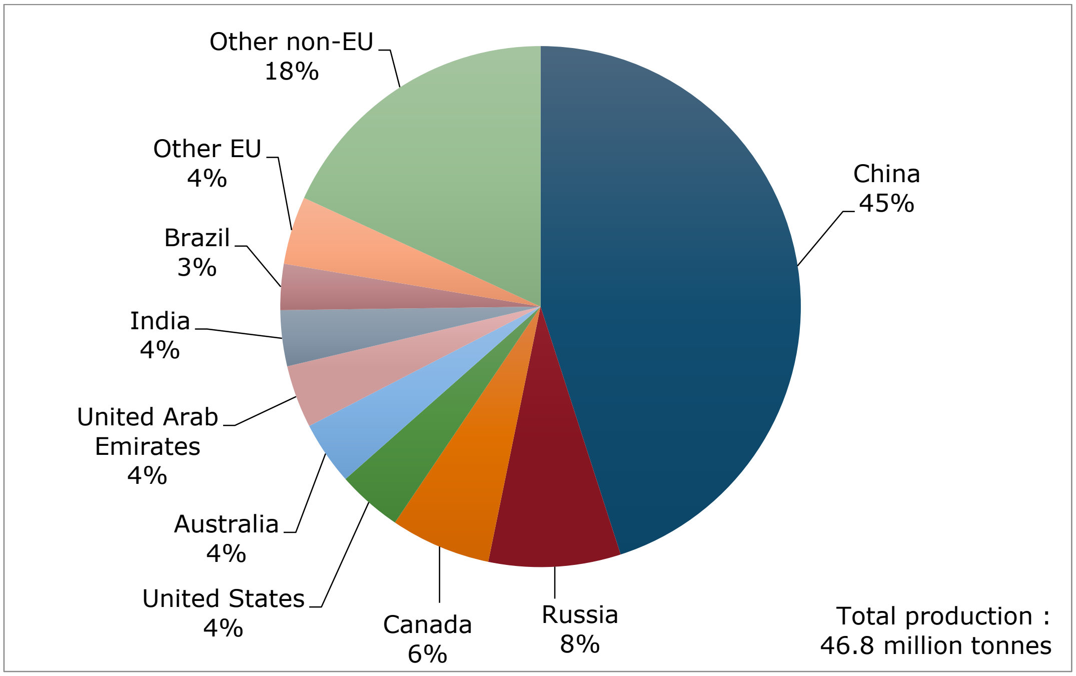


Figure 13: Global production of primary aluminium, average 2010–2014 (Data from BGS World Mineral Statistics database (BGS, 2016))

2.2.2 Supply from secondary materials

Bauxite is consumed during all of its uses and therefore is not available for recycling. Although some refractory products are subsequently recycled this is generally to further refractory uses and is very small in quantity compared to the global production of bauxite. The majority of bauxite uses results in a substance that is subsequently transformed into a different product, e.g. cement into concrete or alumina into aluminum metal. Recycling of bauxite itself is therefore zero.

In contrast to bauxite, aluminium metal is infinitely recyclable without loss of performance. For example, aluminium food or drink packaging can be recycled into metal that is subsequently used in an aircraft. There are two sources of scrap metal 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. For aluminium this includes a wide range of products including aluminium beverage cans or food packaging; components from aircraft, cars or other vehicles; articles arising from demolished buildings; or discarded equipment. Scrap metal and other aluminium-bearing wastes are also generated during the fabrication and manufacture of aluminium products (sometimes referred to as ‘new scrap’ or ‘processing scrap’). This could be in the form of metal that did not meet required specifications, excess metal removed during casting or forging, grinding sludge or turnings generated during machining processes.

The most significant factors in determining the quantity of aluminium from 'old scrap' that is recycled are the collection systems for the wide ranging end-of-life products and the long lifespan of some of the products. The latter means that a significant quantity of the metal is not available to be recycled for many years; hence the published figure that 75% of all the aluminium ever produced is still in use (International Aluminium Institute, 2016d). The reuse and recycling of 'new scrap' is more straightforward than for old scrap because it contains less contamination from other materials and it makes economic sense for a manufacturer to minimise the quantity of raw material that is lost as waste. As a consequence, more than three times as much aluminium is recycled from 'new scrap' than from 'old scrap' (International Aluminium Association, 2015). It must be noted that a third (37%) of EU demand for aluminium metal is satisfied by recycling, including new scrap and old scrap (European Aluminium Statistics, 2016).

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) quoted three figures for the 'end-of-life recycling rate' of aluminium from three different sources as 42%, 60% or 70%. This is measured as 'old scrap' sent for recycling as a proportion of 'old scrap' generated. The UNEP report also quotes recycled content, which represents the 'old scrap' plus 'new scrap' as a proportion of the total quantity of metal available to manufacturers (which would also include primary material), as either 34% or 36% (depending on the data source) (UNEP, 2011). The data sources used in the UNEP report are the USGS from a circular that relates only to the U.S.A. and includes figures from 2000; private communication in 2009 with the Organisation of European Aluminium Refiners and Remelters; and figures from the International Aluminium Institute also relating to 2009.

However, for this criticality assessment, a slightly different indicator has been used: 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'). Using data from the International Aluminium Association (2015), this indicator was calculated to 12%. This appears to be much lower than the figures quoted earlier because it is calculated as the quantity of 'old scrap' (14 million tonnes) divided by the sum of 'primary material' (51 million tonnes) and total scrap ('new' and 'old', 62 million tonnes). Consultation has been carried out in relation to this figure but no data resulting in a different calculated figure has been supplied and consequently the 12% figure has been used in the assessment.

2.2.3 EU trade

Although the EU does produce over 2.23 million tonnes of bauxite per year and 2.23 million tonnes of aluminium per year (averaged over 2010–2014), these figures are small compared to the scale of imports (respectively 13.2 million tonnes and 3.9 million tonnes), which are shown in Figure 14 for bauxite and Figure 15 for primary aluminium metal. The trade codes used in this assessment were CN 2606 0000 for Aluminium ores and concentrates and for primary aluminium CN 7601 1000 unwrought aluminium not alloyed and CN 7601 2010 unwrought aluminium alloys. Figures for exports are even smaller at approximately 0.2 million tonnes and 0.04 million tonnes respectively.

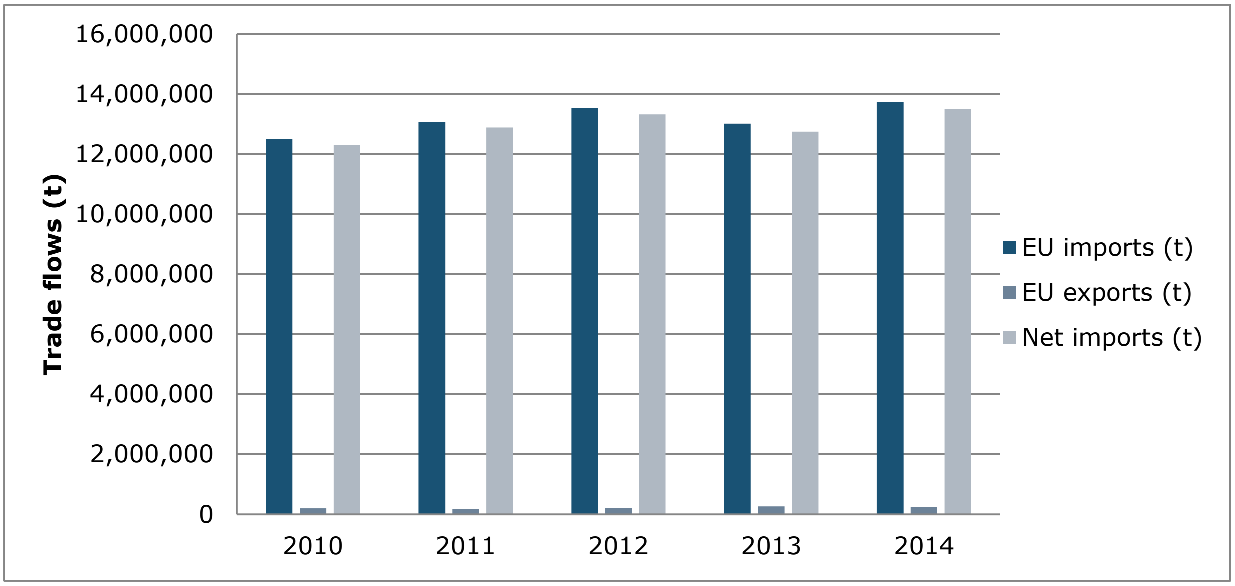


Figure 14: EU trade flows for aluminium ores and concentrates. (Data from Comext - Eurostat, 2016a)

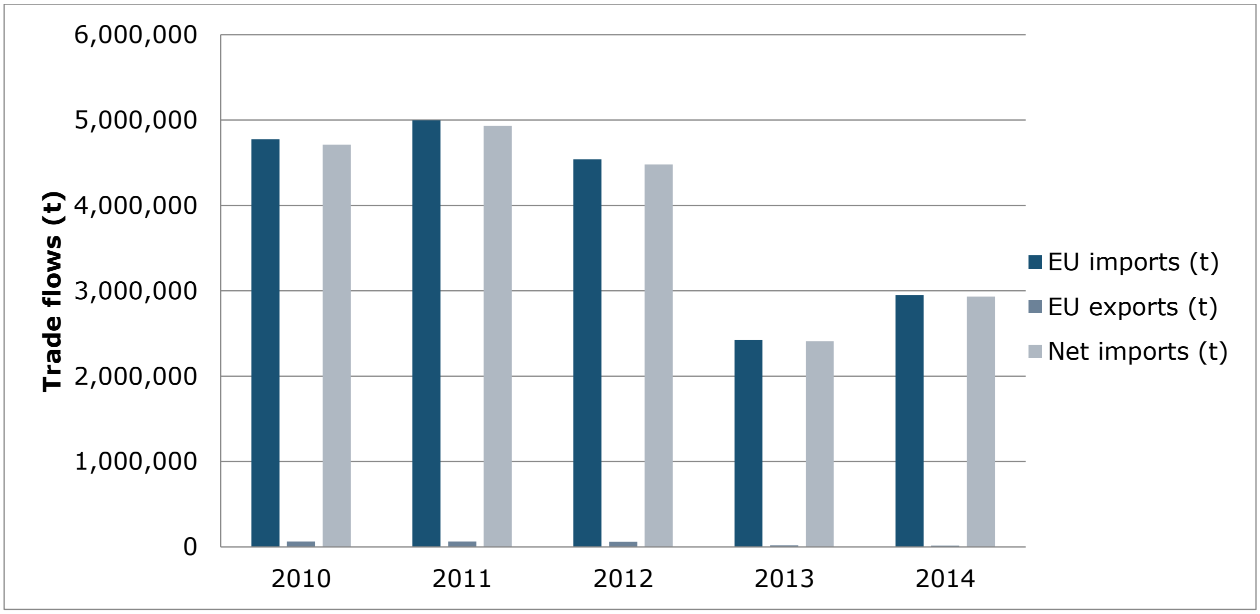


Figure 15: EU trade flows for unwrought aluminium not alloyed and unwrought aluminium alloys. (Data from Comext - Eurostat, 2016a)

The originating countries of these imports are shown in Figure 16 for bauxite and Figure 17 for primary aluminium metal. For bauxite, Figure 16 demonstrates that the EU is largely dependent on Guinea for its supplies with an average of 9.5 million tonnes imported from that country per year. Imports from Brazil amounted to approximately 1.5 million tonnes per year with more than 1 million tonnes per year from Sierra Leone. Imports of primary aluminium were more evenly divided between Norway (an average of 0.84 million tonnes per year), Russia (just under 0.80 million tonnes per year), Mozambique (0.57 million tonnes per year) and Iceland (0.55 million tonnes per year). As before these figures are all averaged over 2010–2014.

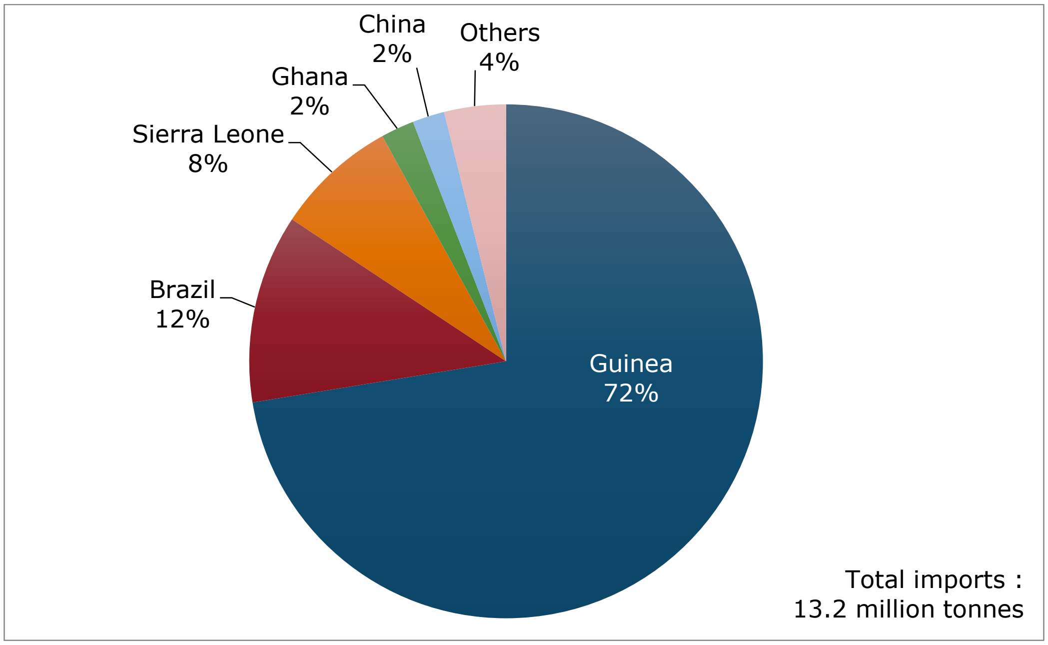


Figure 16: EU imports of aluminium ores and concentrates, average 2010-2014. (Data from Comext - Eurostat, 2016a)

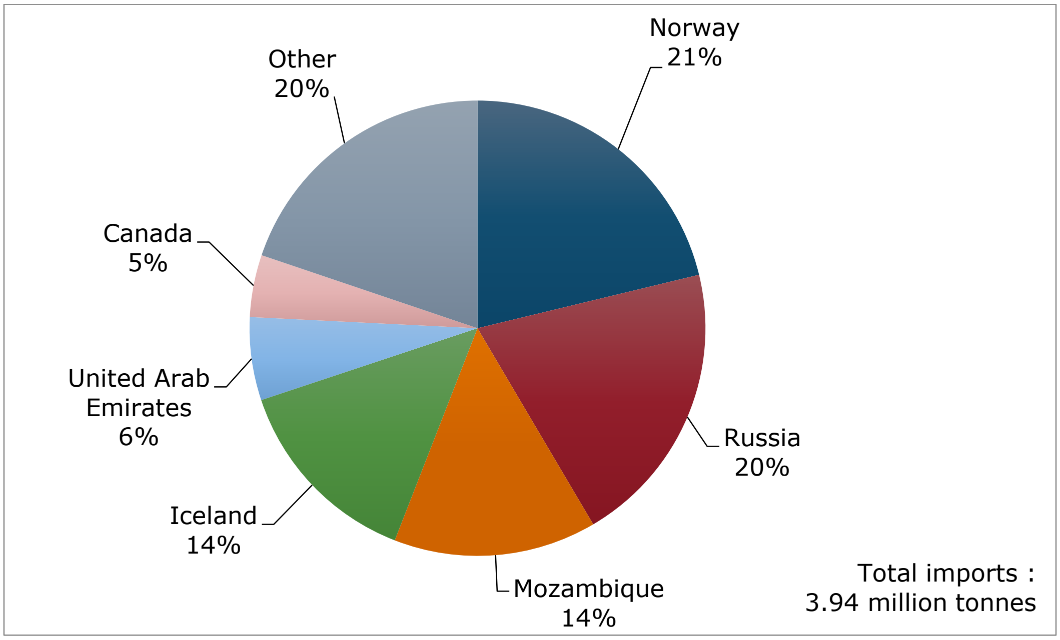


Figure 17: EU imports of unwrought aluminium not alloyed and unwrought aluminium alloys, average 2010-2014. (Data from Comext - Eurostat, 2016a)

2.2.4 EU supply chain

Bauxite is mined in 4 EU countries: Greece (on average nearly 2 million tonnes per year), Hungary (just under 0.2 million tonnes per year), France (just under 86 thousand tonnes per year) and Croatia (just under 6 thousand tonnes per year). These figures are small when compared to the global total production of more than 258 million tonnes, or compared to the largest producing country: Australia (nearly 75 million tonnes per year). All these figures are averaged over 2010–2014 data.

In addition to this production, more than 13 million tonnes per year of bauxite are imported to the EU-28. Of these imports, 32% go to Ireland, with another 26% imported by Spain, 18% by Germany, 9% by Romania, 8% by France, 3% by Greece and 1% by Hungary. The import reliance is 85% for bauxite. The Figure 18 presents the EU sourcing (domestic production + imports) of bauxite. Although no assessment of criticality has taken place for alumina in the 2017 criticality assessment, it is known that alumina refining takes place in these 7 EU countries.

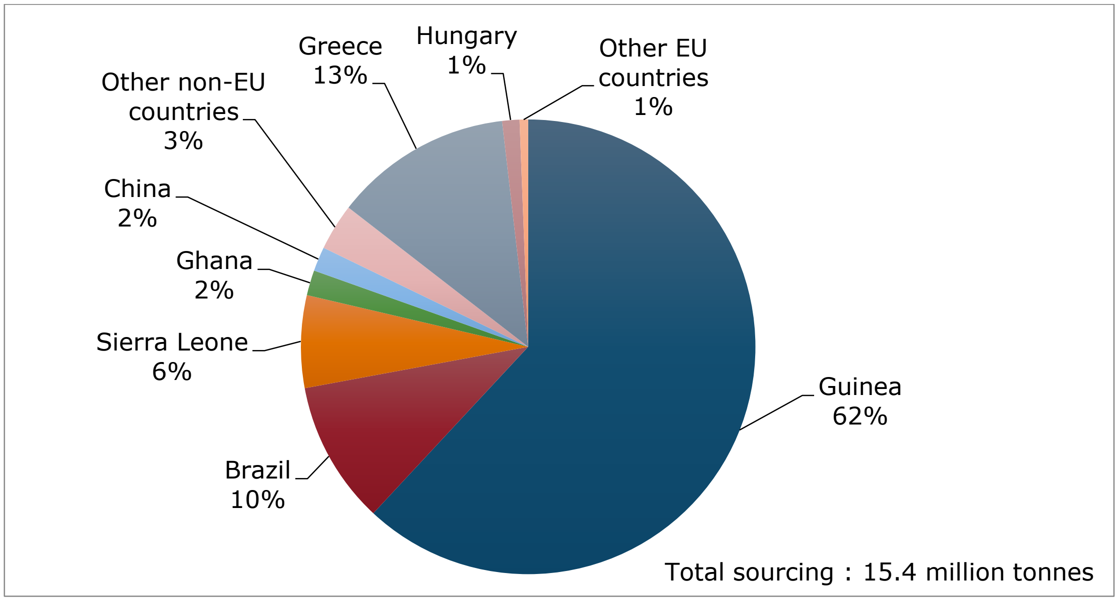


Figure 18: EU sourcing (domestic production + imports) of aluminium ores and concentrates, average 2010-2014. (Data from Comext Eurostat, 2016a; BGS, 2016)

Primary aluminium metal was smelted in 11 EU-28 countries in 2010-2014 (albeit the smelting facility in Italy closed in 2012) with production levels varying between 454 thousand tonnes in Germany and 73 thousand tonnes in Slovenia. Again these figures are relatively small when compared to the global total of nearly 47 million tonnes per year, or compared to the largest producing country: China (more than 21 million tonnes per year). Again these figures are averaged over 2010–2014 data.

In addition to the total EU-28 production of just over 2.2 million tonnes per year, a further 3.9 million tonnes per year were imported into the EU-28. Of these imports, 39% go to the Netherlands, with another 13% imported by Italy, 9% by Germany and 7% by Belgium. The import reliance is 64% for aluminium metal. Figure 19 presents the EU sourcing (domestic production + imports) of aluminium metal.

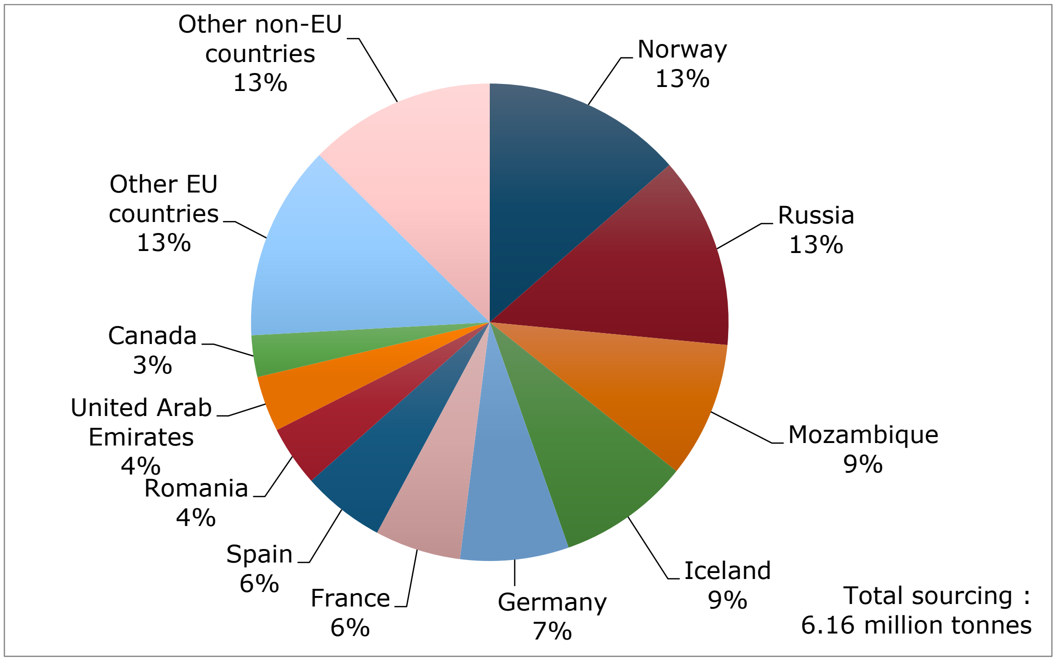


Figure 19: EU sourcing (domestic production + imports) of unwrought aluminium not alloyed and unwrought aluminium alloys, average 2010-2014. (Data from Comext - Eurostat, 2016a; BGS, 2016)

2.3 Demand

2.3.1 EU consumption

During the criticality assessment, EU-28 apparent consumption of bauxite was calculated as 15,297,462 tonnes per year. Of this 2,129,577 tonnes per year came from within the EU (calculated as EU production – exports to non-EU countries) with the remaining 13,167,885 tonnes imported from outside the EU-28. Based on these figures it is not surprising that import reliance is high at 85%.

For primary aluminium metal, the EU-28 apparent consumption was calculated as 6,122,551 tonnes per year and of this 2,186,063 tonnes came from within the EU (again calculated as EU production – exports to non-EU countries). The remaining 3,936,488 tonnes were imported from outside the EU-28 resulting in an import reliance of 64%.

2.3.2 Applications / end uses

The main categories of end uses for bauxite are shown in Figure 20 and for primary aluminium metal in Figure 21.

As already described, the majority of bauxite mined worldwide is used for the production of alumina and thereafter aluminium. Non-metallurgical uses of bauxite are in refractories, cement, abrasives and some chemicals. Refractory materials retain strength at high temperatures and are consequently used for the linings of furnaces, kilns or incinerators or to manufacture crucibles and moulds for casting metals or glass. The majority of refractories are used in the iron and steel industry. Bauxite is also used in the manufacture of high-alumina cement which has a different chemical composition to that of ordinary Portland cement and as a consequence is used for different purposes. These are principally the casting of monolithic refractories or where rapid strength and/or resistances to certain types of corrosion are required.

As an abrasive, calcined bauxite is primarily used for grinding. The chemical uses of bauxite include the production of aluminium sulphate (used as a flocculating agent in water or effluent treatment), aluminium chloride, and aluminium fluoride or sodium aluminate. This category of uses also includes other minor uses such as bauxite's use as a proppant, welding flux, slag adjuster and in road surfacing.

Aluminium has a very wide range of end uses and there is insufficient space in this factsheet to list them all. The following paragraphs provide some examples, for more detail the following website is recommended: http://www.aluminiumleader.com/

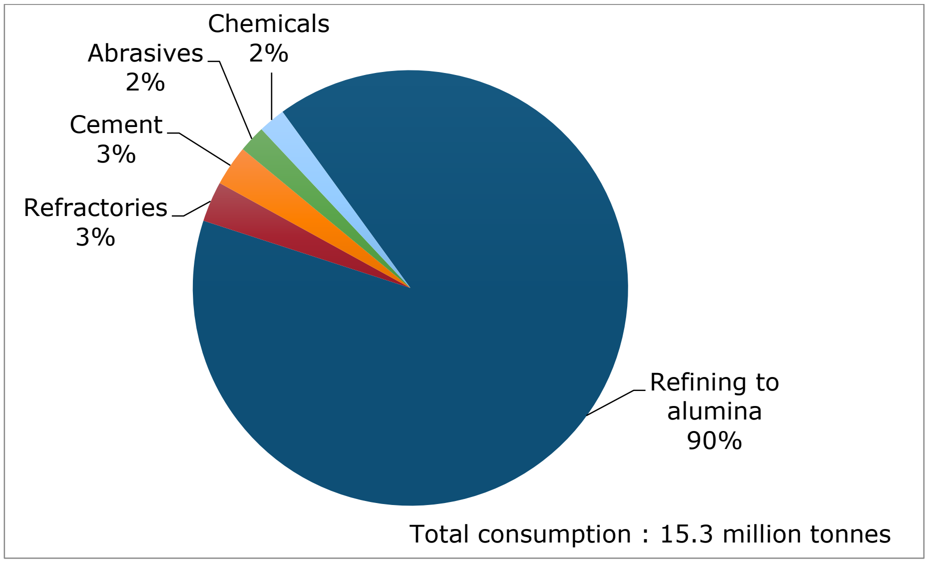


Figure 20: Global end uses of bauxite. (Data from International Aluminium Association and literature, 2016)

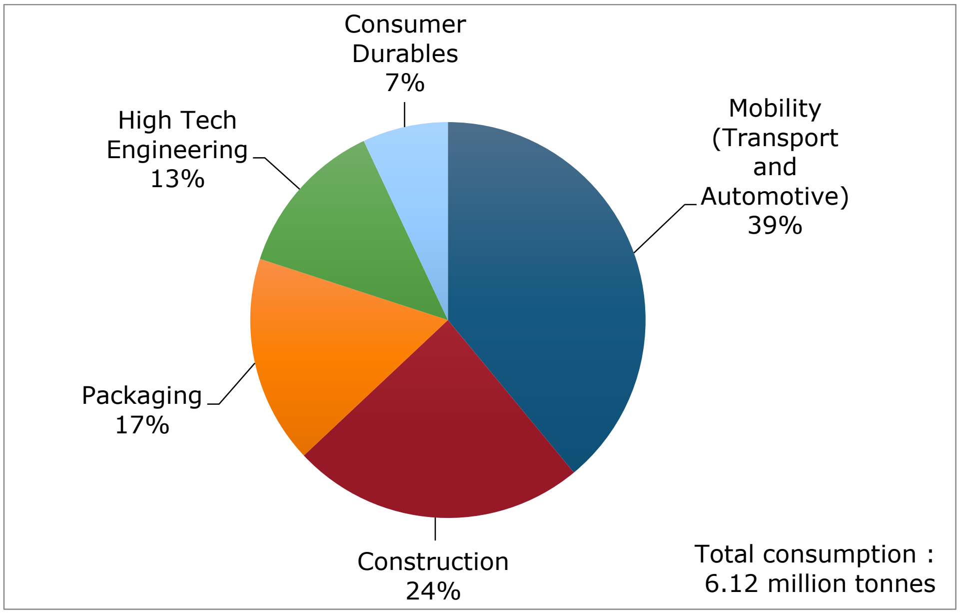


Figure 21: European end uses of aluminium. (Data from European Aluminium Association, 2016)

The largest sector shown in Figure 21 includes all types of vehicles: cars, buses, trains, aircraft, ships, spacecraft, bicycles, etc. Within a car, aluminium is sometimes used for body panels, but it is also used for engine blocks, transmission housings, wheels, radiators, cylinder heads, heat exchangers, pistons, etc. Although aluminium often represents less than 10% of the total quantity of materials utilised in a car, its use can significantly reduce weight with consequent improvements in fuel consumption and carbon emissions. A second example of this sector is the use of aluminium in aircraft where its lightness, workability and strength make it an ideal material. Some of the most common aircraft models in the world today are 70–80% aluminium. Relevant industry sectors are described using the NACE sector codes in Table 5 and Table 6.

Table 5: Aluminium applications, 2 digit and examples of associated 4-digit NACE sectors and the value added of those sectors (Eurostat, 2016c)

Applications for primary aluminium	2-digit NACE sector	Value added of NACE 2 sector (M€)	Examples of 4-digit NACE sector(s)
Mobility (Transport and Automotive)	Both C29 – Manufacture of motor vehicles, trailers and semi-trailers AND C30 – Manufacture of other transport equipment	158,081 AND 53,645	C2910 – Manufacture of motor vehicles; C2920 Manufacture of bodies for motor vehicles; C2932 – Other parts for motor vehicles; C3030 – Manufacture of air and spacecraft; C3011 – Building of ships and floating structures; C3020 – Manufacture of railway locomotives and rolling stock; C3092 – Manufacture of bicycles
Construction	C25 – Manufacture of fabricated metal products, except machinery and equipment	159,513	C2511 – Manufacture of metal structures and parts of structures; C2512 – Manufacture of doors and windows of metal; C2599 – Manufacture of other fabricated metal products n.e.c.
Packaging	C25 – Manufacture of fabricated metal products, except machinery and equipment	159,513	C2592 – Manufacture of light metal packaging
High Tech Engineering	C28 – Manufacture of machinery and equipment not elsewhere specified	191,000	C2811 – Manufacture of engines; C2812 – Manufacture of fluid power equipment; also probably C2453 – Casting of light metals; C2529 – Manufacture of tanks, reservoirs and containers of metal; C2732 – Manufacture of other electronic and electrical wires and cables
Consumer Durables	C28 – Manufacture of machinery and equipment not elsewhere specified	191,000	C2893 – Manufacture of machinery for food processing; C2571 – Manufacture of cutlery; C2751 – Manufacture of electric domestic appliances

Table 6: Bauxite applications, 2 digit and examples of associated 4-digit NACE sectors and the value added of those sectors (Eurostat, 2016c)

Applications for bauxite	2-digit NACE sector	Value added of NACE 2 sector (millions€)	Examples of 4-digit NACE sector(s)
Refining to alumina	C24 – Manufacture of basic metals	57,000	C2442 – Aluminium production
Refractories	C23 – Manufacture of other non-metallic mineral products	59,166	C2320 – Manufacture of refractory products
Cement	C23 – Manufacture of other non-metallic mineral products	59,166	C2351 – Manufacture of cement
Abrasives	C23 – Manufacture of other non-metallic mineral products	59,166	C2391 – Production of abrasive products
Chemicals	C20 – Manufacture of chemicals and chemical products	110,000	C2013 – Manufacture of other inorganic basic chemicals

Within the construction sector, aluminium is used for doors, windows, cladding, roofing, staircases, air conditioning units, solar protection, parts of internal walls and other components. Aluminium retains its useful properties for long periods of time which means it is very useful for architects in designing buildings. The fact that it has strength despite being light in weight means that it is essential in the construction of skyscrapers.

Aluminium is one of the most versatile forms of packaging available. Most people are familiar with the aluminium beverage can but aluminium is also used in foil, food boxes and trays. Its workability means that it can be formed into almost any shape, it protects food or drink against damage from light, liquid, temperature or bacteria and it is non-toxic.

High tech engineering includes mechanical engineering or precision mechanics applications such as pistons, cylinder blocks, pulleys, guide rails, optical equipment, pneumatic cylinders, measuring instruments, etc. and also electrical and heat transfer engineering such as overhead power cables, ladders, cable sheathing, heat exchangers, busbars (electrical conductors), cooling fins, etc.

Consumer durables includes cooking utensils, watches, the outer casing of some types of equipment (e.g. photographic equipment, smart phones, tablet computers, etc.), electrical appliances, LED lighting, paints, alloys for some coins, cookers, boilers, sports equipment mirrors and reflectors, etc. The use of aluminium is widespread because of its many useful properties, for example aluminium utensils are easy to wash, corrosion resistant, not easily damaged and the material is a good heat conductor allowing heat to spread evenly through a cooking pan. It is also lightweight which means it is useful in cycling, climbing or ski-ing equipment and brushed aluminium is increasingly being used by designers for its aesthetic qualities.

2.3.3 Prices

Bauxite is mainly traded under long-term contracts and the prices for these are not normally published.

Aluminium is quoted on the London Metal Exchange and these figures are reported by a wide range of trade journals. These are compiled from the base metal trading conducted by the exchange and therefore the prices vary depending on the contract type. Prices (cash contracts) for primary aluminium have been over US$3,000 per tonne (e.g. in early 2008) or under US$1,500 per tonne (e.g. in early 2009) (see Figure 22). Despite a recent increase in 2016, prices are still generally lower than they were prior to the middle of 2015.

According to the DERA raw materials price monitor and the LMB Bulletin, aluminium (LME, high grade primary) prices have decreased since 2015 as it cost 1,957 US$/t in average on the period 2011-2015 but only 1,584 US$/t in average on the period December 2015 - November 2016, i.e. a price drop of 19.1%. Aluminium oxide prices have also decreased by 36% from the period 2011-2015 (948 € per tonne) vs 2015-2016 (605 € per tonne).

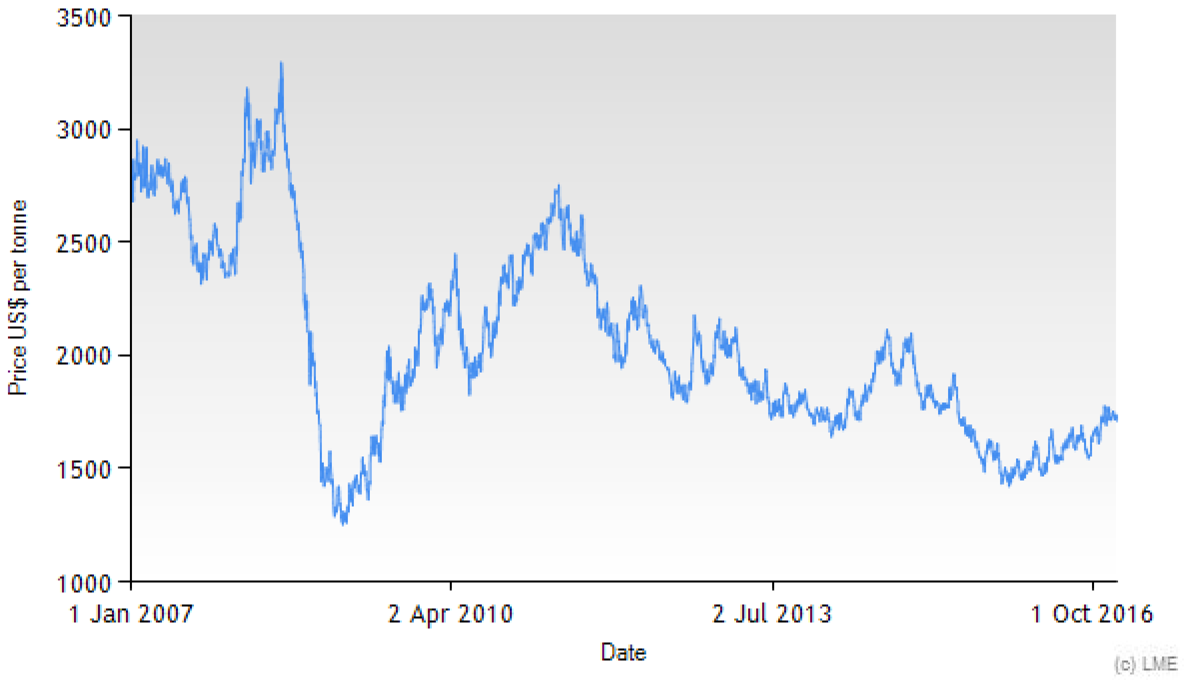


Figure 22: Monthly average cash price for primary aluminium in US$ per tonne (data from LME, 2017)

2.4 Substitution

Substitution has been included in this review of the criticality assessment in a completely new way. Each application has been considered in turn with both product to product and material to material substitute included in the assessment. Consideration has been given to the cost and performance of each potential substitute in each application, relative to that of the material in question, together with the level of production, whether or not the substitute was previously considered to be ‘critical’ and whether the potential substitute is produced as a by-, co- or main product.

Specific data relating to all of these criteria are often difficult to find and a number of assumptions have had to be made to complete the calculations. Consequently a significant degree of uncertainty is associated with the results. The level of precision shown for the Substitution Indices does not fully reflect this uncertainty.

Not all of the materials listed can be substitutes in each of the detailed applications within a category or sector.

For bauxite there are almost no substitutes that are commercially in use. Russia is believed to extract aluminium oxide (alumina) from nepheline raw materials but in all other cases alumina is refined from bauxite. Substitutes for other applications were not considered as their application shares were less than 10% each. Whilst it is theoretically possible to extract alumina from anorthosite, certain types of clay materials and coal fly ash, no evidence was found to suggest that these are currently being carried out on a commercial scale.

For aluminium a variety of substitutes were considered. For the mobility application, composites such as carbon-fibre reinforced plastic have been successfully used for many applications including in cars and the latest aircraft but the cost currently is considered to be considerably greater than aluminium. Steel, magnesium and titanium are also possible substitutes in this sector with steel being the only one of these were costs are similar to aluminium. However, steel is heavier than aluminium and consequently for certain applications the performance could be considered to be lower than aluminium.

In the construction sector, steel, plastics (such as PVC or vinyl) and wood were considered as possible substitutes. In all cases the cost and performance were considered to be similar to aluminium. For packaging, glass, plastics and steel are potential substitutes for aluminium and again for all of these the costs and performance were considered to be similar.

In the high tech engineering application, copper is a potential substitute but the current costs of copper are much greater than aluminium. Cast iron and cast steel may also be substitutes in certain applications at similar cost and performance to aluminium. Potential substitutes for consumer durables were not considered as this application sector is less than 10% of aluminium demand.

2.5 Discussion of the criticality assessment

2.5.1 Data sources

Production data were taken from the British Geological Survey’s World Mineral Statistics dataset (as published in BGS, 2016). Trade data was extracted from the Eurostat COMEXT online database (Eurostat, 2016) and used the Combined Nomenclature (CN) codes 2606 0000 ‘aluminium ores and concentrates’ for bauxite and for aluminium 7601 1000 ‘aluminium, not alloyed, unwrought’ and 7601 2010 ‘unwrought, primary aluminium alloys’. These data were averaged over the five-year period 2010 to 2014 inclusive. Other data sources have been mentioned elsewhere in this factsheet and are listed in section 2.7.

2.5.2 Calculation of economic importance and supply risk indicators

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 5 and Table 6).

. For information relating to the application share of each category, see section on applications and end-uses. The figures for value added were the most recently available at the time of the assessment, i.e. 2013, and are expressed in thousands of Euros.

The calculation of the SR was carried out for bauxite at the ‘ores and concentrates’ stage of the life cycle, and for primary aluminium at the ‘refined material’ stage of the life cycle, in both cases using both the global HHI and EU-28 HHI calculation as prescribed in the methodology.

2.5.3 Comparison with previous EU criticality 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 are not directly comparable.

The results of this review and earlier assessments are shown in Table 7.

Table 7: Economic importance and supply risk results for aluminium and bauxite in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

Assessment	2011		2014		2017	
Indicator	EI	SR	EI	SR	EI	SR
Bauxite	9.5	0.3	8.55	0.57	2.6	2.0
Primary aluminium	8.9	0.2	7.57	0.43	6.5	0.5

Although it appears that the economic importance of bauxite 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 refining to alumina (and then to aluminium) application was listed as "metals" which had a value added of 164,600 thousand Euros. In the 2017 criticality assessment, the 2-digit NACE sector identified as the most appropriate for this sector was "manufacture of basic metals" which has a lower value added of 57,000 thousand Euros. If the 'megasector' was used instead of the 2-digit NACE sector then the EI indicator would have been similar to 2014 rather than the decrease suggested in Table 7. This illustrates exactly why a direct comparison between this review and the previous assessments should not be made.

2.6 Other considerations

No assessment has been made of the criticality of the intermediate stage between bauxite and primary aluminium, namely the production of alumina.

The calculation of economic importance for aluminium is not straightforward due to its wide ranging and varied end-uses. Hence for the mobility application sector two 2-digit NACE sectors have been applied and the calculation formula adjusted to accommodate this. In reality there are other 2-digit NACE sectors that may include some aluminium which have not been incorporated into the assessment.

Table 8: Qualitative forecast of supply and demand of aluminium and bauxite

Manterial	**Criticality of the material in 2017**		**Demand forecast**			**Supply forecast**		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Aluminium (bauxite)		x	+	+	+	+	+	+
Aluminium (metal)		x	+	+	+	+	+	+

The supply and demand of both aluminium metal and bauxite is expected to grow in the future (see Table 8).

2.7 Data sources

2.7.1 Data sources used in the factsheet

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. (2016) International trade in goods database (COMEXT) [online]. http://ec.europa.eu/eurostat/data/database

European Aluminium Statistics (2016) EU aluminium imports dependency. [online] Available at: http://www.european-aluminium.eu/data/economic-data/eu-aluminium-imports-dependency/

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 (2016)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

Gow, N.N. and Lozej, G.P. (1993) Bauxite. Geoscience Canada, Volume 20, Number 1. Available at: https://journals.lib.unb.ca/index.php/GC/article/viewFile/3785/4299

Hill, V.G. and Sehnke, E.D. (2006) Bauxite. *In* Kogel, J.E., Trivedi, N.C., Barker, J.M. and Krukowski, S.T. (Eds). Industrial Minerals and Rocks, Commodities, Markets and Uses. 7th Edition. Society for Mining, Metallurgy and Exploration Inc., Colorado, USA. pp.227–261

International Aluminium Institute (2015) Aluminium Recyclability and Recycling, Towards Sustainable Cities. Cwningen Press. Figure 2.28, P.41. http://www.world-aluminium.org/publications/

International Aluminium Institute (2016a) Mining process. http://bauxite.world-aluminium.org/mining/process.html

International Aluminium Institute (2016b) Refining process. http://bauxite.world-aluminium.org/refining/process.html

International Aluminium Institute (2016c) Reduction. http://primary.world-aluminium.org/index.php?id=286&L=0

International Aluminium Institute (2016d) Recycling transforms products and societies. http://recycling.world-aluminium.org/home.html

London Metal Exchange (2017). Aluminium pricing. https://www.lme.com/metals/non-ferrous/aluminium/#tab2

Minerals4EU (2015) European Mineral Yearbook – Data for bauxite, alumina and aluminium [online]. http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

United Nations Environment Programme. (2011) Recycling Rates of Metals A Status Report. p.44. http://www.unep.org/resourcepanel/Portals/50244/publications/UNEP_report2_Recycling_130920.pdf

USGS (2016). Bauxite and Alumina Mineral Commodity Summary. https://minerals.usgs.gov/minerals/pubs/commodity/bauxite/

2.7.2 Data sources used in the criticality assessment

For Bauxite:

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

European Commission. (2016) EU trade agreements webpage [online]. Directorate General for Trade. http://ec.europa.eu/trade/policy/countries-and-regions/agreements/index_en.htm

Eurostat. (2016) International trade in goods database (COMEXT) [online]. http://ec.europa.eu/eurostat/data/database

Hill, V.G. and Sehnke, E.D. (2006) Bauxite. *In* Kogel, J.E., Trivedi, N.C., Barker, J.M. and Krukowski, S.T. (Eds). Industrial Minerals and Rocks, Commodities, Markets and Uses. 7th Edition. Society for Mining, Metallurgy and Exploration Inc., Colorado, USA. pp. 227–261

International Aluminium Institute (2016a) Mining process. http://bauxite.world-aluminium.org/mining/process.html

Jenson, F. (2015). Indonesia seeks legal route for bauxite miners to resume exports. Reuters, Tuesday 16 June 2015, http://www.reuters.com/article/indonesia-bauxite-idUSL3N0Z22F320150616

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

Parbat, R.N. (2014) 20% Export duty of bauxite in India, its impact on the industry. Al Circle, 30 July 2014.

Smirnov, V. (1996). Alumina Production in Russia Part 1: Historical Background. JOM 48(8) pp. 24–26. http://www.tms.org/pubs/journals/jom/9608/smirnov-9608.html

For Primary aluminium:

Association of Plastic Manufacturers (2016) Building and Construction. http://www.plasticseurope.org/use-of-plastics/building-construction.aspx

BGS (2016). World Mineral Production 2010-2014 [online]. Keyworth, Nottingham British Geological Survey, Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.html

Electrical Engineering Portal. (2016). Copper or Aluminium? Which one to use and when? http://electrical-engineering-portal.com/copper-or-aluminium

European Aluminium Association. (2015) Activity Report 2014. http://www.european-aluminium.eu/annual-report/

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

European Commission. (2016) EU trade agreements webpage [online]. Directorate General for Trade. http://ec.europa.eu/trade/policy/countries-and-regions/agreements/index_en.htm

Eurostat. (2016) International trade in goods database (COMEXT) [online]. http://ec.europa.eu/eurostat/data/database

Glass Alliance Europe. (2016). Industries. http://www.glassallianceeurope.eu/en/industries

Institute of Food Technologists. (2016) Food packaging – roles, materials and environmental issues. http://www.ift.org/knowledge-center/read-ift-publications/science-reports/scientific-status-summaries/food-packaging.aspx

International Aluminium Association (2013). Transport and Aluminium. http://www.world-aluminium.org/media/filer_public/2013/01/15/fl0000172.pdf

London Metal Exchange (2016). Aluminium pricing. http://www.lme.com/metals/non-ferrous/aluminium/

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

Shama Rao, N., Simha, T.G.A., Rao, K.P. and Ravi Kumar, G.V.V. (2015) Whitepaper: Carbon composites are becoming competitive and cost effective. Infosys, https://www.infosys.com/engineering-services/white-papers/Documents/carbon-composites-cost-effective.pdf

UNECE Forests (2016) Forest Products Statistics. Forestry and Timber Section, UNECE Forests, land and Housing Division, United Nations. http://www.unece.org/fileadmin/DAM/timber/statsdata/fps10-14.pdf

Wood Technology Society. (2016). http://www.iom3.org/wood-technology-society

Zuliani, D.J. and Reeson, D. (2012) Making magnesium a more cost and environmentally competitive option. http://www.gossan.ca/pdfs/Conference9MagALLOY-Paper-Vancouver-July2012.pdf

2.8 Acknowledgments

This Factsheet was prepared by the British Geological Survey (BGS). The authors would like to thank B. Forriere of Groupe Renault, G.A. Blengini of JRC, the members of 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

Key facts and figures

Material name and formula	Bentonite, variable	World/EU production (million tonnes)[1]	19,6/ 3
Parent group (where applicable)	N/A	EU import reliance[1]	14%
Life cycle stage / material assessed	Mine production/ Bentonite (crude)	Substitution index for supply risk [SI (SR)][1]	0.89
Economic importance score EI(2017)	2.1	Substitution Index for economic importance [SI(EI)][1]	0.89
Supply risk SR (2017)	0.3	End of life recycling input rate[2]	50%
Abiotic or biotic	Abiotic	Major end uses in EU[1]	Pet litter (36%), Foundry molding sand (27%), Civil engineering (12%)
Main product, co-product or by-product	Main product	Major world producers[1]	United States (34%), China (18%), India (6%)
Criticality results	2011	2014	2017 (current)
	Not critical	Not critical	Not critical

[1] average for 2010-2014, unless otherwise stated; [2] This is not the recycling input rate of bentonite, but the EOL Recycling rate of all major applications that bentonite finds use

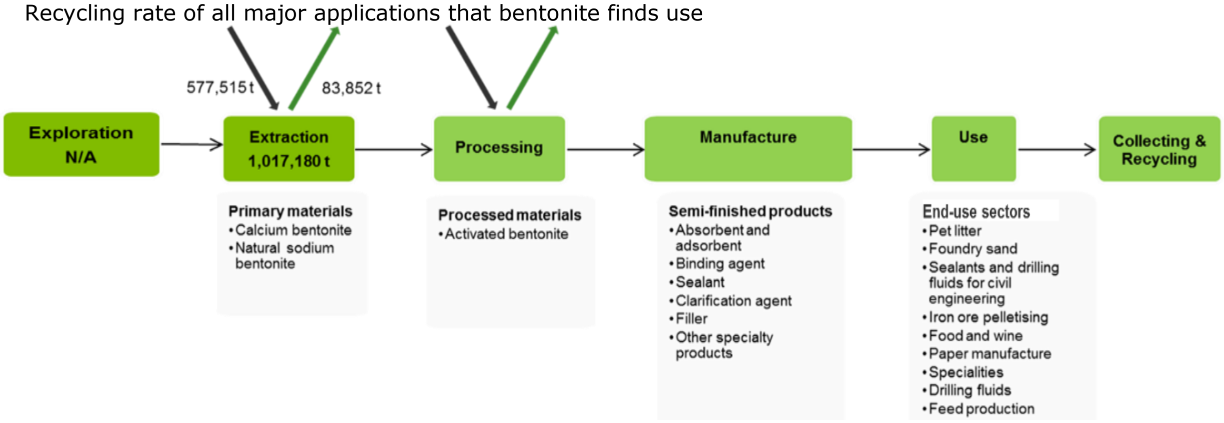


Figure 23: Simplified value chain for bentonite

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU. A quantitative figure on recycling is not included as the EOL-RIR is below 70%. EU reserves are displayed in the exploration box.

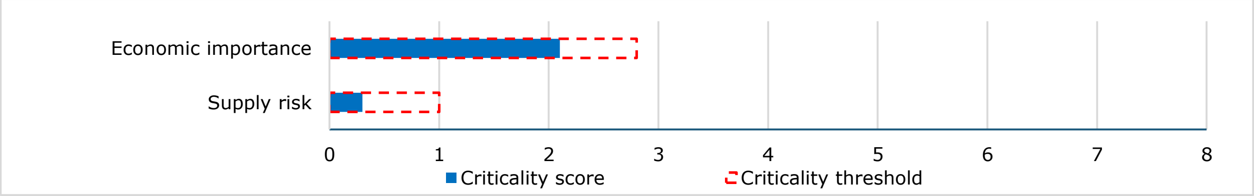


Figure 24: Economic importance and supply risk scores for bentonite

3.1 Introduction

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 from sub-aqueous alteration of fine-grained volcanic ash or from 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 dominant two different types of bentonite are the 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.

Europe is an important global supplier of bentonite. Approximately 15% of the global production is European.

3.2 Supply

3.2.1 Supply from primary materials

3.2.1.1 Geological occurrence

Bentonite is a soft clay or claystone composed primarily by smectite clay minerals. The name bentonite is derived from the Cretaceous Bento Group rocks in eastern Wyoming, USA. Bentonite deposits tend to be large, shallow dipping with greater lateral extend rather than vertical extend (Scogings, 2016).

Bentonite deposits are formed under the following settings (Pohl, 2011):

- Alteration of volcanic ash under alkaline conditions, by reaction with seawater. The Wyoming bentonite, Milos (Greece) bentonite and fuller’s earth in England are typical examples of this formation.
- Hydrothermal (alkaline) alteration by seawater convention at half submerged volcanoes. Milos (Greece) comprises a typical example.
- Weathering of basic tuff, basalt and ultramafic rocks forming smectite-rich soils.
- Smectitic clay as a marine or lake sediment.

High quality bentonite deposits are geologically young. For instance, Tertiary and Quaternary tuffs host the large bentonite deposits of the Aegean island of Milos, Greece.

3.2.1.2 Mining and processing

Bentonite is produced in open pits and it can be used in a raw form following little processing or activated. Following extraction, bentonite is stockpiled, crushed, dried to reach a desirable moisture content, ground and classified to produce a range of products. Activation may take place using soda ash. Depending on the end application, bentonite may be sieved to a granular form or milled into a fine or superfine powder. For special applications, the removal of gangue minerals may be required to produce a pure form, or activation with acids to produce acid activated bentonite or treatment with organics to produce organoclays (IMA Europe, 2016a; Pohl, 2011).

3.2.1.3 Resources and reserves

There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of bentonite 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[2], 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.

For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for bentonite. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for bentonite, 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 bentonite at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU, 2015).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 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.

3.2.1.4 World mine production

World mine production of bentonite is summarized in Figure 25. The United States (6.7 million tonnes), China (3.5 million tonnes), India (1.2 million tonnes) and Greece (1.1 million tonnes) are the major producing countries. Production from the United States and China accounts for 50-60% of the overall supply, equal to approximately 10 million tonnes per annum. Production of bentonite takes place in several other countries in a much smaller scale. In Europe, Greece in the largest producer but Spain (4% of global production), Germany (2%), Cyprus (1%), the Czech Republic (1%) and Slovakia (1%) are also important producers. Overall 14 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 additional 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).

---

[2] www.crirsco.com

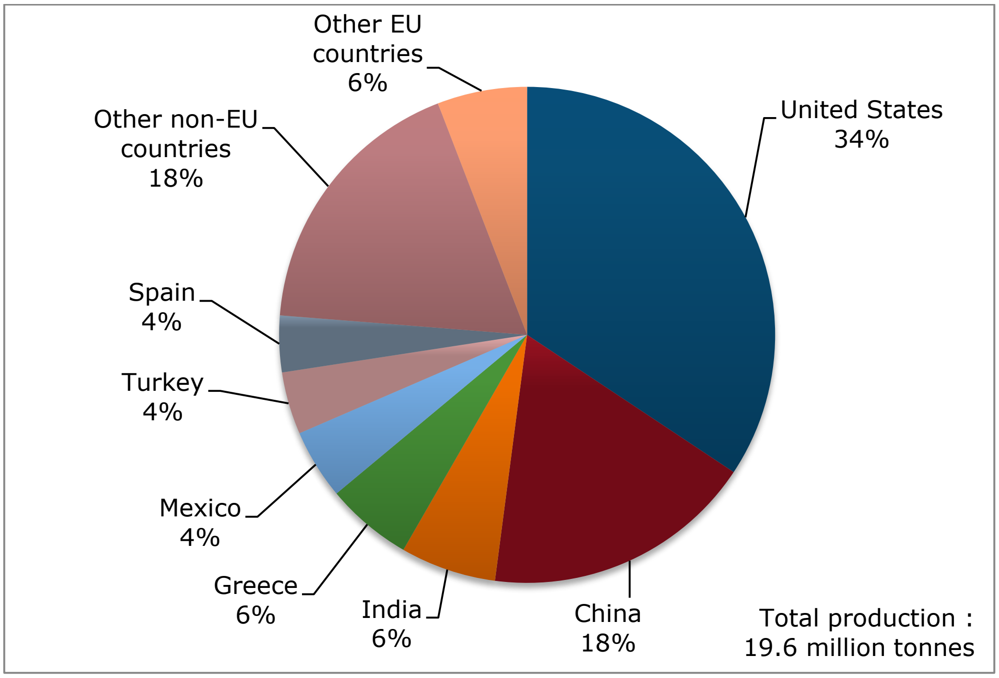


Figure 25: Global mine production of bentonite, average 2010–2014 (Data from BGS World Mineral Statistics database)

3.2.2 Supply from secondary materials

Bentonite is not commonly recovered from waste and therefore there is no availability of bentonite from secondary sources.

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 foundry sands is commonly recycled. The average European recycling rate for foundry sand recycling reported by literature is estimated at 80%. 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. Bentonite used in paper making is not recovered. During the incineration of waste paper, bentonite ends up in the fly ash which is often used by other industries, such as the wall board industry or in agriculture (IMA Europe, 2013). The EoL-RIR of bentonite used is 50% (IMA Europe, 2013).

3.2.3 Trade

3.2.3.1 EU trade

Europe is a net importer of bentonite with an average net import figure from extra-EU28 countries in the period 2010-2014 of 494 thousand tonnes (Figure 26). Europe produced between 2010 and 2014 approximately 3 million tonnes of bentonite per annum, therefore Europe’s import reliance is not high. Europe exports on average 84 thousand tonnes of bentonite per annum (2010-2014 average), which suggest that the majority of the domestic production is consumed within Europe. Imports of bentonite to Europe are primarily from Turkey, India and Morocco (Figure 27). European bentonite is exported in numerous countries, but Russia (12%), Norway (10%) and Israel (7%) are the three major importing countries.

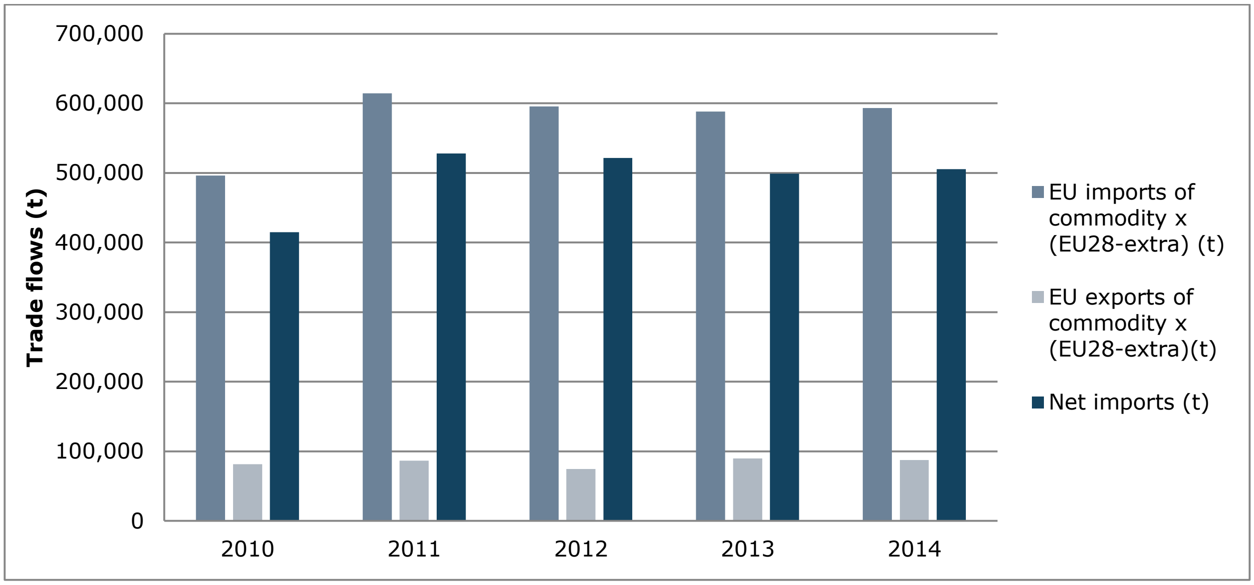


Figure 26: EU trade flows for bentonite (Data from (Eurostat, 2016a))

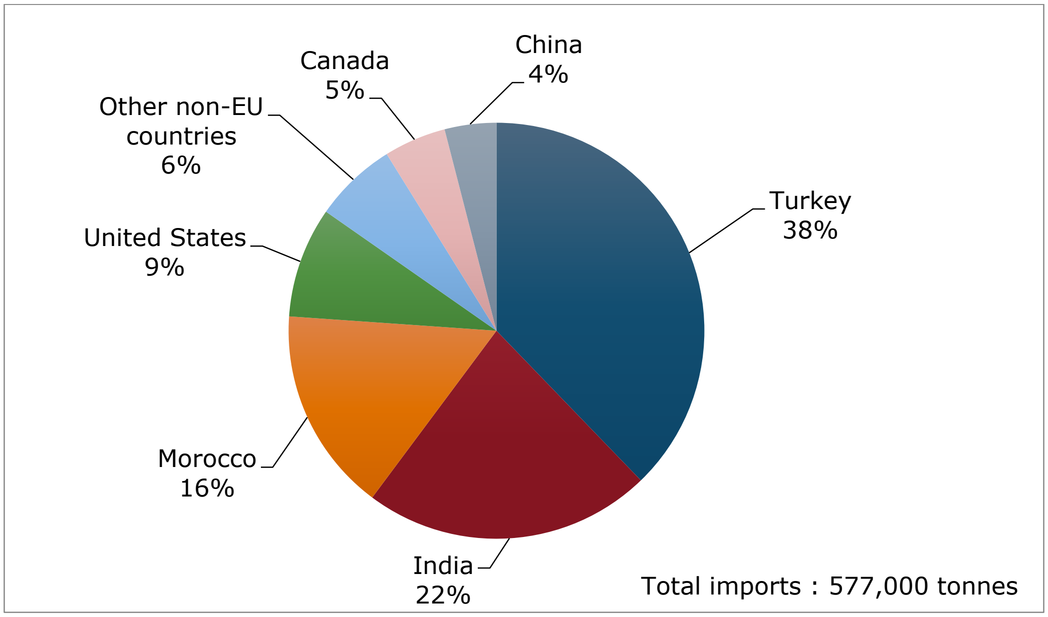


Figure 27: EU imports of bentonite, average 2010-2014. (Data from Eurostat, 2016a)

3.2.3.2 Global trade

Leading global importers of bentonite in the period 2010 and 2014 were Canada (10% of global imports), Germany (10% of global imports) and the Netherlands (5% of global imports). Leading global exporters in the same period included India (24%), USA (24%) and Turkey (9%) (UN Statistics, 2017).

3.2.4 EU supply chain

The 5 years average European production of bentonite between 2010 and 2014 was 3 million tonnes per year, which accounts for 15% of the global production. Main producing countries include Greece, Spain, Germany, Slovakia, Czech Republic and Cyprus [based on data from: (BGS, 2016)]. Europe is a net importer of bentonite and the primary sources of bentonite to Europe from extra-EU28 countries are Turkey, India and Morocco. The import reliance of bentonite in EU-28 is estimated to be 14%. The EU sourcing (domestic production + imports) of bentonite is shown in Figure 28. The only export restriction to Europe is from Morocco, where an export tax of 2.5 % applies since 1997.

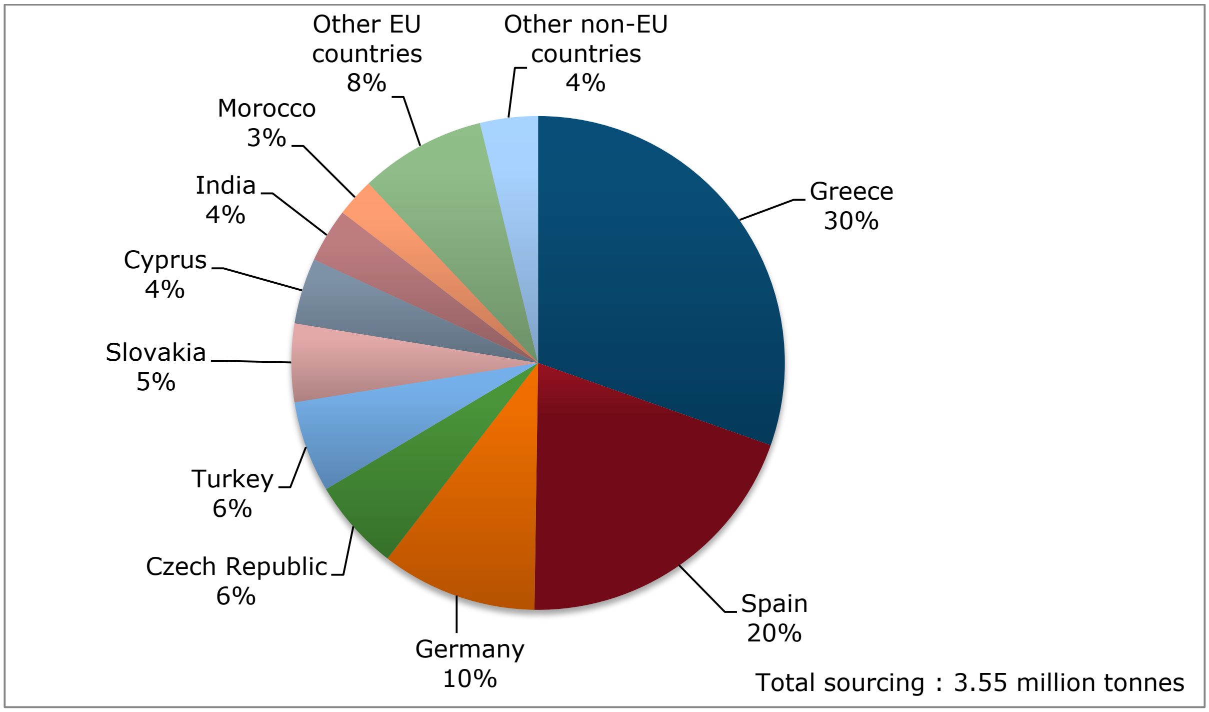


Figure 28: EU sourcing (domestic production + imports) of bentonite, average 2010-2014. (Data from Eurostat, 2016a; BGS, 2016)

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

Bentonite is not recovered during waste management and therefore it is not available from secondary sources.

3.3 Demand

3.3.1 EU consumption

The European apparent consumption in the period 2010 and 2014 (5 year average figure) is estimated at 3.5 million tonnes per year, of which 3 million tonnes per annum is the domestic production, 577 thousand tonnes per annum is the imports to the EU from extra EU-28 countries and 84 thousand tonnes per annum is the exports from the EU to extra EU-28 countries in the same period (5 year average figures). The above figures suggest that the majority of the domestic production is consumed within Europe and it can sufficiently satisfy the EU industry demand for bentonite, without major import reliance issues.

3.3.2 Global consumption

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

3.3.3 Applications / end uses

Bentonite is often named as the 'mineral of thousand uses' and it finds application in a diverse range of markets including pet litter, in 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 29. Relevant industry sectors are described using the NACE sector codes included in
Table 9.

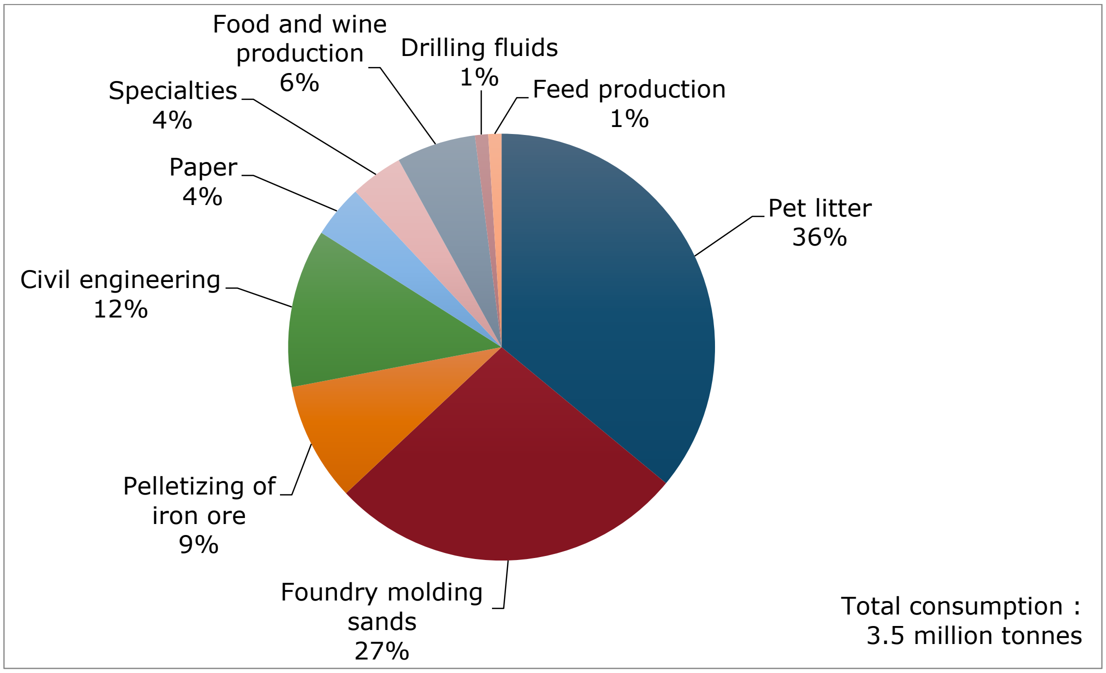


Figure 29: EU end uses of bentonite. Average figures for 2010-2014. (Data from Industrial Minerals Association (IMA-Europe), 2016)

In Europe, the pet litter market presents the greatest share and 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, 2016a). Several additional applications exist, but the ones mentioned in the figure above represent the key ones for the European market.

Table 9: Bentonite, 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2016c)

Applications	2-digit NACE sector	Value added of NACE 2 sector (millions €)	4-digit NACE sectors
Pet litter	C23 - Manufacture of other non-metallic mineral products	59,166.0	C2399 - Manufacture of other non-metallic mineral products n.e.c.
Foundry molding sands	C24 - Manufacture of basic metals	57,000.0	C2452 - Casting of steel
Pelletising iron ore	C24 - Manufacture of basic metals	57,000.0	C2451 - Casting of iron
Civil engineering	B09 - Mining support service activities	6,930.8	B0990 - Support activities for other mining and quarrying
Paper	C17 - Manufacture of paper and paper products	41,281.5	C1712 - Manufacture of paper and paperboard
Specialties	C20 - Manufacture of chemicals and chemical products	110,000.06,930.8	C2030 - Manufacture of paints, varnishes and similar coatings, printing ink and mastics
Food and wine production	C11 - Manufacture of beverages	37,636.4	C1102 Manufacture of wine from grapes
Drilling fluids	B09 - Mining support service activities	6,930.8	B0910 - Support activities for petroleum and natural gas extraction
Feed production	C10 - Manufacture of food products	174,000.0	C1091 - Manufacture of prepared feeds for farm animals

3.3.4 Prices and markets

The price of bentonite depends on its end use and grade and can range from as low as approximately $30 per tonne for cat litter dried crude bentonite to $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).

3.4 Substitution

Substitutes are identified for the applications and end uses of the commodity of interest. In the case of bentonite, substitutes have been identified for the applications of pet litter, foundry moulding sands, pelletising of iron ore and civil engineering uses. 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 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 is attributed to bentonite based products (Hall, 2016). Wood based pet litter comprises wood pellets (.e.g. from pine) and it is 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 comprises a binder. Several alternative binders are available to use, but bentonite is the most popular one and therefore alternatives are used only to satisfy specific needs or functions. Oils, such as linseed oil, other vegetable oils and marine oils may comprise an alternative binder in foundry moulding sands. Organic resins, such as phenolic resin is often used in resin shell sand casting, where good surface smoothness, less casting defects and good dimensional accuracy is a requirement. Phenolic resins however are much more expensive than bentonite. 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 it 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, however, because of its acid constituents (SiO2 and Al2O3) it is considered as a chemical impurity especially for concentrate with high SiO2 content. 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 several civil engineering applications and related products, for example in geosynthetics, in pilling, in the construction of cut-off walls (as a barrier), in excavation and boreholes and others. Polymer support fluids are used as alternatives to bentonite, but it is believed that bentonite support fluids are much more popular (Jefferis and Lam, 2013; Lam and Jefferis 2014).

There are no quantified ‘market sub-shares’ for the identified substitutes of bentonite and the ones uses are based on hypotheses made through expert consultation and literature findings. The literature used to identify substitutes for bentonite is listed in section 3.7.

3.5 Discussion of the criticality assessment

3.5.1 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) (2016)). Production data for bentonite are from World Mineral Statistics dataset published by the British Geological Survey (BGS, 2016). Trade data was extracted from the Eurostat Easy Comext database (Eurostat, 2016a). 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, 2016).

Production data for a limited number of countries also include quantities of other clays similar to bentonite, as shown in Table 10.

Table 10: Information on production data from certain countries used in the assessment

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 2010 to 2014.

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.

Other data sources used in the criticality assessment are listed in section 3.7.

3.5.2 Economic importance and supply risk calculation

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 10). The value added data correspond to 2013 figures.

The supply risk was assessed on bentonite using both the global HHI and the EU-28 HHI as prescribed in the revised methodology.

3.5.3 Comparison with previous EU criticality assessments

A revised methodology was introduced in the 2017 assessment of critical raw materials in Europe. Both the calculations of economic importance and supply risk are now different therefore the results with the previous assessments are not directly comparable.

The results of this review and earlier assessments are shown in Table 11.

Table 11: Economic importance and supply risk results for bentonite in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

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

Although it appears that the economic importance of bentonite has reduced between 2010 and 2017 this is a false impression created by the change in methodology. 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 lower than in the previous years, which is primarily due to the methodological modification and the inclusion of the EU supply flow in the assessment. It is not possible to quantify what proportion of this change is due to the methodology alone, as new data have been used in the assessment.

3.6 Other considerations

3.6.1 Forward look

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 greatly by the status of 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. The building and construction sector is expected to increase, which will result in increased 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, 2013; Scogings, 2016).

Table 12: Qualitative forecast of supply and demand of bentonite

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
Bentonite		x	+	+	?	+	+	?

3.7 Data sources

3.7.1 Data sources used in the factsheet

BGS (2016). World Mineral Production 2010-2014. [online] Keyworth, Nottingham British Geological Survey, Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.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 (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. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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) (2016)a. Bentonite factsheet [online] Available at: http://www.ima-europe.eu/about-industrial-minerals/industrial-minerals-ima-europe/bentonite

Industrial Minerals Association (IMA-Europe) (2016)b. 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%2024.10.2013_0.pdf

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 (2014). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

OECD (2016). 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 (2013). Bentonite. 2013 Minerals Yearbook. [online] Available at: https://minerals.usgs.gov/minerals/pubs/commodity/clays/

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 (2016). World Mineral Production 2010-2014 [online]. Keyworth, Nottingham British Geological Survey, Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.html

Engineered casting solutions (2006). Guide to Casting and Molding Processes. [online] Available at: https://www.afsinc.org/files/methods.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 (2016). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

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

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) (2016). 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%2024.10.2013_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 British Geological Survey (BGS). The authors would like to thank the Industrial Minerals Association, the European Bentonite Association, 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. CHROMIUM

Key facts and figures

Material name and Element symbol	Chromium, Cr	World/EU production[1]	Extraction : 30 Mt / 750 kt Refining : 5.9 Mt / 220 kt
Parent group (where applicable)	N/A	EU import reliance[1]	75%
Life cycle stage/ material assessed	Refined production / ferrochromium	Substitution index for supply risk [SI(SR)][1]	1.00
Economic importance score (EI)(2017)	6.8	Substitution Index for economic importance [SI(EI)][1]	1.00
Supply risk (SR) (2017)	0.9	End of life recycling input rate (EOL-RIR)	21%
Abiotic or biotic	Abiotic	Major end uses in EU[1]	Product made of stainless steel: 74%; Products made of alloy steel: 19%
Main product, co-product or by-product	Main product	Major world producers[1]	*Extraction*: China (33%), South Africa (31%), Kazakhstan (13%) *Refined*: South Africa (48%), Kazakhstan (18%), India (12%), Turkey (11%)
Criticality results	2011	2014	2017
	Not critical	Critical	Not critical

[1] 2010-2014 average, unless otherwise stated.

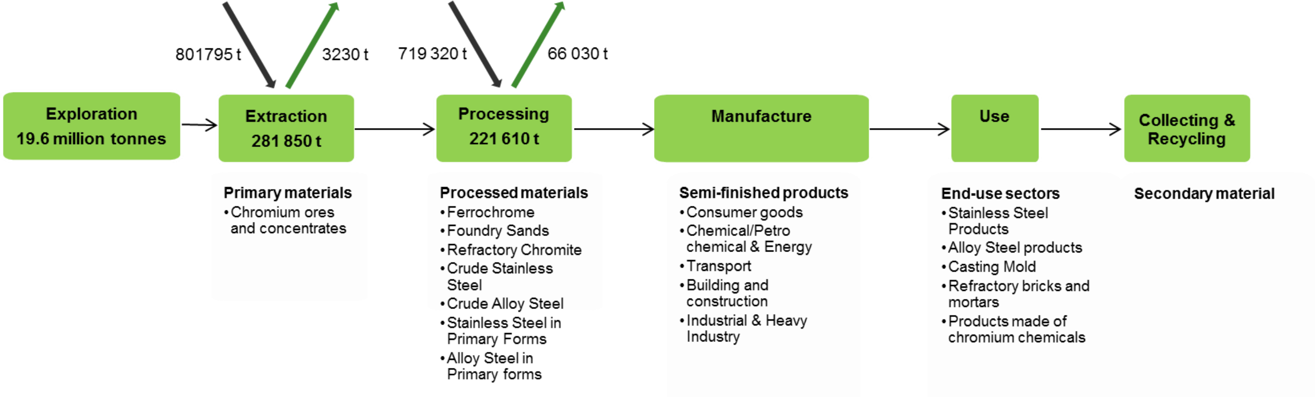


Figure 30: Simplified value chain for chromium

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU. A quantitative figure on recycling is not included as the EOL-RIR is below 70%. EU reserves are displayed in the exploration box.

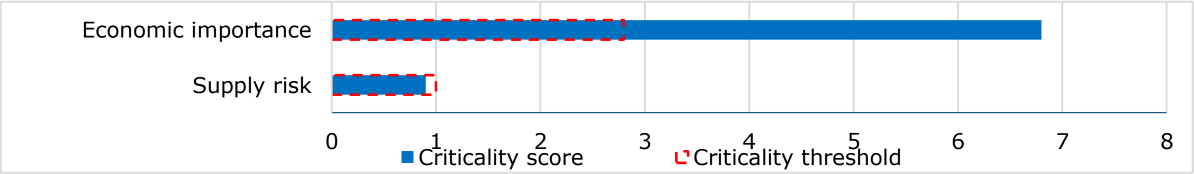


Figure 31: Economic importance and supply risk scores for chromium

4.1 Introduction

Chromium (Cr, atomic number 24) is a silvery-white, corrosion-resistant, hard metal. Chromium is mined as chromite ore. The two main products of chromium ore refining are ferrochromium and metallic chromium. Ferrochromium is an essential component of stainless steel and other alloy steels. Chromium has unique properties which today remain unrivalled for preventing corrosion, providing high strength and resistance, it also makes steel stainless conferring it durable, hygienic and resistance characteristics. While chromium metal and Cr(III) ion are not considered toxic, many hexavalent chromium Cr(VI) compounds are toxic and carcinogenic (Bio Intelligence Service, 2015).

4.2 Supply

4.2.1 Supply from primary materials

4.2.1.1 Geological occurrence and exploration

Chromium is the 22nd most abundant element in Earth's crust with an average concentration of 100 ppm, and an abundance of 92 ppm in the upper crust (Rudnick, 2003). Chromite deposits can be found in ultramafic or certain anorthositic rocks (Motzer, 2004). Within these rocks chromium materializes as chromium spinel which is a mineral with a highly variable chemical composition. The generic formula of chromium spinels is $(Fe,Mg)Cr_2O_4$, a solid solution between chromite ($FeCr_2O_4$) and magnesiochromite ($MgCr_2O_4$). Moreover, the Cr element can also be substituted by Al, forming another solid solution with hercynite ($FeAl_2O_3$), and thus resulting in a decrease of Cr% in the mineral. Large variations in the total and relative amounts of Cr and Fe 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 Cr:Fe ratio which determines the chromium content of the ferrochromium produced (ICDA, 2016c). For a simpler description in the further development, 'chromite' will be used as a general term to describe Cr spinel minerals.

Commercial chromite deposits are found mainly in two forms: stratiform seams in basin-like intrusions, often multiple seams through repeated igneous injections, and the more irregular podiform or lenticular deposits (ICDA, 2016c). The best known example of a stratiform deposit is the Bushveld Igneous Complex of South Africa. This complex contains most of the current world's chromite reserves. The Great Dyke of Zimbabwe, traversing nearly the length of the country, is very similar and has been linked to the Bushveld in geological history. These two features are well-known also for their important and very large commercial deposits of the platinum-group metals (ICDA, 2016c). Other stratiform deposits occur in Madagascar and in the Orissa district of India.

The podiform deposits are relatively small in comparison and may be shaped as pods, lenses, slabs or other irregular shapes. Many have been extensively altered to serpentine and they are often faulted. They are generally richer in chromium than the stratiform deposits and have higher Cr:Fe ratios. Ore reserves in Kazakhstan are of the podiform type (ICDA, 2016c). Podiform ores were originally highly sought after, especially those from the deposits in Zimbabwe, as the best source of metallurgical grade chromite for high-carbon ferrochromium. These ores also tend to be massive (hard lumpy) ores, as opposed to the softer, more friable ores from the stratiform deposits, and this makes for better electric smelting operation.

There is a third type of chromite deposit but of very limited 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, 2016c). Chromium may also be concentrated in high-iron lateritic deposits containing nickel and there have been attempts to smelt these to produce a chromium-nickel pig iron for subsequent use in the stainless steel industry (ICDA, 2016c).

According to the website Minerals4EU, there are some exploration activities in Portugal, Ukraine and Albania, but no more specific information (Minerals4EU, 2016).

4.2.1.2 Resources and reserves

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 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[3], 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.

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, 2015).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.

Current global resources of chromium ore are estimated to be around 12 billion tonnes of shipping grade chromite (containing 45% of Cr_2O_3), equivalent to about 3.7 billion tonnes of chromium content (USGS, 2016). Based on the current level of demand, the world resources should be adequate for centuries. Majority (close to 95%) of the global chromium resources are located in South Africa and Kazakhstan (USGS, 2016).

The EU known resources of chromium are located in Finland in the Kemi mine and amounts 19.6 million tonnes of chromium content (Bio Intelligence Service, 2015). Resource data for some countries in Europe are available in the Minerals4EU website (see Table 13) (Minerals4EU, 2014) but cannot be summed as they are partial and they do not use the same reporting code.

The world known reserves are higher than 480 million tonnes of shipping grade chromite (containing 45% of Cr_2O_3), equivalent to about 148 million tonnes of chromium content. The world main reserves are also located mainly in South Africa and Kazakhstan (USGS, 2016) (see Table 14). The EU known reserves of chromium are located in Finland in the Kemi mine and amounts 50 million tonnes with 26% of chromium content, i.e. about 9

---

[3] www.crirsco.com

million tonnes of chromium (Bio Intelligence Service, 2015). Reserve data for some countries in Europe are available in the Minerals4EU website (see Table 13) but cannot be summed as they are partial and they do not use the same reporting code.

Table 13: Resource data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Quantity	Unit	Grade	Code resource type
Finland	None	127	Mt	22% Cr_2O_3	Historic resource estimate
Sweden	Historic	38.6	Mt	0.43% Cr	Historic resource estimate
Serbia	JORC	0.089	Mt	1.5% Cr	Total
Greece	USGS	2	Mt	35-40% Cr_2O_3	Measured
Albania	Nat. rep. code	48.4	Mt	30-42% Cr_2O_3	Category A

Table 14: Global reserves of commodity Chromium in year 2015 (USGS, 2016)

Country	**Commodity Chromium Reserves** (thousand tonnes of shipping grade chromite)
Kazakhstan	230,000
South Africa	200,000
India	54,000
USA	620
Turkey	NA
Other countries	NA
Total	> 480,000

Table 15: Reserve data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Quantity	Unit	Grade	Code reserve type
Finland	FRB	50.1	Mt	26% Cr_2O_3	Proved
Ukraine	Russian Classification	453,816	t	Cr_2O_3	C2
Turkey	None	25	Mt	Cr_2O_3	-

4.2.1.3 Mining, processing and extractive metallurgy

Mining of chromite deposits is carried out both by open-pit and by underground mining. Underground mining of stratiform deposits is most often required but can be particularly difficult due to the narrow seam thickness (less than 1.5m), weathering close to surface and faulting. Open-pit mining is generally applied to the podiform ores at first but this progresses to underground mining as deeper levels of the deposit are reached. Weathering through serpentinisation and faulting are often encountered (ICDA, 2016c).

Chromium ore is extracted, beneficiated and separated in 4 distinct grades: metallurgical grade (42-46% Cr_2O_3), refractory grade (30-40% Cr_2O_3), foundry sand grade (44-46.5% Cr_2O_3) and chemical grade (40-46.5% Cr_2O_3) (ICDA, 2016b).

The main primary material is metallurgical-grade chromium ore, as 96% of the chromite globally extracted and beneficiated is transformed in metallurgical grade chromium (ICDA, 2016b). Chemical grade represents 2.1% of the chromite extracted, foundry sand grade 1.7% and chemical grade 0.2% (ICDA, 2016b).

The metallurgical grade chromium is processed into ferrochromium by electric arc carbothermic reduction. This process consumes huge amounts of electricity (requiring up to 4,000 kWh per tonne material weight (ICDA, 2016c)). Ferrochromium is an alloy of chromium and iron containing 50% to 70% chromium by weight. Ferrochromium is used, along with scrap, to produce stainless steel and alloy steel. About 73% of the ferrochromium is transformed into stainless steel and the remaining 37% into carbon and other specialty alloys (ICDA, 2016b).

Refractory-grade chromium ores are processed into refractory chromite and are used to manufacture refractory bricks and mortars, whereas foundry-grade chromium ores are processed in foundry sands and used for the production of casting moulds. The main processed materials from chemical-grade ore are hexavalent sodium dichromate and chromium trioxide (both toxic and carcinogenic). These chemicals are manufactured into other chromium compounds with various final applications (leather tanning, chrome plating, pigments…).

4.2.1.4 Mine production of chromium ores and concentrates

The world mine production of chromium reached 26.4 million tonnes of marketable chromite ore in 2014 according to USGS (USGS, 2016). The value is higher according to the BGS (BGS, 2016) with 30 million tonnes in 2014. The content of chromium in such shipping grade is about 30.8% (Bio Intelligence Service, 2015). The main countries producing chromite ore are: South Africa, Kazakhstan, India and Turkey (USGS, 2016). According to BGS (BGS, 2016), Finland is also a major player in the world production of chromium ores and concentrates in 2014 (see Figure 32). The EU mine production of chromium is located only in Finland, and is averaged at about 750ktonnes of chromium ore per year over the period 2010-2014 (BGS, 2016).

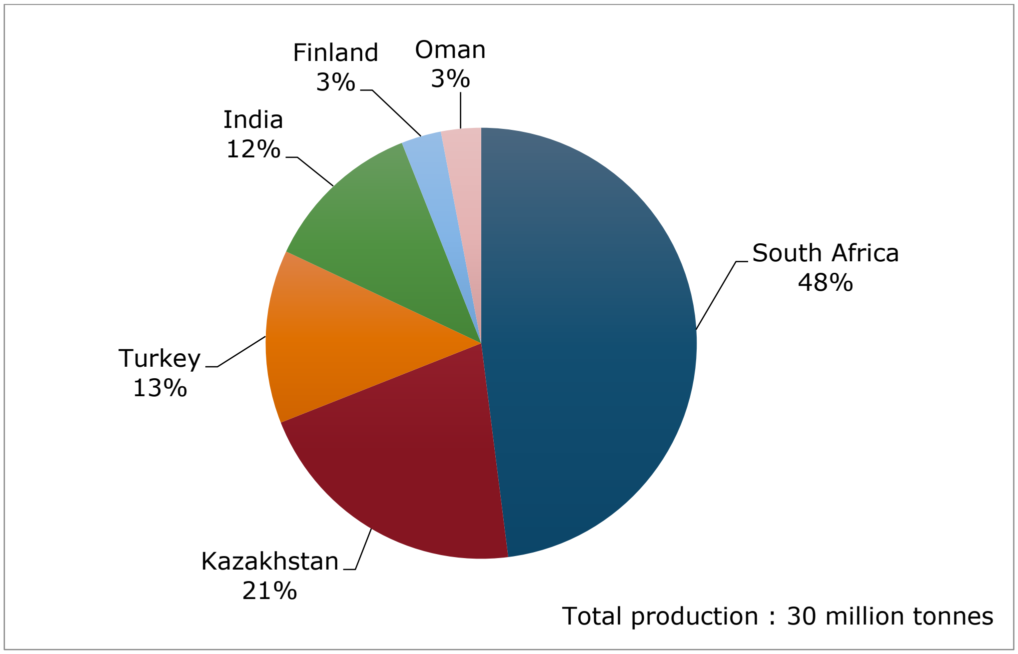


Figure 32: Global mine production of chromium, average 2010–2014 (BGS, 2016)

4.2.1.5 Refined production of ferrochromium

The world production of ferrochromium reaches about 5,900 kt of chromium content, with South Africa and China the two main producers, followed by Kazakhstan and India (BGS, 2016) (see Figure 33). Only Finland, Sweden and Germany have capacity to refine chromium in the EU, with an annual production of about 220 kt, in average on the 2010-2014 period (ICDA, 2016a).

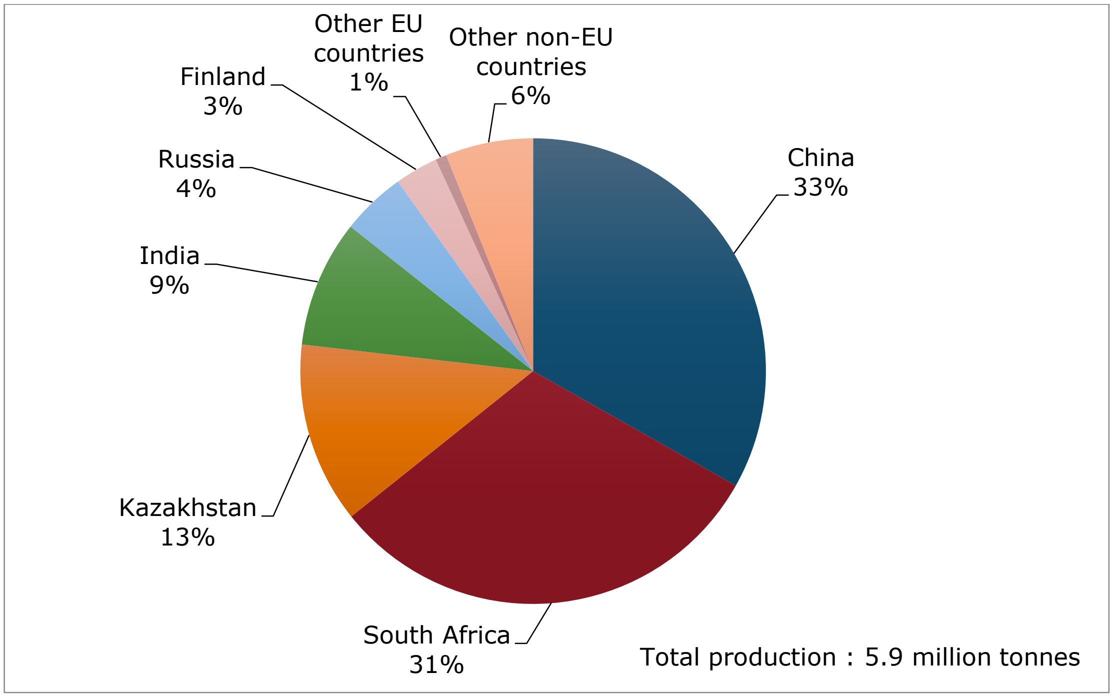


Figure 33: Global production of ferrochromium, average 2010–2014 (BGS, 2016)

4.2.2 Supply from secondary materials

The post-consumer functional recycling of stainless steel is well established and reaches recycling rates between 70% and 92%, depending on the product. However the detection and sorting of alloy steel products is more difficult, thus the majority of these products ends up in carbon steel (i.e. non-functional recycling).

For all the uses of chromium, the end-of-life recycling input rate is 21% in the EU.

4.2.3 EU trade

Regarding the refined material ferrochromium (used to process stainless steel and alloy steel), about 300 kt is produced in the EU (see next section for details), while imports of ferrochromium reach 720 kt in chromium content per year on average in the 2010-2014 period (Figure 34); mainly from South Africa, i.e. around 60% of the imports of ferrochromium (see Figure 35). The import reliance is 75%.

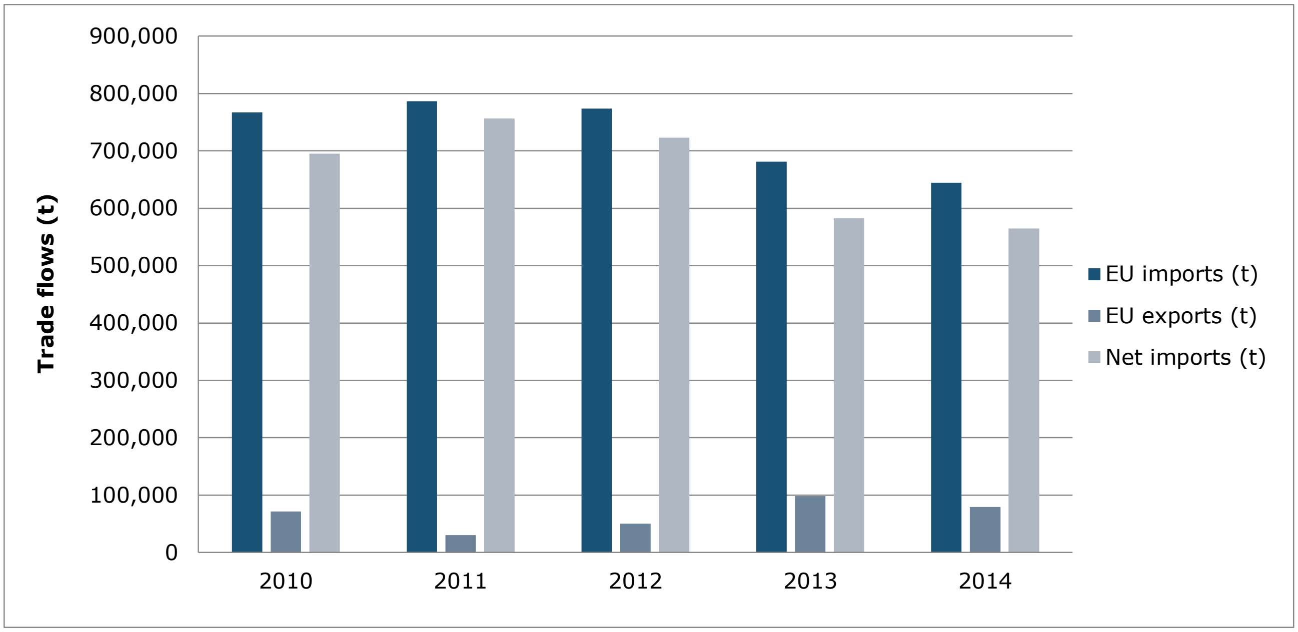


Figure 34: EU trade flows for ferrochromium (Eurostat, 2016a)

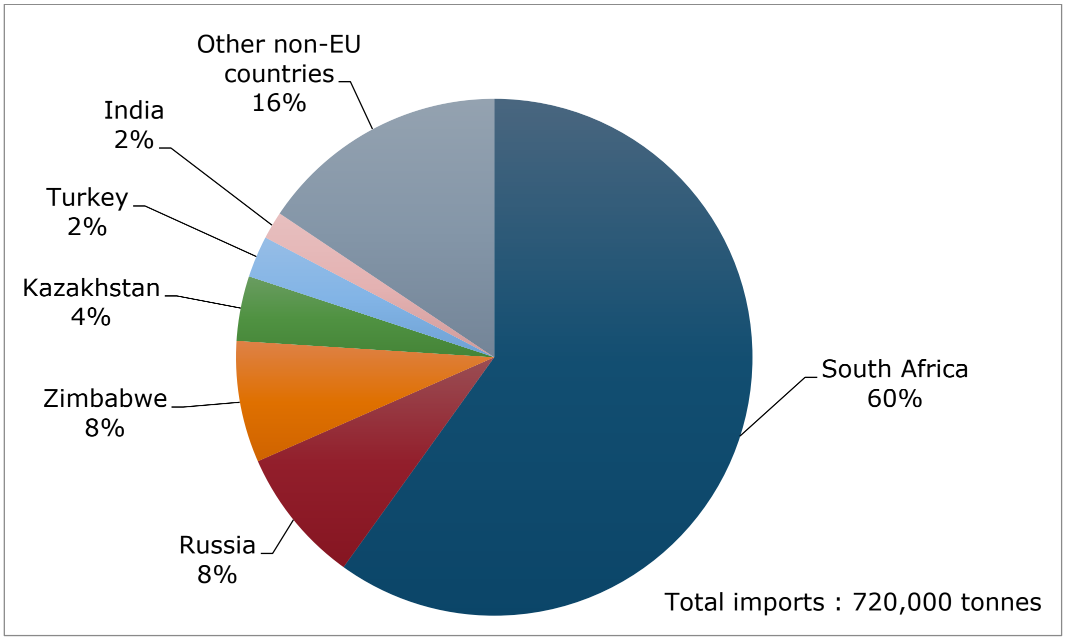


Figure 35: EU imports of ferrochromium, average 2010-2014. (Eurostat, 2016a)

4.2.4 EU supply chain

The first stages of the value chain mainly take place outside the EU. The annual EU production of chromium ore is of 280 kt in chromium content and comes from the mine of Kemi in Finland - the only mine located in the EU (Bio Intelligence Service, 2015). Finland was the sole producer of chromite ore in the European Union. Tasman Metals Ltd. acquired the Akanvaara and Koitelainen chromite projects in north-eastern Finland (Lappi Maakunta) (USGS, 2014).

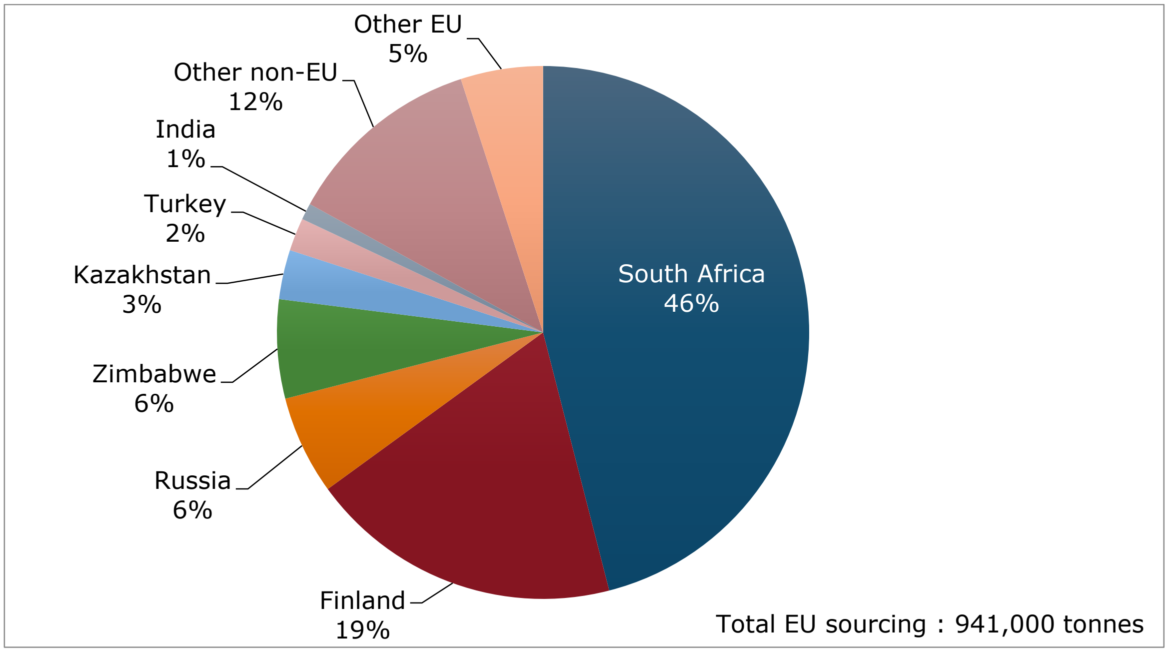


Figure 36: EU sourcing (domestic production + imports) of ferrochromium, average 2010-2014. (Data from Eurostat, 2016a; Eurostat, 2016b; BGS, 2016)

Regarding the refined material ferrochromium (used to produce stainless steel and alloy steel), there are only 3 producers of ferrochromium in the EU (ICDA, 2016b; Euroalliages, 2016). About 220 kt of FeCr is produced in the EU, in Finland, Sweden and Germany, while imports of ferrochromium reach 720 kt in chromium content on average in the 2010-2014 period (see Figure 36). The import reliance is 75%.

South Africa, the main supplier of the EU for ferrochromium, has put an export tax, as for China, India and Zimbabwe in chromium ores (OECD, 2015). No free trade agreements exists with EU suppliers (European Commission, 2016).

The total EU production of crude stainless steel and alloy steel represents around 1,700 ktonne of chromium, with an important input of chromium as scrap. The availability of stainless steel scrap is the limiting factor to a higher use of scrap in this sector. Availability in Europe is also endangered by the stainless steel scrap exports to emerging countries such as India and China which have not yet moved towards a structured recycling industry or the domestic scrap availability is much lower than domestic demand (Industrial expert, 2016).

The European industry uses semi-finished products made of stainless steel and alloy steel to manufacture various finished products: refractory bricks and mortars, moulds for casting, and products made of chromium chemicals which represent a minor volume of all chromium contained in finished products. However, these are key strategic products for the European industry (for economic and technological reasons), due to their use in the aviation and energy (nuclear) sectors.

4.3 Demand

4.3.1 Demand and consumption of chromium in the EU

The EU consumes about 875,000 tonnes of chromium, mainly for the production of stainless steel due to its oxide-forming properties. The annual consumption of chromium by EU stainless steel production can be estimated at around 600kt of chromium annually. Chromium is also a key component of aluminium alloy production (USGS, 2014). In addition, chromium is also the material of choice under the form of chrome metal for aircraft motor system (Safran, Rolls Royce) as it resists high temperatures and very extreme conditions, making it a safe material. Military, nuclear, oil & gas as well as defence industry also rely on chrome metal superalloys.

4.3.2 Uses and end-uses of chromium in the EU

The end-uses of chromium products in the EU are (Bio Intelligence Service, 2015; ICDA, 2016b) (see Figure 37):

- Products made of Stainless Steel: Ferrochromium is used, along with scrap, to produce stainless steel (about 73% of ferrochromium is used to produce stainless steel). The finished products can be found in all end-use sectors with a dominance in consumer goods for households (cutlery, kitchen surfaces, cookware, appliances, sinks, etc.), but it is an essential material e.g. in hospitals, energy production, industrial equipment, engines and vehicles. In buildings, stainless steel expands the lifespan significantly. According to ICDA, 25% of stainless steel is used in process industries, 17% in consumer goods, 15% in architecture and building, 11% in catering, 10% in appliances, 9% in food processing, and 10% in transportation (ICDA, 2016b).
- Products made of Alloy Steel: Ferrochromium is also used to produce carbon and other specialty alloys (27% of ferrochromium uses). Alloy steels are highly used in industrial application where hardness is required (machine parts for example) (ICDA, 2016b). Specialty steels are produced for applications such as tools, injection moulds, camshafts, dies, bearings and mill rollers (ICDA, 2016c).
- Casting moulds: Foundry-grade chromium ores are processed in foundry sands and used for the production of casting moulds. Most of the final applications are in the heavy industry (iron and steelmaking, foundries).
- Refractory bricks and mortars: Refractory-grade chromium ores are processed into refractory chromite and are used to manufacture refractory bricks and mortars, which are essential in all metal production, and used in many industries and households.
- Products made of chromium chemicals: Chemicals based from chromium are used for leather tanning (27%), chrome plating (19%), pigments (19%), wood preservatives (9%), chrome metal (22%) etc. (ICDA, 2016b). It is estimated that 90% of leather tanning uses chromium compounds. Chromium (III) oxide ("chrome green") is used to manufacture chrome metal, at only 14,000 tonnes per year but highly strategic as it is used in superalloys necessary for super alloys in the aviation, aerospace, nuclear industry and energy sector (e.g. gas turbine) (Bio Intelligence Service, 2015).

Relevant industry sectors are described using the NACE sector codes (Eurostat, 2016c) provided in table 16.

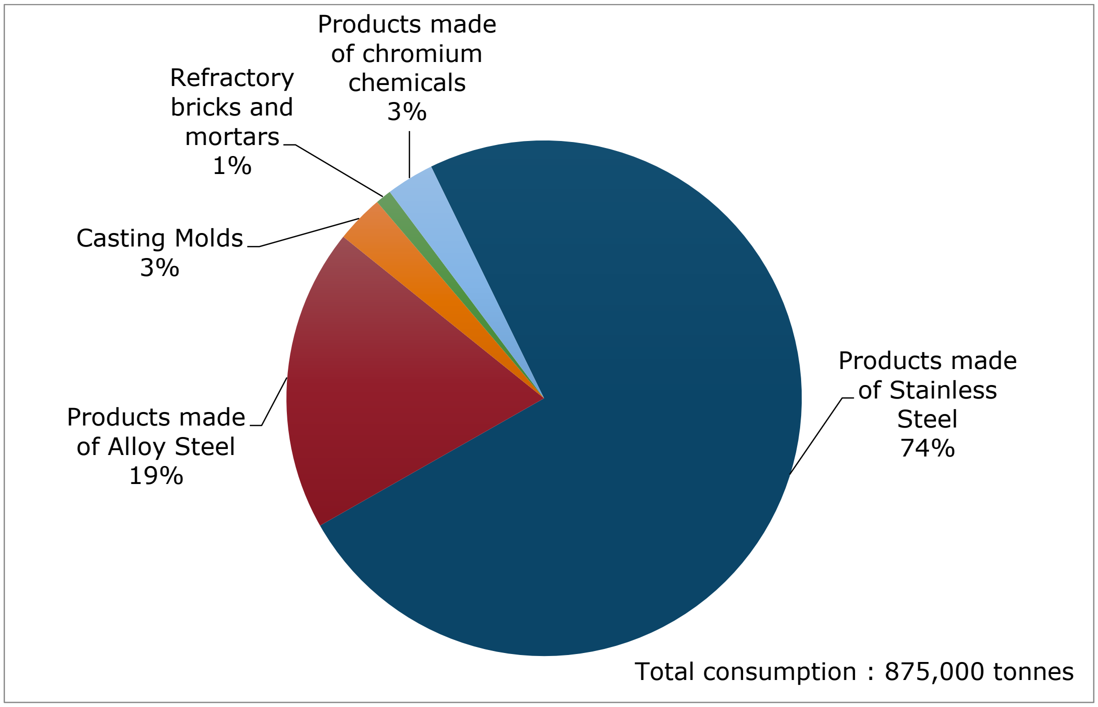


Figure 37: EU end uses of Chromium. Average figures for 2010-2014. (Data from Bio Intelligence Service, 2015)

Table 16: Chromium applications, 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2016c)

Applications	**2-digit NACE sector**	**Value added of NACE 2 sector (M€)**	**4-digit NACE sectors**
Products made of Stainless Steel	C25 - Manufacture of fabricated metal products, except machinery and equipment	159,513	C2593- Manufacture of cutlery; 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	159,513	C2599- Manufacture of other fabricated metal products n.e.c.
Casting Moulds	C24 - Manufacture of basic metals	57,000	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	59,166	C2391- Manufacture of refractory products; C2395- Manufacture of mortars
Products made of chromium chemicals	C20 - Manufacture of chemicals and chemical products	110,000	C2011- Manufacture of dyes and pigments; C2029- Manufacture of other chemical products n.e.c.

4.3.3 Prices

Chromium materials are not openly traded. Purchase contracts are confidential between buyer and seller; however, trade journals report composite prices based on interviews with buyers and sellers (USGS, 2014).

Prices of chromium depends greatly on its forms: chromite, ferrochromium, or metal. According to the DERA raw materials price monitor and the LMB Bulletin, all chromium prices have decreased of about 20% since 2015 compared to the period 2011-2015:

- Chromite (metallurgical grade) costs 184.6 US$/kg Cr in average on the period 2011-2015 but only 140 US$/kg Cr in average on the period December 2015 - November 2016, i.e. a price drop of 24.2%.
- Ferrochromium costs 2.34 US$/kg Cr in average on the period 2011-2015 but only 1.88 US$/kg Cr in average on the period December 2015 - November 2016, i.e. a price drop of 19.4%.
- Chromium metal costs 10,235 US$/kg Cr in average on the period 2011-2015 but only 7,529 US$/kg Cr in average on the period December 2015 - November 2016, i.e. a price drop of 26.4%.

4.4 Substitution

Currently chromium has no substitute in super alloys and in stainless steel production. In some cases, in metallurgical uses, scrap containing chromium can replace ferrochromium (USGS, 2016).

4.5 Discussion of the criticality assessment

4.5.1 Data Sources

To perform this criticality assessment data from BGS (BGS, 2016), Eurostat (Eurostat, 2016a,b) as well as the MSA study (Bio Intelligence Service, 2015) were used. Data provided in this factsheet are an average over 2010-2014, unless specified in comment. The CN8 codes used for ferrochromium are 720241 (ferro-chromium, containing by weight > 4% of carbon) and 720249 (ferro-chromium, containing by weight ≤ 4% of carbon).

4.5.2 Economic importance and supply risk calculation

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 16). The value added data correspond to 2013 figures.

The life cycle stage assessed in for the SR indicator is the processing step; Chromium processed material under study is ferrochromium. The Supply Risk (SR) is calculated using both the HHI for global supply and the HHI for EU supply as prescribed in the revised methodology. China and South Africa account for about 30% each of the global supply of ferrochromium, whereas the EU supply is clearly dominated by South Africa (60%).

4.5.3 Comparison with previous EU assessments

Chromium was identified as critical in the 2014 assessment, whereas it is considered non-critical in the 2017 assessment (also non-critical in 2011). The revised criticality methodology affects both the economic importance and supply risk calculations of chromium, which explains the key difference in EI and SR results across the three assessments.

In the 2017 assessment, the EI for chromium (6.8) meets the minimum EI criticality threshold, however its SR result (SR=0.9) does not. The decrease in SR compared to 2014 is due to several aspects. Firstly, it is important to note that the stage assessed in the 2017 assessment is the refining stage due to unavailability of high quality global supply data at the extraction stage. The main primary material assessed is metallurgical-grade chromium ore, which is processed into ferrochromium and used, along with scrap, to produce stainless steel and alloy steel. The 2017 assessment incorporates actual EU sourcing data in the SR calculation, which results in a marginally lower SR result (SR=1.0 in 2010, SR=0.9 in 2017).

In the 2014 assessment, the primary global supply of chromium (ores and concentrates) in 2010 was attributed to South Africa (43%) and Kazakhstan (20%). China was not identified as a major global supplier of chromium ores and concentrates. In the 2017 assessment, 86% of the primary global supply of ferrochromium (refined material) comes from four main countries China (33%), South Africa (31%), Kazakhstan (13%) and India (9%) (See Figure 4). However, in terms of the share of EU supply, South Africa accounts for 46% and Finland accounts for 19% (see Figure 7).

The results of the 2017 and previous assessments are shown in Table 17.

Table 17: Economic importance and supply risk results for chromium in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

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

Although it appears that the economic importance of chromium has reduced between 2014 and 2017 this is a false impression created by the change in methodology. 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 calculations of the Supply Risk (SR) for 2010 and 2014 lists have been performed for the extraction step (Cr ores) whereas the SR in 2017 assessment is calculated for the processing step (ferrochromium).

Despite the fact that in this 2017 exercise chromium is not considered as a critical raw material anymore, it should be underlined that it is very close to the thresholds, and that the chromium processing industry is of high strategic value for Europe (Industrial expert, 2016). Moreover, according to industrial experts, the fact that China became a major FeCr producer seems to have dilluted the supply risk in our calculation, however they question the availability of Chinese material on the EU market due to their huge internal demand and 20% export tax applied (Industrial expert, 2016).

4.6 Other considerations

4.6.1 Future Supply and Demand Outlook

Overall on the global level the consumption of chromium is anticipated to closely follow the stainless steel industry trends (USGS, 2014). A CAGR of 3% - 4% is globally forecast between 2015 and 2025, mainly based on stainless steel demand (SMR, 2014) – see also section 4.3.

However, in terms of forecast for the EU, considering the unpredictability of the current market, it is difficult to provide a viable prediction. One thing for certain is that the demand for chrome ore has been on the rise during the past 10 years, mainly due to increase in demand in China as well as aerospace, defence and construction industry (Industrial expert, 2016). Moreover, according to experts (ICDA, 2016b), China has put in 2016 a 20% export tax on ferrochromium (and plan to do the same on chromium ores), and has bought the South Africa and Zimbabwe mines, resulting in an increasing concentration of the China domination over the chromium market. As a consequence, demand and prices are increasing because of China demand.

Table 18: Qualitative forecast of supply and demand of chromium

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

4.6.2 Environment

While chromium metal and Cr(III) ions are not considered toxic, many hexavalent chromium (Cr(VI)) compounds are toxic and carcinogenic (Bio Intelligence Service, 2015).

4.7 Data sources

4.7.1 Data sources used in the factsheet

BGS (2016) World Production of Ferro Alloys (Ferro Chrome) 2010-2014

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 (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. Chromium profile

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

Eurostat (2016)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

ICDA (2016)a Ferrochrome production 2010-2014.

ICDA (2016)b. Personal communication during the review.

ICDA (2016)c. What is Chrome [online] Available at: http://www.icdacr.com/

Industrial expert (2016) Personal communication during the review.

Minerals4EU (2014). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

Motzer & Engineers (2004) Chemistry, Geochemistry, and Geology of Chromium and Chromium Compounds. online] Available at:

http://www.engr.uconn.edu/~baholmen/docs/ENVE290W/National%20Chromium%20Files%20From%20Luke/Cr(VI)%20Handbook/L1608_C02.pdf

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

SMR (2014). Update of the Chrome Industry, Presentation at 28th Stainless & Alloys Conference, Chicago 2014

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

USGS (2016) Mineral Commodity Summaries: Chromium [online] Available at: http://minerals.usgs.gov/minerals/pubs/commodity/chromium/mcs-2016-chrom.pdf [accessed December 2016].

USGS (2014) 2014 Minerals Yearbook - Chromium [online] Available at:: http://minerals.usgs.gov/minerals/pubs/commodity/chromium/myb1-2014-chrom.pdf [accessed December 2016].

4.7.2 Data sources used in the criticality assessment

BGS (2016) World Production of Ferro Alloys (Ferro Chrome) 2010-2014

ICDA (2016) Ferrochrome production

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 (2016) Trade Agreements http://ec.europa.eu/trade/policy/countries-and-regions/agreements/

Eurostat (2016)a. COMEXT 2010-2014 EU trade since 1988 by HS2, 4, 6 and CN8, (FERRO-SILICO-CHROMIUM, FERRO-CHROMIUM, CONTAINING BY WEIGHT > 4% or <= OF CARBON)

Eurostat (2016)b. PRODCOM, Sold Production Exports and Imports 2010-2014 of Ferro-Chromium, Eurostat (CN8 24101260)

Fung & Korinek (2013), “Economics of Export Restrictions as Applied to Industrial Raw Materials”, OECD Trade Policy Papers, No. 155, OECD Publishing

OECD (2009) Workshop on raw materials - Export restrictions on strategic raw materials and their impact on trade and global supply.

USGS (2016) Mineral Commodity Summaries

ZEW Centre for European Economic Research (2013) 'Strategic Trade Policies and its impact on the stainless steel industry' (presentation)

ZEW Centre for European Economic Research (2013) 'Strategic Trade Policies and its impact on the stainless steel industry'(full report)

4.8 8 Acknowledgments

This Factsheet was prepared by Deloitte. The authors would like to thank industrial experts from ICDA, Eurofer and Euroalliages, as well as the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this factsheet.

5. COKING COAL

Key facts and figures

Material name	Coking coal	World/EU production[1]	1,033 Mt /22.9 Mt
Parent group (where applicable)	N/A	EU import reliance[1]	63%
Life cycle stage assessed	Refining	Substitution index for supply risk [SI(SR)][1]	0.92
Economic importance (EI)(2017)	2.3	Substitution Index for economic importance [SI(EI)][1]	0.92
Supply risk (SR) (2017)	1.0	End of life recycling input rate	0%
Abiotic or biotic	Abiotic	Major end uses in the EU[1]	Base metal production (95%)
Main product, co-product or by-product	Main product	Major world producers[1]	China (54%), Australia (15%), United States (7%) Russia (7%)
Criticality results	2011	2014	2017
	Not assessed	Critical	Non critical

[1] 2010-2014 average, unless otherwise stated.

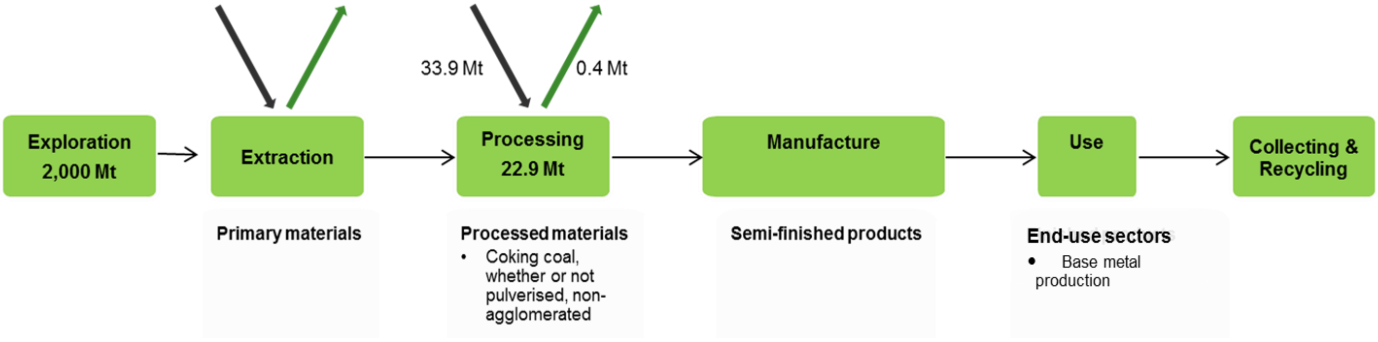


Figure 38: Simplified value chain for coking coal

The green boxes of the production and processing stages in the figure above suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU. EU reserves are displayed in the exploration box.

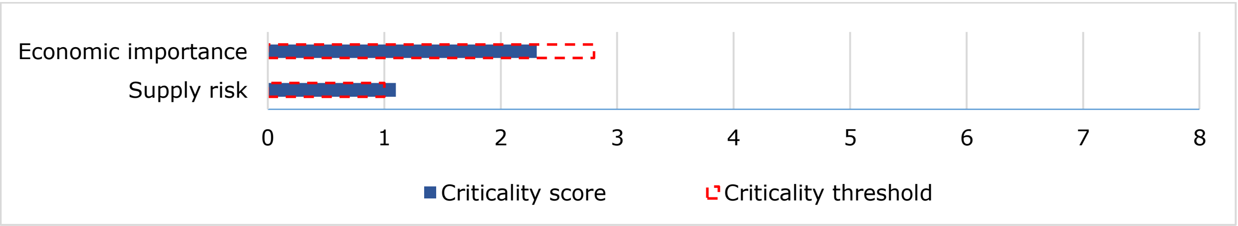


Figure 39: Economic importance and supply risk scores for coking coal

5.1 Introduction

Coal is a combustible, black or brownish-black rock, composed of fossilised plant remains. Thus it consists of organic macerals (microscopically recognizable constituents of organic matter) and smaller amounts of inorganic minerals. Coal is classified depending on the composition, the carbon content, the amount of impurities (minerals) etc. This ranking reaches from lignite with a lower caloric value (about 25 MJ/kg) to anthracite (more than 35 MJ/kg) (BGS, 2010).

Between 10% and 20% of the worlds coal is traded as coking coal (Euracoal, 2013). Coking coal is sometimes also referred to as metallurgical coal, semi-soft coking coal (or SSCC) or hard coking coal (HCC) and has specific requirements to its composition. Coking coal is used to make furnace coke or metallurgical coke (the two terms are equivalent, often simply named coke). Rather than being a raw material, furnace coke is an intermediate product to be charged in the blast furnace with the iron ore in order to produce pig iron. Coke is produced in coking ovens of the integrated steel production route using coking coal as input. The type of blend determines the attributes of the coking coal (and the amount of carbon), such as fluidity, volatile matter, swelling, calorific value etc. The properties of coking coal need to be more tightly regulated than steam coal given the effects of coking coal on the quality of the resulting steel.

The use of coking coal is indistinguishable from the production of base metals, and therefore a major raw material resource, in terms of volume, for the European manufacturing sector.

5.2 Supply

5.2.1 Supply from primary materials

5.2.1.1 Geological occurrence

Coking coals require certain chemical and physical properties, such as low sulphur and phosphorus content and a high heating value. Therefore brown coal (lignite) is not capable for the use as coking coal and only black coal (anthracite, also called stone coal) is used. Different properties of coking coal and thermal coal are further explained by WCA (2016). No separate crustal abundance for high carbon layers is assessed by Rudnick & Gao (2003).

5.2.1.2 Processing and refinery

The processing depends on the quality of the coal and the intended use. Usually the coal is crushed, separated by size and subsequently treated in an oscillating column of water, where the unwanted rock fragments sink faster than coal. This method is known as washery (BGS, 2010). What follows are four main steps: comminution, sizing, concentration and dewatering. The coking coal is produced by processing coal in a series of oxygen-deficient ovens aimed at concentrating the carbon content of the cokes (BGS, 2010).

5.2.1.3 Resources and reserves

There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of coking coal 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[4], 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.

For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for coking coal. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for coking coal, 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 coking coal the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU, 2015).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 Minerals4EU project is the only repository of some mineral resource and reserve data, but not for coking coal. In addition there are no resource and reserve data on coking coal at national/regional level reported using the United Nations Framework Classification (UNFC) (Minerals4EU, 2014). There are no data about coking coal in the Mineral4EU website, for both resources and reserves in Europe.

The reported reserves are set at 2,000 Mt (Bio by Deloitte, 2015). Being a refined product, coal reserves can be an indication of raw materials suitable for producing coking coal. Table 19 shows the reserves in 2016, which however include anthracite and lignite coal. It is clear that coal reserves are documented to be present all around the world, given the large group of other countries in the total. Land area and industrial development also strongly influence the size of the reserves.

Table 19: Global reserves of coal in year 2015 (Data from BP, 2016)

Country	**Coal Reserves (million tonnes)**	**Percentage of total (%)**
United States	237,295	27
Russia	157,010	18
China	114,500	13
Australia	76,400	9
India	60,000	7
Germany	40,584	5
Indonesia	28,017	3
Poland	5,465	1
Mongolia	2,520	0.3
Czech Republic	1,052	0.1
Other	168,688	19
World total (rounded)	*891,531*	*100*

5.2.1.4 World refined production

Total world supply of coking coal is estimated at an annual 1,033 Mt between 2010 and 2014. As can be seen in Figure 40, China was the largest producer of coking coal, producing

---

[4] www.crirsco.com

more than half of world. Other large producers were Australia (15%), Russia (7%) and the USA (7%). The total European production of coking coal only accounts between 2 and 3% of world production, with Poland, Germany and the Czech Republic being the biggest producers within the EU. This compares with over 10% of global crude steel production that occurred in the EU in recent years.

In recent years, a strong growth in the world production of coking coal could be observed, mainly driven by the production in China (from 280 million tonnes in 2005 to over 450 million tonnes in 2010) and the USA (from 45 million tonnes to 70 million tonnes). During this period the output of other large producers was constant or growing slowly.

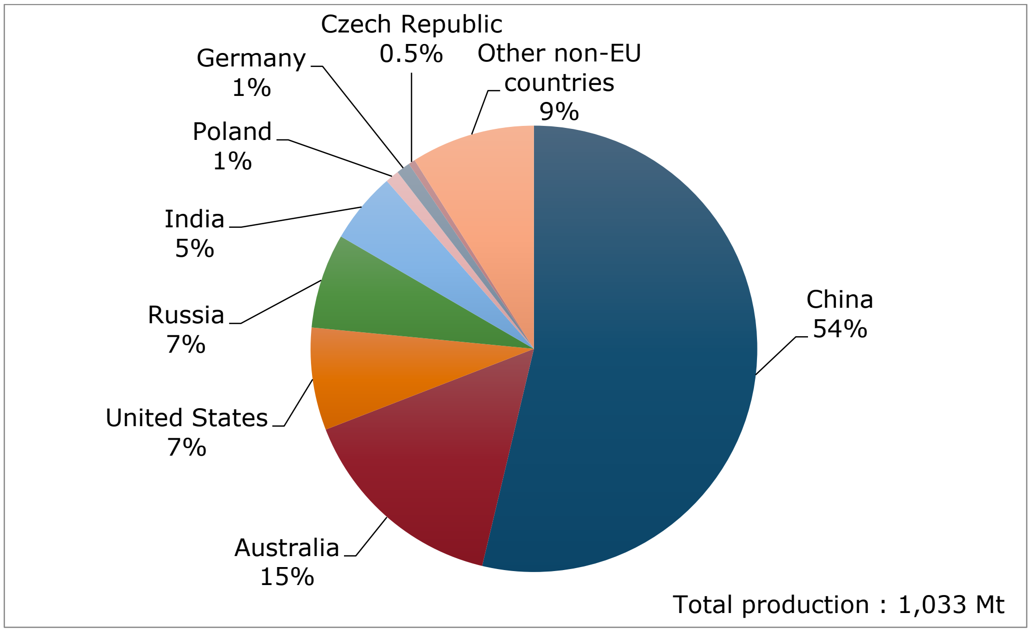


Figure 40: Global production of coking coal, average 2010–2014 (Data from BGS World Mineral Statistics database, 2016)

5.2.2 Supply from secondary materials

End of life recycling input rate for coking coal is estimated to be non-existent. Coking coal, once burned, cannot be used again as coking coal using currently available technologies.

5.2.3 EU trade

The EU has historically been a net importer of coking coal because demand from the steel industry exceeded native supply and due to uncompetitive operating conditions (Euromines 2016). Imports have remained relatively consistent at around 40 million tonnes, with a slight increase in 2013 and 2014 (Figure 41). Exports are consistently below 2% of imports, generally at a few hundreds of tonnes.

The majority of coking coal imported to the EU is from the USA and Australia (Figure 42).

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.

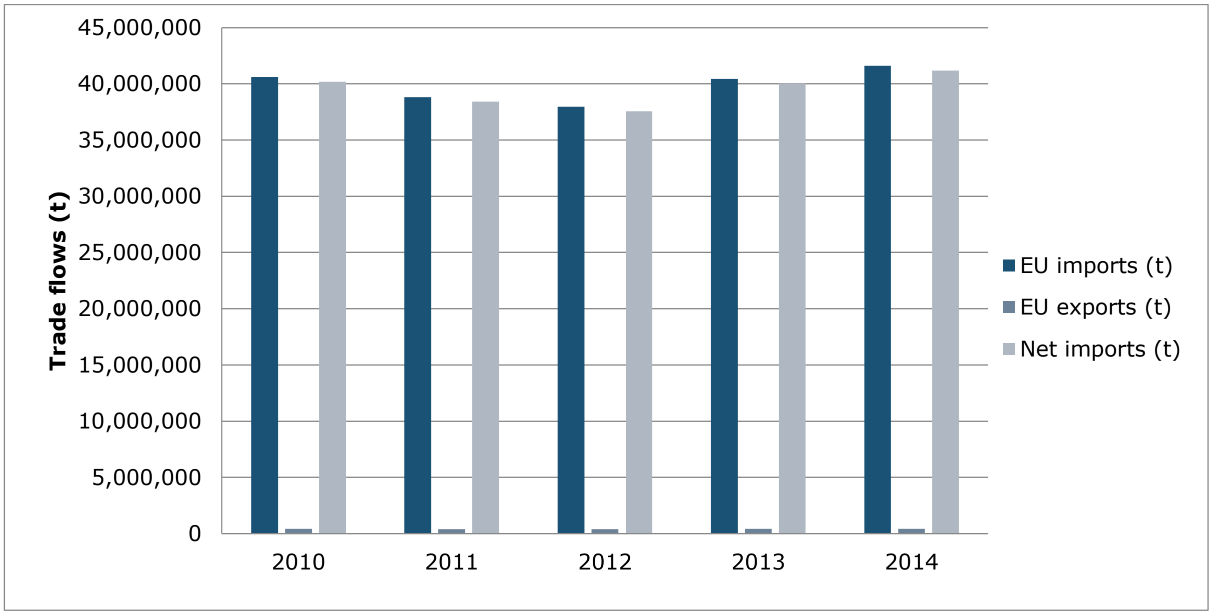
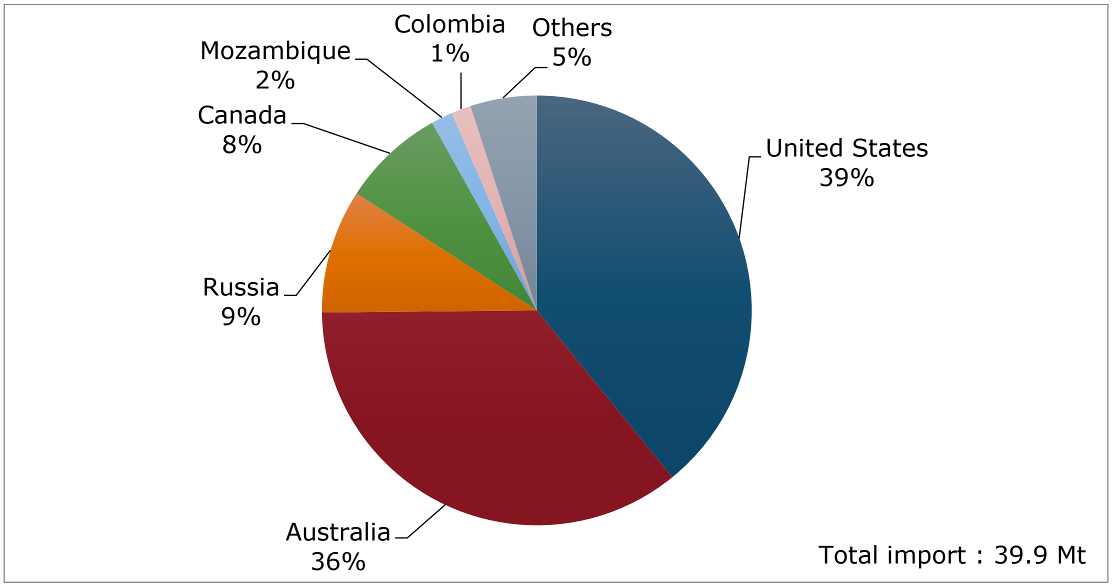


Figure 41: EU trade flows for coking coal (Data from Comext (Eurostat, 2016a)).



`

Figure 42: EU imports of coking coal, average 2010-2014 (Eurostat, 2016a).

5.2.4 EU supply chain

Primary and secondary steelmaking, and processing of steel, takes place in almost all MS of the EU. The industry had a Value Added of around 7 billion EUR between 2010 and 2014, and was a net exporter of over 10 Mt of steel.

The EU relies for the supply of coking coal for 63% on its imports. The EU sourcing (domestic production + imports) is shown in Figure 43.

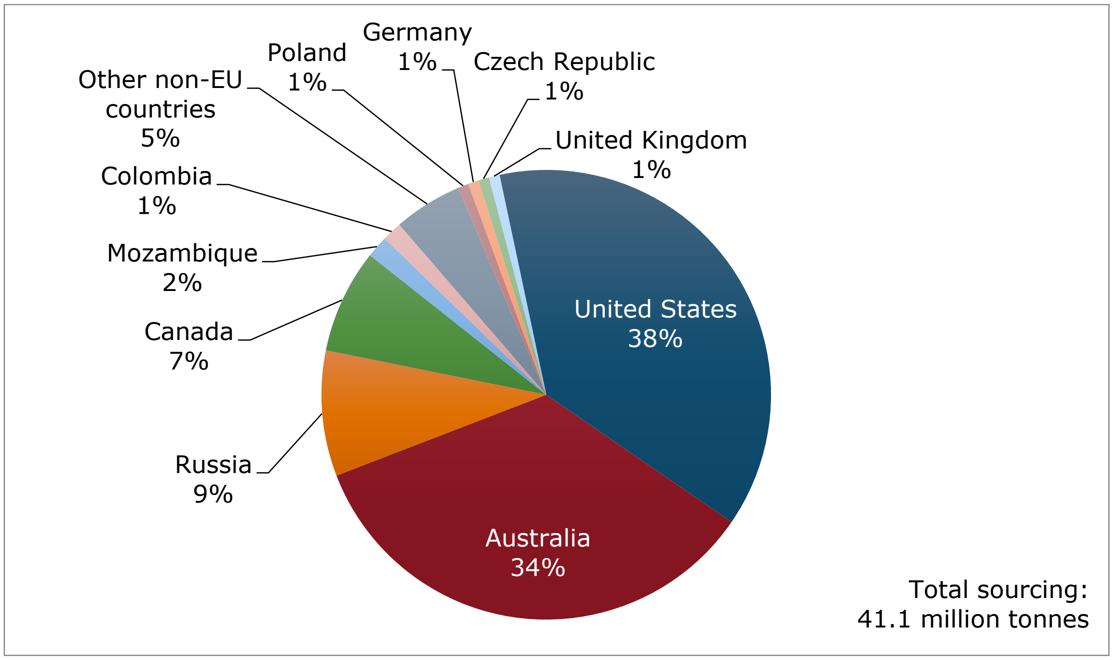


Figure 43: EU sourcing (domestic production + imports) of coking coal, average 2010-2014 (Eurostat, 2016a; WMD, 2016)

The EU can consider to increase their own supply in the medium term if market prices allow to do so, effectively controlling their reliance on USA and Australia as supplier.

According to the OECD´s inventory on export restrictions, India exerts captive mining. China uses export taxes of 10% on coking coal. India, Russia and China have a licensing requirement in place for exports. Further export restrictions in other countries are not reported (OECD, 2016).

5.3 Demand

5.3.1 EU consumption

The EU consumption of coking coal is 62.8 Mt on an annual basis.

5.3.2 Applications / End uses

As shown in Figure 44, use in steel production is the most common application of coking coal. Almost two thirds of world steel production is made in blast furnaces fired with coal, mainly in the form of coke. Other applications are in alumina refineries, paper manufacturing, and the chemical and pharmaceutical industries. Several chemical products can be produced from the by-products of coke ovens.

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 20). The value added data correspond to 2013 figures.

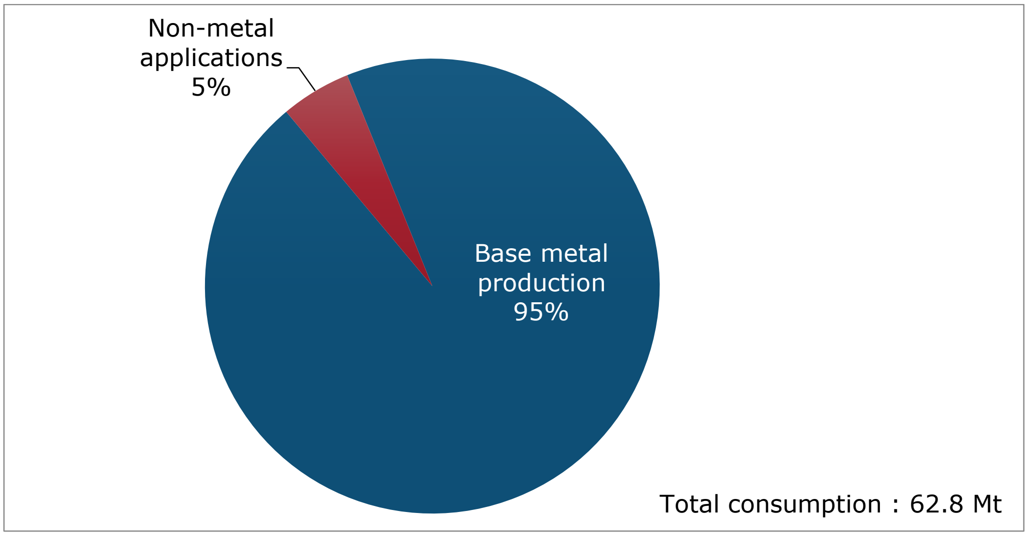


Figure 44: Global/EU end uses of coking coal. Average figures for 2010-2014 (Data from BGS, 2010)

Table 20: Coking coal applications, 2-digit NACE sectors, 4-digit NACE sectors, and value added per sector (Data from the Eurostat database (Eurostat, 2016c))

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (millions €)
Non-metal applications	C23 - Manufacture of other non-metallic mineral products	C23.99 – Manufacture of other non-metallic mineral products n.e.c.	59,166
Base metal	C24 – Manufacture of basic metals	C24.10 - Manufacture of basic iron and steel and of ferro-alloys	57,000

5.3.3 Prices

The time series of constant coking coal prices for japan and Northwest Europe show that prices for this commodity have risen sharply after 2003 after a period of stable prices. These changes in price follow the price changes seen for steel, linked to growing demand from countries such as China as infrastructure is expanded. Additional data, not shown in the graph, show that after 2011 prices are reduced by around 50% in 2014 compared to the 2011 price level. The average price of coal between 2011 and 2015 according to (DERA, 2016) was rather stable at 100.62$/tonne ce (MCIS steam coal marker price, cif NW Europe), with an steady increase of the price in 2015 first half of 2016. Due recent market dynamics in the coking coal sea borne market, prices rocketed above 250 $/tonne in the second half of 2016 due to material shortage.

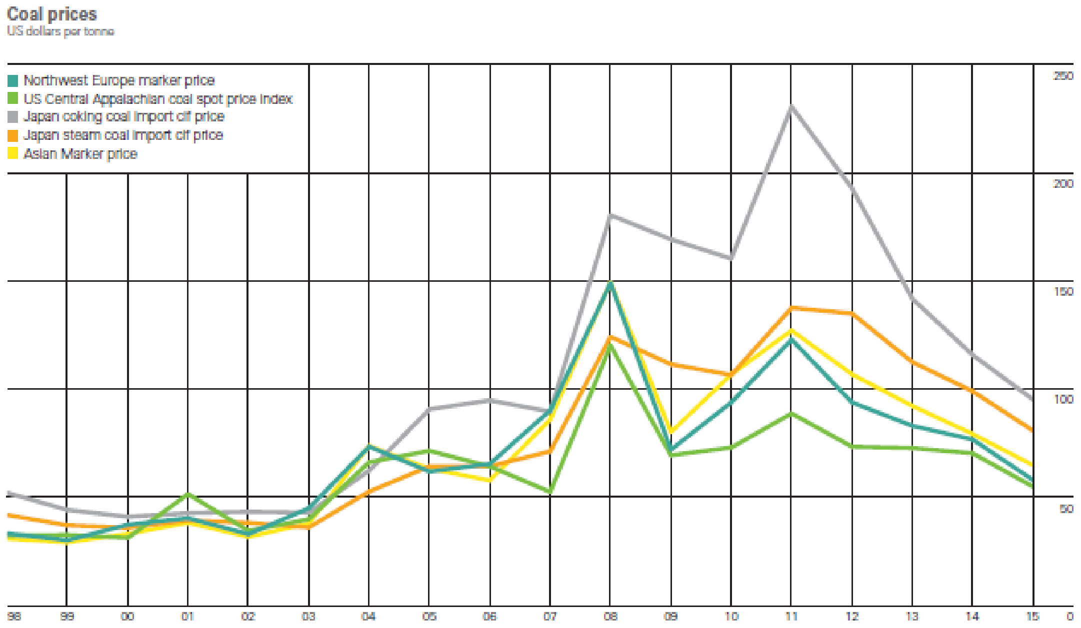


Figure 45: Global developments in price of coking coal (Data from BP 2016)

5.4 Substitution

Coking coal acts as a reducing agent in steel making. However, there is no other satisfactory material available, which can replace metallurgical coke as a permeable support of blast furnace charge. As a permeable support, coking coal acts as the only solid material in the furnace that supports the iron bearing burden and provides a permeable matrix necessary for slag and metal to pass down into the hearth and for hot gases to pass upwards into the stack (Diez et al., 2001).

There are reports about possible substitution options emerge in the future decade. In particular, pulverised metallurgical coal (which still needs to be primary coal (Euromines, 2016), that can be directly injected in blast furnaces rather than in the coke oven. It is claimed that pulverised coal injection can replace about 25 to 40% of coke in the blast furnace, reducing the amount of coke required and the associated emissions (Bio by Deloitte, 2015).

5.5 Discussion of the criticality assessment

5.5.1 Data sources

The CN code used for the trade analysis of coking coals was 2701 12 10, labelled Coking coal, whether or not pulverised, non-agglomerated.

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.

5.5.2 Calculation of Economic Importance and Supply Risk indicators

The subject of the present criticality analysis is coking coal as defined by EUROFER, which represents 100% of steel production in Europe. Although some consider coking coal to be a primary raw material, coking coal is not extracted from the earth as such and is therefore a refined product; this is the stage in the chain that is assessed.

The supply risk was assessed for coking coal using both the global HHI and the EU-28 HHI as prescribed in the revised methodology.

5.5.3 Comparison with previous EU assessments

Coking coal was identified as critical in the 2014 assessment, whereas it is considered non-critical in the 2017 assessment. It was not assessed in 2011. Compared to the previous 2014 assessment, a sharp decline can be observed in the economic importance result in the 2017 assessment. This is the direct result of isolating base metal from metal products on NACE-2 digit level and discarding the mega sector approach. This results in a lower overall GVA, and thereby impacting the Economic Importance score for coking coal. The change in supply risk results is small and mainly due to minor changes in supplier countries. The recycling rate or substitution options have not changed. See Table 21.

Table 21: Economic importance and supply risk results for coking coal in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017.

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Coking coal	N/A	N/A		8.9	1.2		2.3	1.0

5.6 Other considerations

5.6.1 Forward look for supply and demand

The coking coal market is a more uniform world market, reflecting the small number of supply countries: principally Australia, the USA, Russia and Canada, but with strong growth potential in the new entrants Mongolia and Mozambique. China, the world's largest producer, is currently not exporting coking coal due to internal use. No change is expected for the next decade (Bio by Deloitte, 2015). See Table 22.

On the supply-side, increases in mining capacity are expected to narrow the market deficit over the coming years. These include significant expansions in the already dominant market player, Australia, as well as new entrants to the market such as Mozambique and Indonesia.

Table 22: Qualitative forecast of supply and demand of coking coal

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
Coking coal		X	+	+	+	+	+	+

5.6.2 Environmental and regulatory issues

Within MS, there are reports of certain coke mining facilities leaking mine water, contaminating groundwater with acidic solutions containing iron oxide. (BGS, 2010)

5.6.3 Supply market organisation

Based on press releases from one large mining company in Poland (NWR), "more than 500 million euros" are going to be invested within the next five years. This is, however, a very large project and due to liquidity problems of the company it is possible that this project will be cancelled. (Bio by Deloitte, 2015).

5.7 Data sources

5.7.1 Data sources used in the factsheet

Bio by Deloitte (2015). Study on Data for a Raw Material System Analysis. Background data (unpublished)

BP (2016). Statistical review of world energy. Available at: http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/coal/coal-reserves.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

Diez, M.A., Alvarez, R., Barriocanal, C. (2001). Coal for metallurgical coke production: predictions of coke quality and future requirements for cokemaking. International Journal of Coal Geology 50 (2002) 389–412. Available at: https://social.stoa.usp.br/articles/0016/5403/coal_for_metallurgical_coke_production.pdf

Euracoal (2016). Country profiles. [online] Available at : https://euracoal.eu/info/country-profiles

Euromines (2016). Herbestreit, C. expert consultation.

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

Eurostat (2016)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

KPMG (2013) Metallurgical coal bulletin; and IHS, BHP Billiton and Anglo American Presentations.

Minerals4EU (2014). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

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.

WCA (2016). Basic coal facts [online] Available at: http://www.worldcoal.org/file_validate.php?file=WCA_Basic%20Coal%20Facts_0.pdf

5.7.2 Data sources used in the criticality assessment

BGS (2010). Commodity profile, coking coal. Available at: http://www.bgs.ac.uk/mineralsuk/mines/coal/home.html

BGS (2016). World Mineral Production 2010-2014 [online]. Keyworth, Nottingham British Geological Survey, Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.html Euracoal (2013). Coal industry across Europe. Available at: https://euracoal.eu/library/publications/

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

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

5.8 Acknowledgments

This Factsheet was prepared by the Netherlands Organisation for Applied Scientific Research (TNO). The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this Factsheet.

6. COPPER

Key facts and figures

Material name and Element symbol	Copper, Cu	World/ EU production (tonnes)[1]	17,145,448/816,101
Parent group (where applicable)	-	EU import reliance[1]	82%
Life cycle stage/ material assessed	Extraction/ ores	Substitution index for supply risk [SI(SR)][1]	0.97
Economic importance score (EI) (2017)	4.7	Substitution Index for economic importance [SI(EI)][1]	0.95
Supply risk (SR) (2017)	0.2	End of life recycling input rate	55%
Abiotic or biotic	Abiotic	Major end uses in the EU[1]	Electrical equipment (22%), Metal products (21%) Machinery (15%)
Main product, co-product or by-product	Main product	Major world producers[1]	Chile (32%), China (9%), Peru (8%)
Criticality results	2011l	2014	2017
	Not critical	Not critical	Not critical

[1] average for 2010-2014, unless otherwise stated;

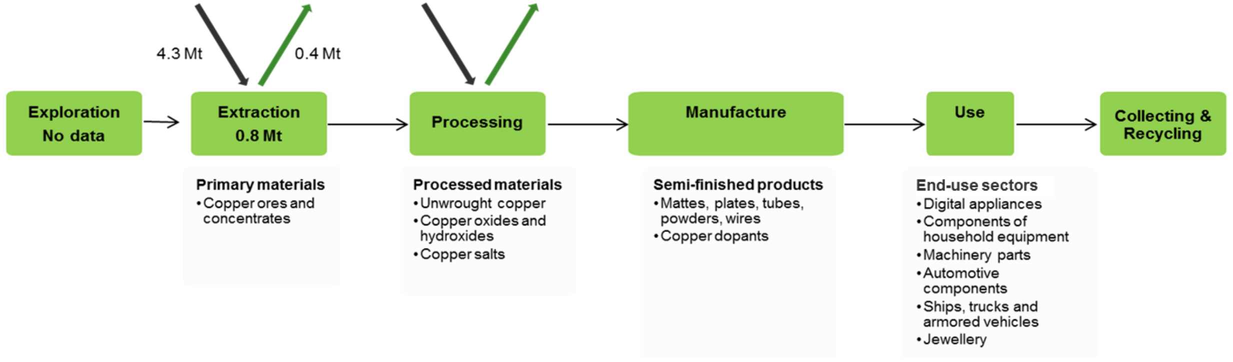


Figure 46: Simplified value chain for copper

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports. EU reserves are displayed in the exploration box.

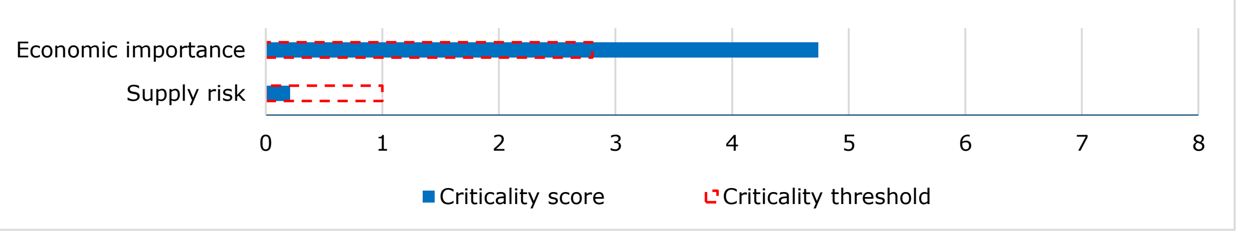


Figure 47: Economic importance and supply risk scores for copper

6.1 Introduction

Copper is a chemical element with symbol Cu and atomic number 29. Copper (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).

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.

6.2 Supply

6.2.1 Supply from primary materials

6.2.1.1 Geological occurrence/exploration

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, 2003). Copper combines with a number of elements and more than 150 copper minerals have been identified (BGS, 2007).

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 are the world's second most important source of copper (about 20% of world production), grading about 2% Cu. Volcanogenic massive sulphide (VMS) deposits are also important sources of copper, with grades at 1% Cu (BGS, 2007). A major VMS deposit is located in Spain.

The Minerals4EU website reports that some exploration projects in Europe for copper is done in Greenland, UK, Spain, Portugal, Sweden, Switzerland, Macedonia, Kosovo, Albania, Ukraine, Poland, Czech Republic, Slovakia, Hungary and Romania (Minerals4EU, 2014). Moreover, Greece and Bulgaria are major porphyry copper targets, with two significant exploration projects going on.

6.2.1.2 Mining, mineral processing and extractive metallurgy

There are three main techniques for mining copper: open pit mining, underground mining and in-situ leaching. Open pit mining is the most common form and appropriate for low grade ores that are close to the surface (<100m). For example the open pit copper mine at Bingham Canyon in Utah, USA is one of 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 in the Mopani mines in the Zambian Copperbelt.

Mined ores generally contain 0.5%-3% Cu. The first phase in processing the ore is concentration which increases the copper content to 25-35%. This is carried out at the mine site, involving crushing and grinding, followed by chemical and/or 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).

6.2.1.3 Resources and reserves

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[5], 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.

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, 2015).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.

A USGS global assessment of copper deposits indicated that identified resources contain about 2.1 billion tons of copper (porphyry deposits accounted for 1.8 billion tons of those resources), and undiscovered resources contained an estimated 3.5 billion tons (USGS, 2016b). Europe has significant deposits in Poland with resources of about 34 million tonnes of copper (USGS, 2013). Resource data for some countries in Europe are available in the Minerals4EU website (see Table 23) (Minerals4EU, 2014) but cannot be summed as they are partial and they do not use the same reporting code.

The world known reserves of copper amount 720 million tonnes (USGS, 2016b), mainly located in America (Chile, USA, Peru and Mexico), see Table 24.

Reserve data for some countries in Europe are available in the Minerals4EU website (see Table 23) but cannot be summed as they are partial and they do not use the same reporting code.

---

[5] www.crirsco.com

Table 23: Resource data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Quantity	Unit	Grade	Code Resource Type
Spain	Various	17.97	Mt	0.99%	Measured
Portugal	NI43-101	33.95	Mt	1.68%	Measured
UK	NI43-101 JORC	0.023 2.114	Mt Mt	0.02% 0.58%	Measured Indicated
Ireland	None	14.13	Mt	0.85%	Historic Resource Estimates
Sweden	NI43-101 JORC FRB-standard	5.02 0.493 528.9	Mt Mt Mt	2.2% 0.7% 0.21%	Measured Measured Measured
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
Finland	NI43-101 JORC	342 521	Mt Mt	0.23% 0.13%	Measured Measured
Ukraine	Russian Classification	31.1	kt	-	P1
Hungary	Russian Classification	129.7	Million m^3	1.71 t/m^3	A+B
Slovakia	None	43.92	Mt	0.72%	Not specified
Albania	Nat. rep. code	66,703	Mt	1-4%	Cat A
Romania	UNFC	448	Mt	-	333
Serbia	NI43-101	65.3	Mt	2.6%	Inferred
Czech Republic	Nat. rep. code	49	kt	0.45%	Potentially economic
Macedonia	Ex - Yugoslavian	35.3	Mt	0.42%	A
Greece	USGS	2.8	Mt	-	Measured
Turkey	NI43-101 JORC	4.46 36.26	Mt Mt	2.67% 1.95%	Measured Measured

Table 24: Global reserves of copper in year 2016 (Data from USGS, 2016)

Country	Copper reserves (tonnes)	Percentage of total (%)
Chile	210,000,000	29
Australia	88,000,000	12
Peru	82,000,000	11
Mexico	46,000,000	6
United States	33,000,000	5
China	30,000,000	4
Russia	30,000,000	4
Dem. Republic Congo	20,000,000	3
Zambia	20,000,000	3
Canada	11,000,000	2
Other countries	150,000,000	21
World total (rounded)	*720,000,000*	*100*

Table 25: Reserve data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Quantity	Unit	Grade	Code Reserve Type
Spain	various	10.13	Mt	2.58%	Proven
Portugal	NI43-101	16.52	Mt	1.82%	Proven
Sweden	NI43-101	3.8	Mt	2.2%	Proven
	FRB-standard	516.2	Mt	0.24%	Proven
Finland	NI43-101	1.5	Mt	0.27%	Proved
	JORC	189	Mt	0.8%	Proven
Poland	Nat. rep. code	23.67	Mt	-	Total
Romania	UNFC	98	Mt	-	121
Macedonia	Ex - Yugoslavian	35.31	Mt	0.42%	A
Turkey	NI 43-101	4.49	Mt	3.02%	Proven

6.2.1.4 World mine production

The annual global production of copper ore between 2010 and 2014 was 17.1Mt on average. Figure 48 shows that Chile is the leader in world copper mining, with over 5.5 million tonnes in the period 2010-2014, accounting for about one third of world production. With the addition of Peru (8%), China (9%) and the USA (7%), the four largest mining countries share more than half of the world production. In recent decades there has been strong growth in production in South America, mainly in Chile (from 16% in 1985 to 32% of world production today) (BGS, 2007). Asian production is of growing importance (e.g. China's production increased from less than 4% in 1994 to 9% today) (USGS, 2016). Many of the world's largest copper mines are located in Chile (two of the five top spots in terms of production in 2016: Escondida and Collahuasi). The other three mines are located in other countries around the world (Grasberg in Indonesia, Cerro Verde in Peru, and Morenci in United States), but all of them are operated by major miner Freeport-McMoRan.European production is characterized by Poland which accounts for over half of the copper being mined in Europe.

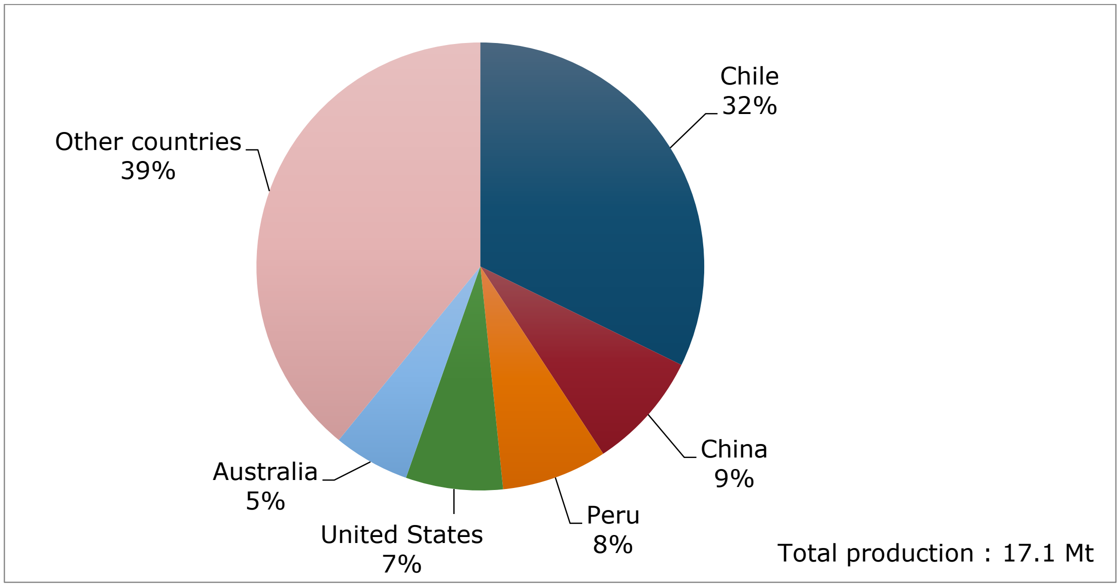


Figure 48: Global mine production of copper, average 2010–2014 (Data from BGS World Mineral Statistics database)

6.2.2 Supply from secondary materials

End of life recycling input rate for copper is estimated to be 55%. This value is found using the 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).

Most of the recycled copper originates from new or old primary scrap (not being end-of-life scrap). Depending on its impurity content the scrap must be conditioned and is then used for smelting and casting new products (Lossin, 2001).

As European mined copper is not sufficient to meet demand, the European Union is highly dependent on refining and smelting imported concentrates as well as recycling production scrap and end-of-life products (BGS, 2007).

6.2.3 EU trade

Figure 49 shows the data for copper ore imports to the EU between 2010 and 2014 (volumes are expressed in metal content, not gross weight of ores). The reliance of the EU on foreign copper ores and concentrates has been constant in recent years, around 82%. A general trend of a growing volume of international trade can be seen since 2011.

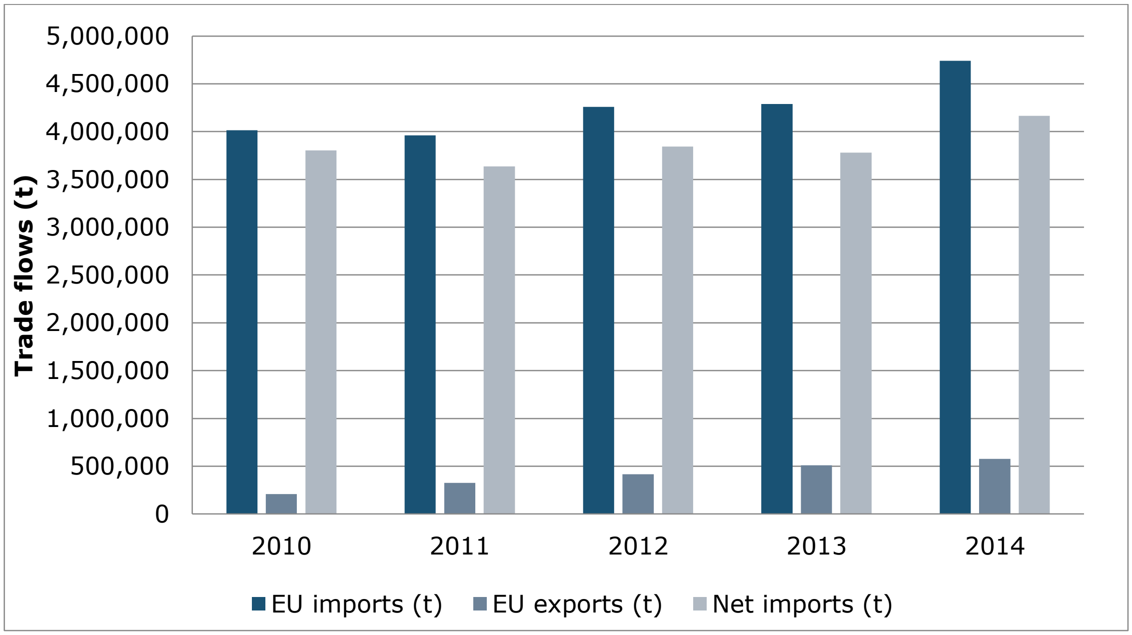


Figure 49: EU trade flows for copper content in copper ore (Data from Comext - Eurostat, 2016a)

According to Eurostat ComExt data (see Figure 50), by far the greatest amount of copper imported into the EU was from Peru and Chile. Other notable originating countries are also found in the Americas, Brazil (11%), Argentina (9%) and Canada (6%).

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.

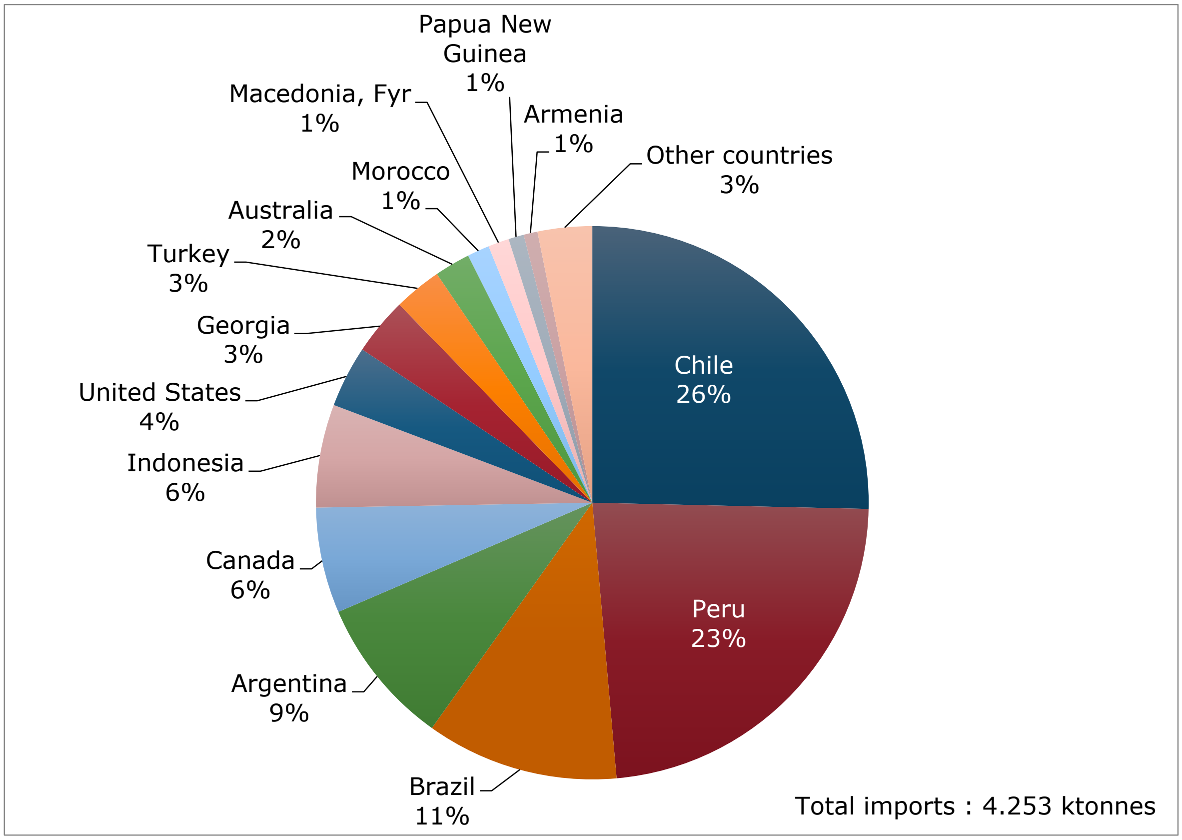


Figure 50: EU imports of copper, average 2010-2014 (Data from Comext - Eurostat, 2016a)

6.2.4 EU supply chain

Mining activity in the EU chiefly takes place in Poland, Bulgaria, Spain, Sweden and Portugal, and amounts to a total of around 816 thousand tonnes on average annually between 2010 and 2014.

In 2014, the EU28's refined copper production was 2.8 Mt, representing 3.7% of worldwide production (ISCG, 2016). Additional data sources (BGS, 2016) imply a share of EU-28 production that is around 11% (with 1,740 tonnes of EU domestic production and 15,300 tonnes of global refined copper). The main production sites are in Germany, Poland, Spain, Sweden, Finland, Belgium and Bulgaria. 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 EU28, 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).

The EU relies for the supply of copper for 82% on its imports. The Figure 51 presents the EU sourcing (domestic production + imports) for copper.

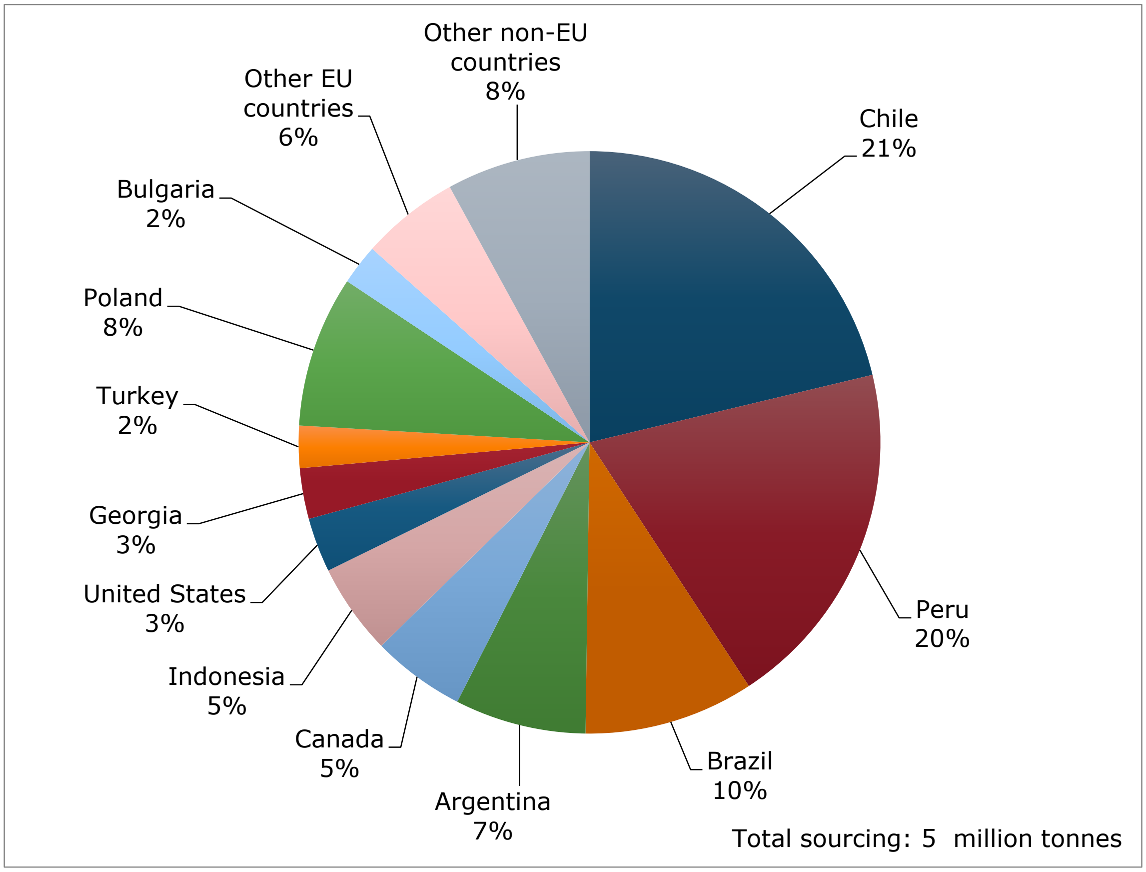


Figure 51: EU sourcing (domestic production + imports) of copper, average 2010-2014 (Data from Comext - Eurostat, 2016a; BGS, 2016)

Several countries have restrictions concerning trade with copper (OECD, 2016). According to the OECD´s inventory on export restrictions, Argentina (10%), China (10%), Dem. Republic of Congo (10% + 3% surtax) and Zambia (15%) use an export tax on ores and concentrates. 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.

Russia uses different export taxes of 10% (copper mattes, cement copper and copper base alloys) and 50% (copper waste and scrap). There is also a wide range of other countries imposing trade restrictions on products with a high percentage of copper content.

6.3 Demand

6.3.1 EU consumption

The EU consumption (defined by production and import as discussed in previous sections) was on average just above 5Mt annually between 2010 and 2014. Another source (ISCG, 2016) suggests the use of refined copper to be around 3.3 Mt. Both the net production, import and export of copper ores and concentrates are significant in the EU.

6.3.2 Applications / End uses

Due to its unique properties, copper is crucial for many applications (Figure 52).

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, 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; there is an average 25kg 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).

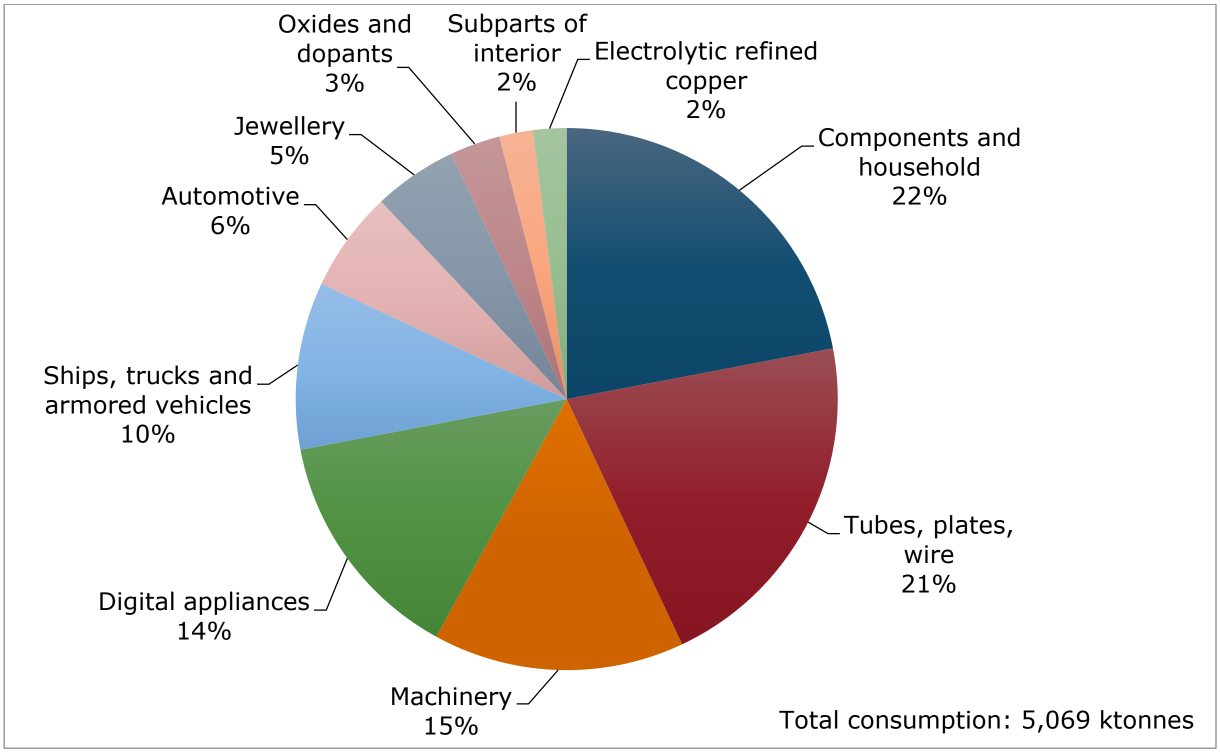


Figure 52: Global/EU end uses of copper. Average figures for 2010-2014 (Data from ICA, 2012; Glöser et al., 2013a)

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). The value added data correspond to 2013 figures.

Table 26: Copper applications, 2-digit NACE sectors, 4-digit NACE sectors and value added per sector (Data from the Eurostat database (Eurostat, 2016c))

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	110,000.0
Electrolytic refined copper	C24 - Manufacture of basic metals	C24.10 -Manufacture of tubes, pipes, hollow profiles and related fittings, of steel	57,000.0
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	159,513.4
Digital appliances	C26 - Manufacture of computer, electronic and optical products	C26.11 - Manufacture of electronic components	75,260.3
Components and household	C27 - Manufacture of electrical equipment	C27.32 -Manufacture of other electronic and electric wires and cables	84,608.9
Machinery	C28 - Manufacture of machinery and equipment n.e.c.	C28.15 -Manufacture of bearings, gears, gearing and driving elements	191,000.0
Automotive parts	C29 - Manufacture of motor vehicles, trailers and semi-trailers	C29.20 - Manufacture of bodies (coachwork) for motor vehicle	158,081.4
Ships, trucks and armoured vehicles	C30 - Manufacture of other transport equipment	C30.20 -Manufacture of railway locomotives and rolling stock	53,644.5
Subparts of interior	C31 - Manufacture of furniture	C31.01 -Manufacture of office and shop furniture	28,281.7
Jewellery	C32 - Other manufacturing	C32.11 - Manufacture of jewellery and related articles	41,612.6

6.3.3 Prices

Figure 53 shows how the supply and demand situations worldwide 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 by military was still so high that prices went up dramatically, until first oil crisis induced a price decrease. Between 2003 and 2007, a boom in Asia, low production and low stocks led to an excess of demand over supply and a significant price increase. Since then the global recession has reduced demand and hence prices. The average price of grade A copper on the London Metal Exchange between 2011 and 2015 was 7,292.49 US$/t (Figure 53). The volatility of the price was relatively low in that period (DERA, 2016).

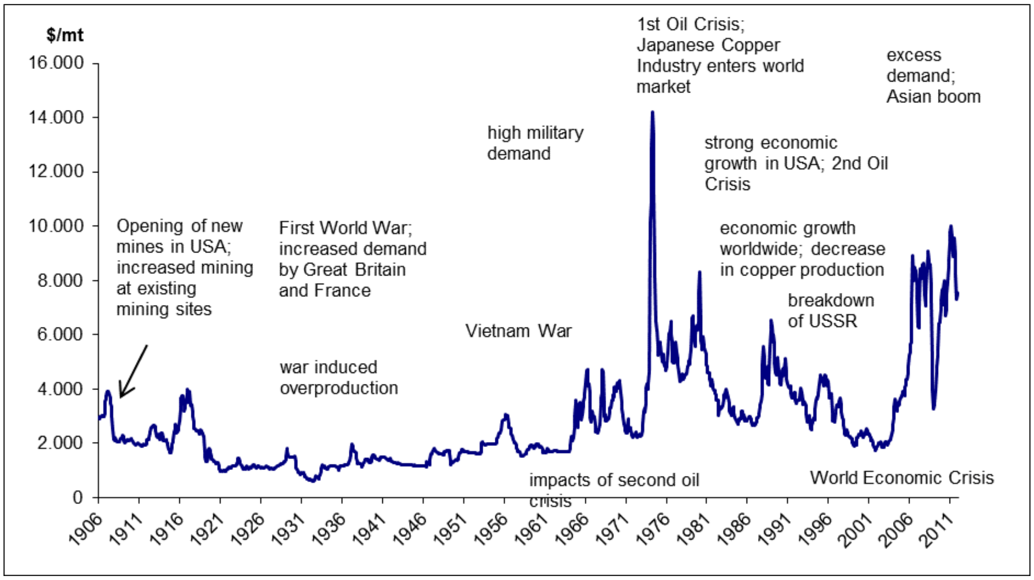


Figure 53: Global developments in price of copper. Average figures for 1906-2013. (Data from DERA 2013, translated to English by Fraunhofer ISI)

Figure 54: Monthly average cash price for copper in US$ per tonne (data from LME, 2017)

6.4 Substitution

Most 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).

The unique properties of copper (especially regarding thermal and electrical conductivity) make it difficult to substitute. 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.).

The shares of the substitute materials of copper are all assumed to be 50%. This numerical value is relatively large, since there are relatively few technical impediments (Tercero Espinoza et al., 2013) to substitute copper as described above. The substitution decision is normally taken from an economic point of view.

6.5 Discussion of the criticality assessment

6.5.1 Data sources

The product group describing the international trade of copper ores and concentrates is coded 2603 0000.

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.

6.5.2 Calculation of Economic Importance and Supply Risk indicators

The decision to analyse the criticality of copper in the extraction or refining stage of the supply chain is significant and not straightforward. There are several sources confirming a concentration of the production of refined copper compared to the copper ores and concentrates. China imports significant quantities of copper ores and waste/scrap for smelting and refining into pure forms of copper to sell on domestic and international markets. China's copper-processing capacity has grown rapidly in recent years. Its smelter production grew from 0.4 Mt in 1990 to 3.5 Mt in 2009, while its refinery production grew from 0.6 Mt to 4.2 Mt over the same period (USGS, 2011). In 2014, China accounted for nearly a third of the world's copper refinery production. This concentration value is in the same order of magnitude of the mining of copper ores and concentrates (USITC, 2012), hence the decision to analyse copper at the extraction stage of the supply chain and not at the refining stage.

After iron and aluminium, copper is the metal that is most ubiquitously present the manufactured goods used in the advanced economies of the world. The allocation of copper to determine the economic importance is therefore particularly difficult. The many stages of the value chain make it hard to determine which information source refers to what product group and corresponding sector. The allocation of (ICA, 2012) was selected given the balanced distribution of copper over various life-phases and NACE-2 sectors.

The supply risk was assessed for copper ore using both the global HHI and the EU-28 HHI as prescribed in the revised methodology.

6.5.3 Comparison with previous EU assessments

The results of copper are relatively similar to previous criticality assessments (European Commission, 2014). The decrease in economic importance has to do with the allocation to NACE-2 digit sectors rather than the mega sector approach. This change in methodology reduced the Economic Importance of materials used in metal products especially, such as copper. See Table 27.

Table 27: Economic importance and supply risk results for copper in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017.

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Copper	5.71	0.21		5.76	0.22		4.7	0.2

6.6 Other considerations

6.6.1 Forward look for supply and demand

According to (Marscheider-Weidemann et al., 2016) copper demand will grow in the coming decades. The demand for electrical motors (in industrial applications and electrical vehicles) will lead to additional consumption of copper. It is assumed that the known global reserves of copper can meet any demand increases. See Table 28.

Table 28: Qualitative forecast of supply and demand of copper

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
Copper		X	+	+	+	+	+	+

6.6.2 Environmental and regulatory issues

The REACH regulations has in impact of the use of copper in chemicals. Despite improved conditions accurate registration, authorisation and restriction of substances, industrial stakeholders' flag a need to better assess risks from the manufacturing and use of hazardous substances and mixtures (Eurometaux, 2016).

The price spikes after 2000 have infamously created a criminal habit of taking copper objects from the public space throughout the EU. Disruptions of infrastructure in recent years, trains and local roads in particular, have been commonplace as result of the economic value of copper as a material. Other supply disruptions come from strikes of workers in various Latin American countries.

6.6.3 Supply market organisation

The mining operations, in the EU and globally, are balanced given a competitive market with a globally determined price of the commodity. Despite the abundance of suppliers of both ores and processed copper, single shocks in the supply of copper can originate from individual incidents. For instance, total U.S. refined production decreased by about 5% mainly owing to a smelter maintenance shutdown and a concentrate shortfall at Bingham Canyon's integrated smelter (USGS, 2016).

6.7 Data sources

6.7.1 Data sources used in the factsheet

BGS (2007). Commodity profile copper. Available at: http://www.bgs.ac.uk/downloads/directDownload.cfm?id=1410&noexcl=true&t=Copper%20

CDA (2016). Copper Development Association inc. Applications – Machined products. [online] Available at: https://www.copper.org/applications/rodbar/

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

DKI (2016) Deutsches Kupferinstitut/copperalliance Anwendungen für Kupfer und Kupferegierungen. [online] Available at: https://www.kupferinstitut.de/de/werkstoffe/anwendung.html

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

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 (2016)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

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 Study Group (2016). Statistical yearbook. Available at: http://www.icsg.org/index.php/publications

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

Minerals (2016). The mineral copper. [online] Available at: http://www.minerals.net/mineral/copper.aspx

Minerals4EU (2014). 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. 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.

USGS (2013) 2013 Minerals Yearbook - Poland. Available at: https://minerals.usgs.gov/minerals/pubs/country/2013/myb3-2013-pl.pdf

USGS (2016)a. Brininstool, M. Copper USGS Minerals Yearbook 2014. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/copper/myb1-2014-coppe.pdf

USGS (2016)b. Mineral Commodity Summaries. Available at: https://minerals.usgs.gov/minerals/pubs/mcs/2016/mcs2016.pdf

USGS (2011). Edelstein, D. L.. USGS mineral yearbook copper. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/copper/myb1-2009-coppe.pdf

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

6.7.2 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

Glöser, S., Marcel 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: http://copperalliance.org/wordpress/wp-content/uploads/downloads/2012/11/technology_roadmap_2012_en.pdf

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

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. 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

6.8 Acknowledgments

This Factsheet was prepared by the Netherlands Organisation for Applied Scientific Research (TNO). The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this Factsheet. Specific experts that have contributed their input and feedback to the factsheet and criticality assessments are listed in the data sources section.

7. DIATOMITE

Key facts and figures

Material name and Formula	Diatomite SiO_2 (80-90%) and Al_2O_3	World/EU production (tonnes)[1]	2,067,964 / 361,953
Parent group (where applicable)	-	EU import reliance[1]	16%
Life cycle stage assessed	Extraction	Substitution index for supply risk [SI (SR)][1]	0.92
Economic importance (EI)(2017)	3.8	Substitution Index for economic importance [SI(EI)][1]	0.92
Supply risk (SR) (2017)	0.3	End of life recycling input rate	0%
Abiotic or biotic	Abiotic	Major end uses in the EU[1]	Food and beverages (49%), Paints and other chemicals (34%), Absorbents (9%)
Main product, co-product or by-product	Co-product	Major world producers[1]	United States (36%), China (20%), Denmark (6%)
Criticality results	2011	2014	2017 (current)
	Not critical	Not critical	Not critical

[1] average for 2010-2014, unless otherwise stated;

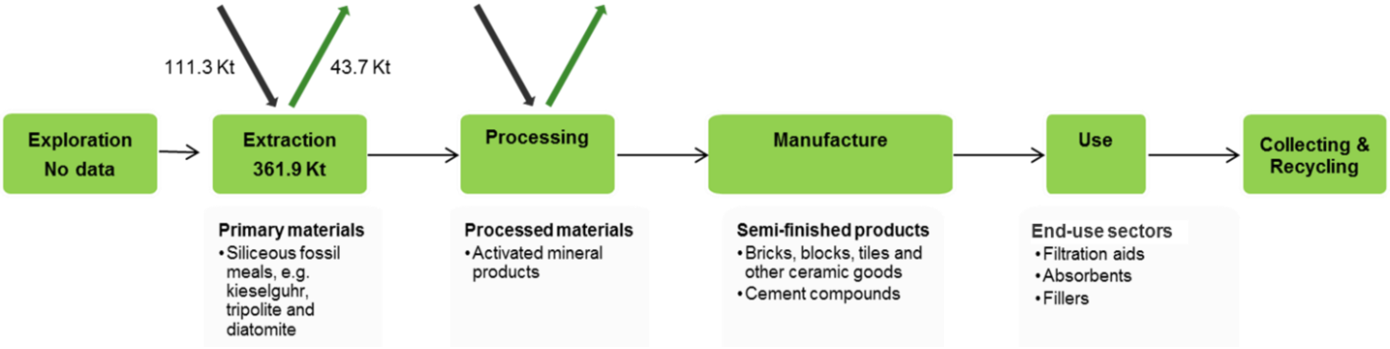


Figure 55: Simplified value chain for diatomite

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU. EU reserves are displayed in the exploration box.

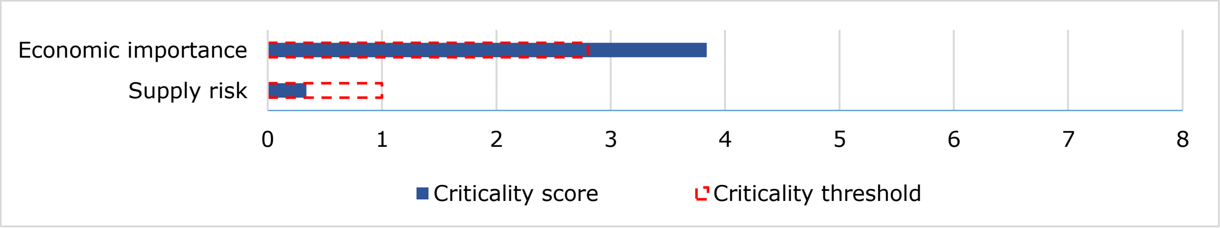


Figure 56: Economic importance and supply risk scores for diatomite

Introduction

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 at least 15,000-20,000 different forms of diatoms known, given the fact that is created from thousands of different fossilized species. Synonyms of diatomite are tripolite and kieselguhr. Further distinction 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.

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 and or other aggregates. (IMA, 2011)

7.1 Supply

7.1.1 Supply from primary materials

7.1.1.1 Geological occurrence/exploration

Diatomite deposits are formed from the 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. (Crangle, 2008). 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).

7.1.1.2 Processing

Diatomite is beneficiated according to the final purpose and three groups can be defined: natural grades, calcined grades and flux-calcined grades. Natural grades are milled, dried at relatively low temperatures and classified to remove extraneous matter and to produce a variety of different particle-size grades. These natural powders which consist primarily of amorphous silica, are generally off-white in colour.

Calcined grades are produced from the natural material by calcination, or sintering, at higher temperatures usually in excess of 900^{o} C in a rotary kiln. After calcination, the diatomite is further processed into products with selected particle size ranges that can include filter aids, multifunctional fillers and aggregates. During calcination any organics and volatiles are removed and the colour typically changes from off-white to tan or pink.

Flux-calcined grades are also produced from the natural material by calcining in a rotary kiln. Temperatures in excess of 900^{o} C, are used in the presence of a flux such as soda-ash (sodium carbonate). During flux-calcination the diatoms further increase in particle size though agglomeration, and in many instances become bright white in colour depending upon the conditions chosen. Further milling and air separation control the final particle size distribution to produce filter aids of relatively high permeability and fine white multifunctional fillers (IMA, 2011).

7.1.1.3 Resources and reserves

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 (available data are displayed in Table 29). 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[6], 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.

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, 2015).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 29: Global reserves of diatomite in year 2016 (Data from Crangle, 2016).

Country	**Diatomite Reserves (tonnes)**
United States	250,000,000
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
Russian federation	N/A
Spain	N/A
United States	N/A
World total (rounded)	*Large*

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 USA 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 in the Minerals4EU website (Minerals4EU, 2014) but cannot be summed as they are partial and they do not use the same reporting code (see Table 30).

---

[6] www.crirsco.com

Table 30: Reserve data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Quantity	Unit	Grade	Code Reserve Type
Spain	None	5,011	kt	-	Proven
Denmark	None	16.1	Million m^3	-	e
Czech Republic	Nat. rep. code	1,808	kt	-	Economic explored
Slovakia	None	2.207	Mt	-	Verified (Z1)

7.1.1.4 World mine production

The global production of diatomite between 2010 and 2014 was annually 2,068Mt on average. Figure 57 shows that between 2010 and 2014, the USA was the largest producer of diatomite with an output of almost 36%, followed by China 20% and Denmark 6%. There are many countries that produce diatomite for their own use, which is reflected in the large share of countries producing smaller quantities.

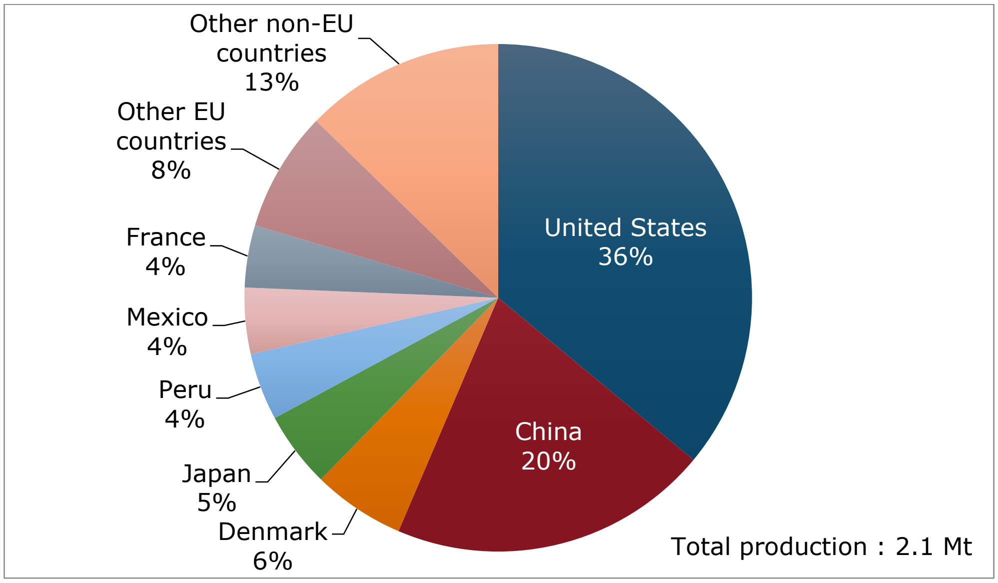


Figure 57: Global mine production of diatomite, average 2010–2014 (Data from BGS World Mineral Statistics database, 2016)

7.1.2 Supply from secondary materials

End of life recycling input rate for diatomite is estimated to be 0%.

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 it is used in agricultural industries, e.g. as fertiliser or animal feed. It 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 processes of diatomite. The EOL-RIR rate might be too low, as the material is not used in a dissipative way (BGR, 2016).

7.1.3 EU trade

Figure 58 shows the data for total diatomite imports to the EU between 2010 and 2014. The volumes, as well as the balance between imports and exports, remain fairly constant over the years. Despite the occurrence and extraction in the EU, there is a positive net import.

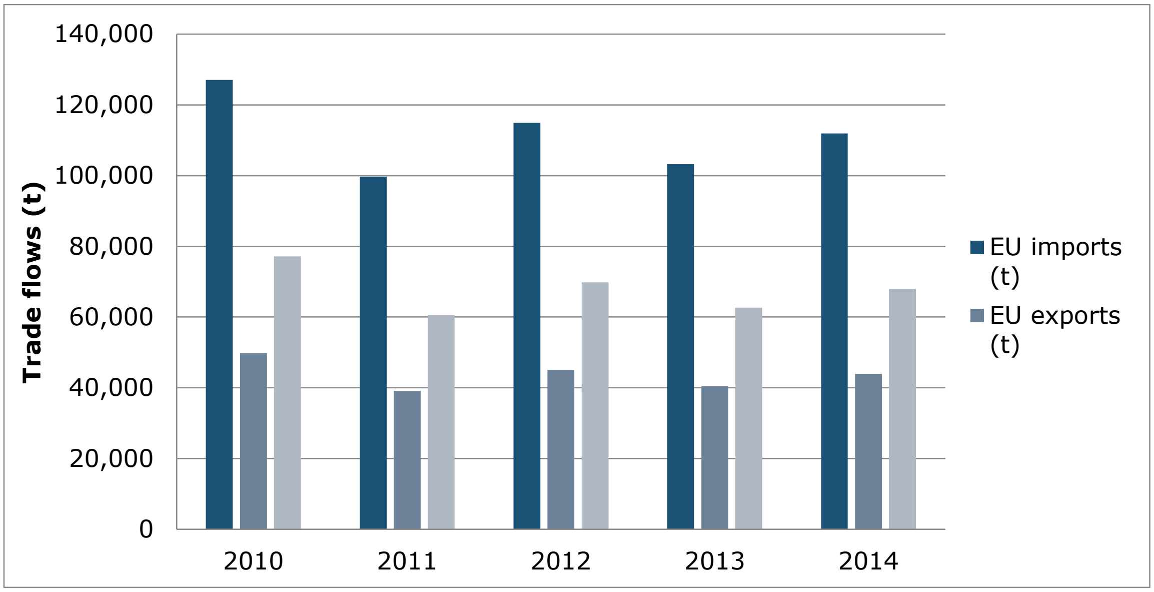


Figure 58: EU trade flows for diatomite (Data from Comext (Eurostat, 2016a))

According to Comtrade data, by far the largest amount of diatomite imported into the EU was from the USA, Turkey and Mexico. Several smaller quantities of diatomite are traded with the EU from other countries.

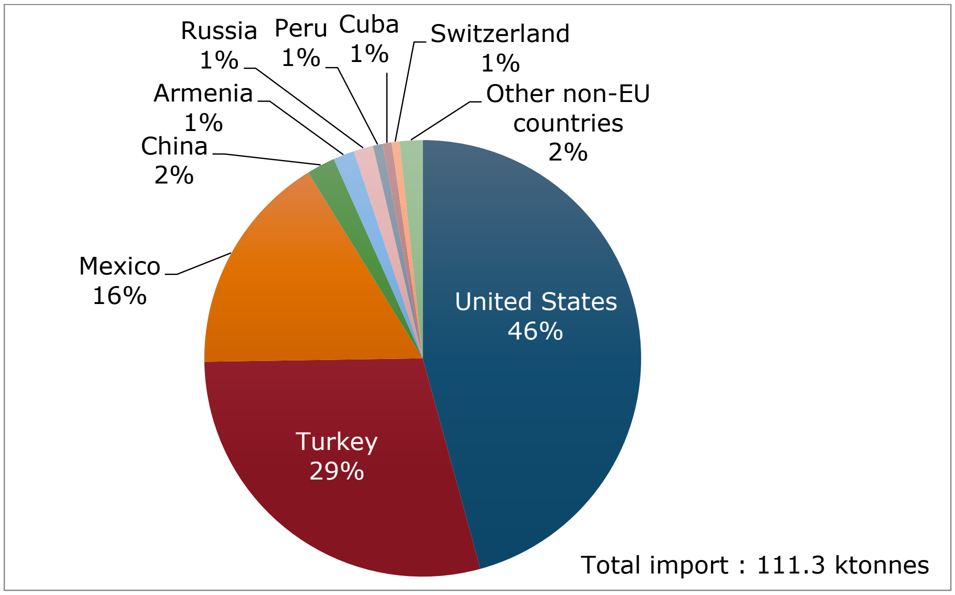


Figure 59: EU imports of diatomite, average 2010-2014 (Data from Comext - Eurostat, 2016a)

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.

7.1.4 EU supply chain

The EU relies for the supply of diatomite for 16% on its imports. Especially France and Denmark provide most of the required amounts for European supply chains. The EU sourcing (domestic production + imports) of diatomite is shown in Figure 60. The diatomite provides the chemical industry and mineral products industry, which together have a value added of close to 150 bio. EUR.

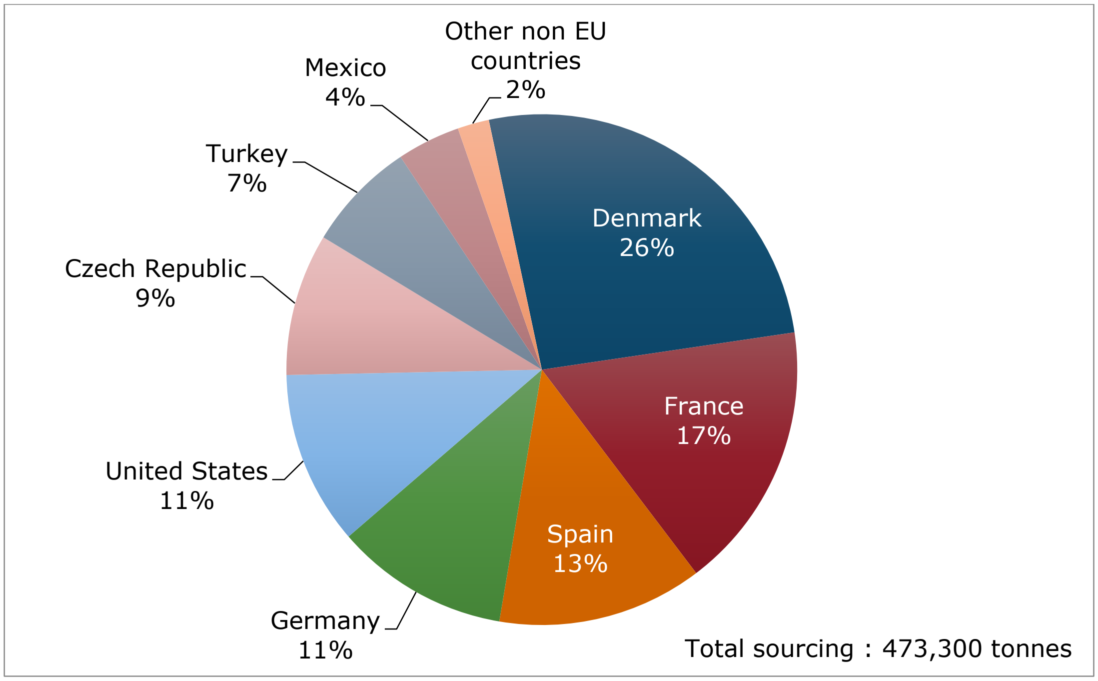


Figure 60: EU sourcing (domestic production + imports) of diatomite, average 2010-2014 (Data from Comext - Eurostat, 2016a; BGS, 2016)

There are no trade restrictions reported to product groups that mainly contain diatomite industrial minerals (OECD, 2016).

7.2 Demand

7.2.1 EU consumption

The EU consumption of diatomite averaged around 473Kt annually between 2010 and 2014. 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.

7.2.2 Applications / End uses

The unique properties of diatomite include being lightweight, having a high porosity, being highly absorbent, being highly pure, being multi-shaped and inertness (IMA, 2011).

Diatomite has a wide range of applications. The most important are:

- Filter aids (allocated to food industry): With its high porosity in combination with low density and inertness, diatomite is an excellent filtration medium. Diatomite provides the 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 (allocated to various industries): With their high capacity for liquids, diatomite variances are 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) Furthermore diatomite is used in the clean-up of spills in different industries (IDPA, 2016).

- Fillers/carriers (allocated to food & beverage manufacturing and chemical industry): Diatomite is used as a filler in rubber or plastic. High quality dust white grade is also used as delustering agent in paints and to adjust their viscosity.
- Some minor amounts of diatomite are used as powder in polishes, toothpastes, and silver polishes. It is also used as packing material for hazardous liquids. (allocated to various industries)

Figure 61 provides an overview of the use of diatomite. In terms of economic sectors, diatomite is allocated to the food industry (filtration aid), chemical industry and other applications (NACE 20 and 23) by 49% and 34%. Base metal and machinery manufacturing receive smaller shares.

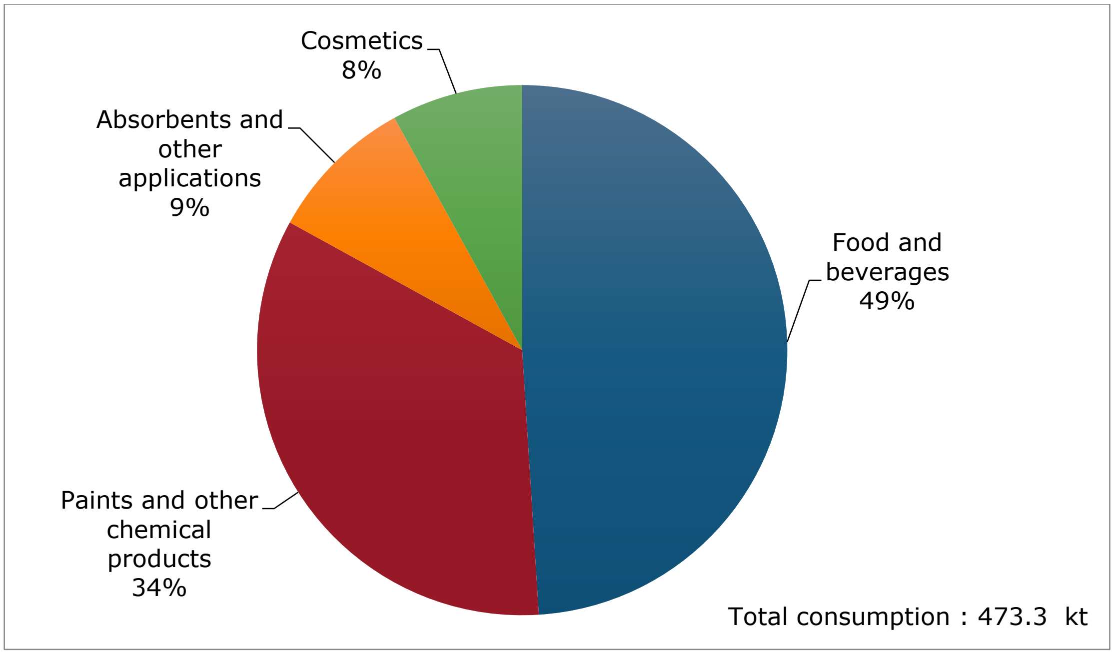


Figure 61: Global/EU end uses of diatomite. Average figures for 2010-2014 (Data from Crangle 2016)

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. See Table 31.

The applications and sector names seem somewhat different for diatomite given the generic and versatile character of diatomite applications. The value added data correspond to 2013 figures.

Table 31: Diatomite applications, 2-digit NACE sectors, associated 4-digit NACE sectors, and value added per sector (Data from the Eurostat database (Eurostat, 2016c)

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (millions €)
e.g. Food processing agents and paints	C20 - Manufacture of chemicals and chemical products	C20.22 - Manufacture of paints, varnishes and similar coatings, printing ink and mastics	110,000.0
e.g. Filters	C23 - Manufacture of other non-metallic mineral products	C23.64 - Manufacture of mortars	59,166.0

Applications	**2-digit NACE sector**	**4-digit NACE sector**	**Value added of sector (millions €)**
e.g. Absorbents	C24 - Manufacture of basic metals	C24.54 - Casting of other non-ferrous metals	57,000.0
e.g. Fillers	C28 - Manufacture of machinery and equipment n.e.c.	C28.21 - Manufacture of ovens, furnaces and furnace burners	191,000.0

7.2.3 Prices

The time-series of the price of diatomite is shown in Figure 62. The time frame starts at 1945, to show both the long history that diatomite has as an industrial mineral as well as the slow moving price trends that are associated with the material. The price volatility is relatively low. Price increases were mostly instigated by the increase in transportation costs (IDPA, 2016). The average price of diatomite filter aids between 2011 and 2015 was 619,50 US$/t (DERA, 2016).

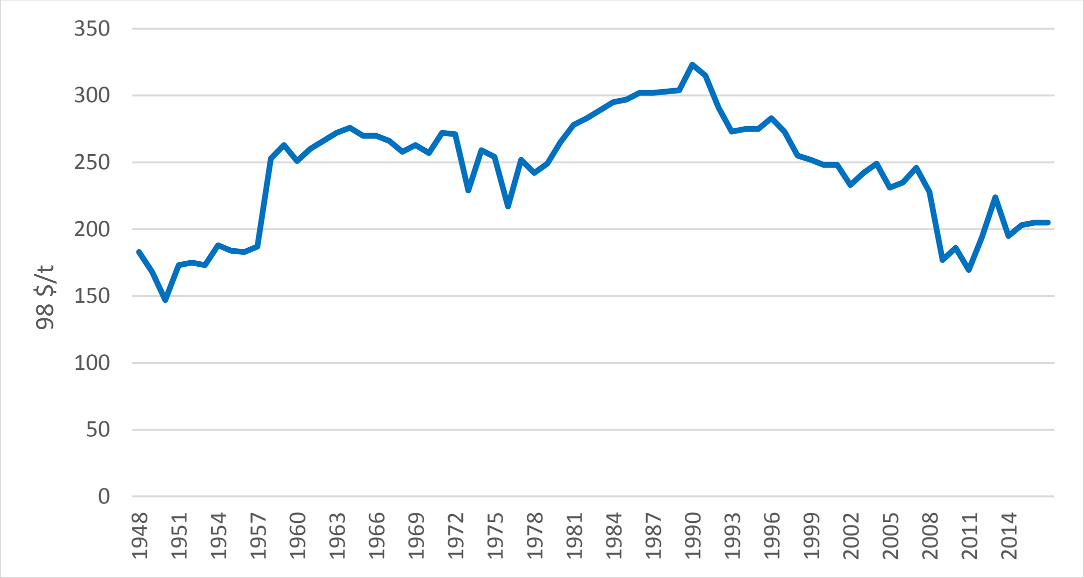


Figure 62: Developments in price of diatomite in the US. (Data from USGS 2016)

7.3 Substitution

Although diatomite has unique properties it can be substituted in nearly all applications. Possible substitutes for the filtration are expanded perlite and silica sands, as well as synthetic filters (ceramic, polymeric or carbon membrane) compete with diatomite as a filter aid. In the beverage industry, cellulose or potato starch can also replace diatomaceous earth; and there are other methods to filter beer such as mechanical centrifuging (Crangle, 2016). Possible substitutes for the filler applications are kaolin clay, Ground Calcium Carbonate (GCC), ground mica, perlite or talc can replace diatomite in some filler applications. The high costs associated with these alternatives and sometimes the lowered performance and a 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 (Crangle, 2016).

7.4 Discussion of the criticality assessment

7.4.1 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.

7.4.2 Calculation of Economic Importance and Supply Risk indicators

The economic use of diatomite is determined by distance to market and the related transport costs (BGR, 2016). The criticality analysis has therefore no real basis at the refinery stage, and is conducted at the extraction stage.

The supply risk was assessed for diatomite using both the global HHI and the EU-28 HHI as prescribed in the revised methodology.

7.4.3 Comparison with previous EU assessments

The results of the 2017 assessment are consistent with the previous two assessments. The economic importance change between 2014 and 2017 is due to a shift in allocation between sectors. More diatomite is allocated to the chemical products manufacturing. The NACE2 sector has a higher value added than that of the mega sector used in 2014 (European Commission, 2014). See Table 32.

Table 32: Economic importance and supply risk results for diatomite in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017.

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Diatomite	3.73	0.34		3.02	0.24		3.8	0.3

7.5 Other considerations

7.5.1 Forward look for supply and demand

In the coming decade(s), the supply of diatomite is expected to remain constant. Both the demand and supply of diatomite are not expected to see drastic changes (BGR, 2016).

Table 33: Qualitative forecast of supply and demand of diatomite

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
Diatomite		X	0/+	0/+	0/+	0/+	0/+	0/+

7.5.2 Environmental and regulatory issues

The EU Occupational Health and Safety Agency (EU-OSHA) has proposed new campaigns aiming at new regulation in 2012 and 2013 regarding occupational exposure to crystalline silica, for instance in the context of lung cancer. The resulting mining practices do not create risks that are above exposure to many other work environments (IMA, 2016).

7.6 Data sources

7.6.1 Data sources used in the factsheet

BGR (2016). 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 (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. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

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

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 (2014). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

USGS (2016). Crangle, R. D. USGS 2015 Minerals Yearbook, diatomite. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/diatomite/myb1-2015-diato.pdf

7.6.2 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

USGS (2016). Crangle, R. D. USGS 2015 Minerals Yearbook, diatomite. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/diatomite/myb1-2015-diato.pdf

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

7.7 Acknowledgments

This Factsheet was prepared by the Netherlands Organisation for Applied Scientific Research (TNO). The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this Factsheet.

8. FELDSPAR

Key facts and figures

Material name and Formulas	Feldspar, $KAlSi_3O_8$, $NaAlSi_3O_8$, $CaAl_2Si_2O_8$	World/EU production (tonnes)[1]	26,792,265/ 10,395,772
Parent group (where applicable)	-	EU import reliance[1]	0%
Life cycle stage assessed	Extraction	Substitution index for supply risk [SI (SR)][1]	0.97
Economic importance (EI)(2017)	2.4	Substitution Index for economic importance [SI(EI)][1]	0.90
Supply risk (SR) (2017)	0.7	End of life recycling input rate	10%
Abiotic or biotic	Abiotic	Major end uses in the EU[1]	Ceramics (36%), Flat glass (30%), Container glass (30%)
Main product, co-product or by-product	Main product	Major world producers[1]	Turkey (26%), Germany (22%), Italy (8%)
Criticality results	2011	2014	2017
	Not critical	Not critical	Not critical

[1] average for 2010-2014, unless otherwise stated;

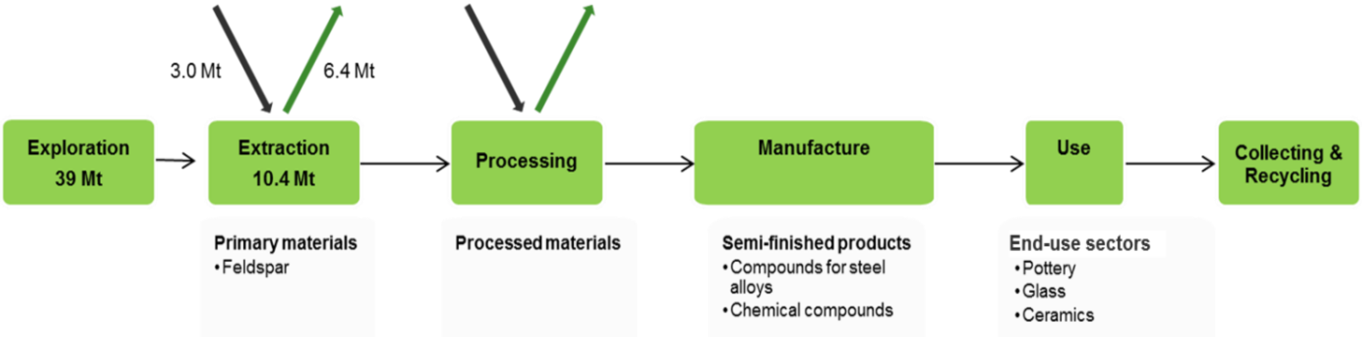


Figure 63: Simplified value chain for feldspar

The green boxes of the extraction and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU. EU reserves are displayed in the exploration box.

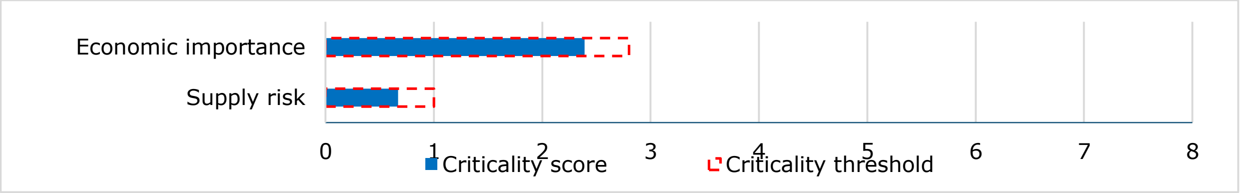


Figure 64: Economic importance and supply risk scores for feldspar

8.1 Introduction

Feldspar is group of non-metallic minerals, which are silicates of aluminium, containing sodium, potassium, calcium or combinations of these elements. The term feldspar traces back to 1785, when it was composed from the German words Feld (field) and Spath (spar). In this sense, feldspar describes a group of minerals which are by far most common in the Earth's crust, forming about 60% of terrestrial rocks. However, only a part of feldspar is suitable for industrial use. European resources contain potassium feldspar as well as sodium feldspar and mixed feldspars. In industrial uses feldspar is primarily used for its high alumina and alkali content. Feldspar surrounds us in our daily life in the form of drinking glasses, glass for protection, glass wool for insulation, floor tiles, shower basins and tableware.

8.2 Supply

8.2.1 Supply from primary materials

8.2.1.1 Geological occurrence/exploration

Feldspar minerals are essential components in all types of rocks, such as igneous, metamorphic and sedimentary rocks, to such an extent that the classification of a number of rocks is based upon feldspar content. The mineralogical composition of most feldspars can be expressed in terms of the ternary system orthoclase ($KAlSi_3O_8$), albite ($NaAlSi_3O_8$) and anorthite ($CaAl_2Si_2O_8$) (IMA-Europe 2013).

The minerals of which the composition is comprised between albite and anorthite are known as the plagioclase feldspars, while those comprised between albite and orthoclase are called the alkali feldspars due to the presence of alkali metals sodium and potassium. The alkali feldspars are of particular interest in terms of industrial use of feldspars. Amongst the numerous rocks in which they are present, feldspars are particularly abundant in igneous rocks like granite, which contains up to 50% or 70% of alkaline feldspar. Granite, however, rarely is used for its feldspatic content. Rather, a whole range of rocks geologically connected to granite are used. Most often, commercial feldspar is mined from pegmatite or feldspathic sand deposits. Aplite, which is a fine-grained igneous rock with the same mineralogical composition as granite, also is mined frequently for its feldspar content (IMA-Europe 2013).

8.2.1.2 Processing

The beneficiation of feldspar is an established relatively simple process. It is aimed at removing the impurities of the rock whilst maintaining the alumina content at a required level. The feldspar is successively drilled, grinded, filtered, dried and “deslimed”. The challenge is to recover a product that is slime free and has a grain size of around 0.6mm (Michaud, 2016).

8.2.1.3 Resources and reserves

There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of feldspar 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[7], 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.

For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for feldspar. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for feldspar, 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 feldspar the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU, 2015).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.

According to USGS, identified and undiscovered resources of feldspar are more than adequate to meet anticipated world demand. Quantitative data on resources of feldspar existing in feldspathic sands, granites, and pegmatites generally have not been compiled. Ample geologic evidence indicates that resources are large, although not always conveniently accessible to the principal centers of consumption.

The global reserves of feldspar are among the largest of any commercially exploited raw material. This makes a challenging task to define and document accurately. Only some countries have documented feldspar reserves (USGS, 2016). Reserve data for some countries in Europe are available in the Minerals4EU website (Minerals4EU, 2014) but cannot be summed as they are partial and they do not use the same reporting code.

Table 34: Global reserves of feldspar in year 2016 (Data from USGS, 2016)

Country	Feldspar Reserves (tonnes)
Argentina	N/A
China	N/A
Germany	N/A
Italy	N/A
Korea, Republic of	N/A
Malaysia	N/A
Spain	N/A
Thailand	N/A
Egypt	1,000,000,000
Iran	630,000,000
Brazil	320,000,000
Turkey	240,000,000
India	45,000,000
Czech Republic	25,000,000
Poland	14,000,000
World total (rounded)	*Unknown, but large*

---

[7] www.crirsco.com

Table 35: Reserve data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Quantity	Unit	Grade	Code Reserve Type
Spain	None	174.1	Mt	-	Proven
Italy	None	1	Mt	-	Estimated
Ukraine	Russian Classification	362.38	kt	-	(RUS)A
Poland	Nat. rep. code	5.19	Mt	-	Total
Romania	UNFC	2	Mt	-	111
Slovakia	None	3.093	Mt	-	Probable (Z2)
Czech Republic	Nat. rep. code	25,889	kt	-	Economic explored

8.2.1.4 World mine production

The global production of feldspar between 2010 and 2014 was annually 26.8Mt on average. Turkey, Italy and Germany are the leading producers for feldspar worldwide. EU production accounts for close to one-third of the total world production (Figure 65).

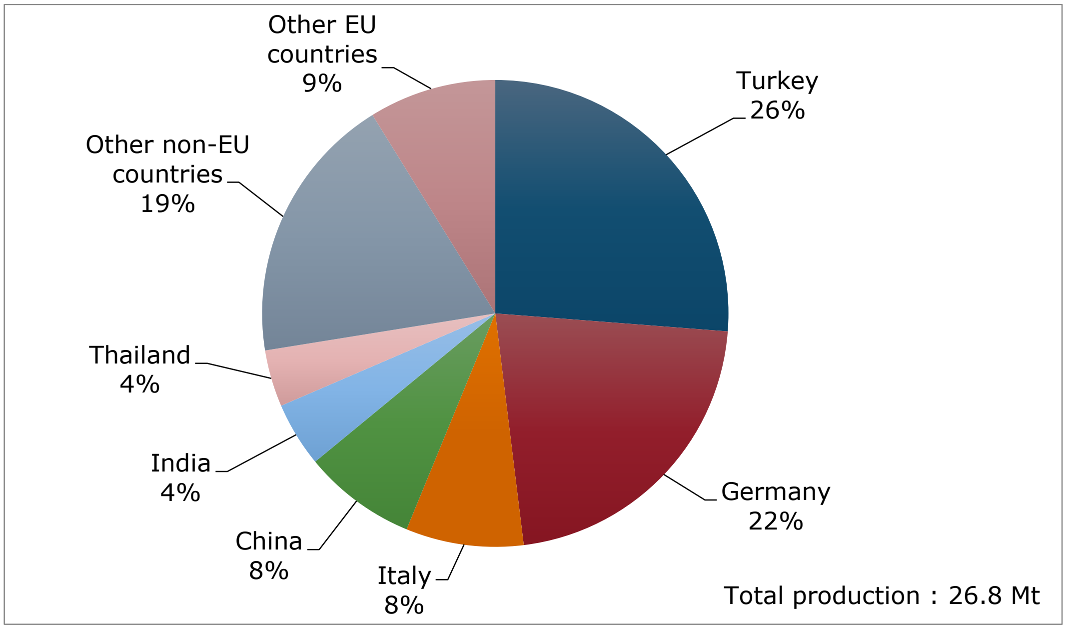


Figure 65: Global mine production of feldspar, average 2010–2014 (Data WMD 2016)

8.2.2 Supply from secondary materials

Feldspar is not recycled by producers of feldspar containing products. The end-of-life recycling input rate is therefore set at 10%.

In general, glass can be recycled by nearly 100% without any loss in purity and quality, reducing feldspar consumption up to 70% in glass manufacturing. The average glass recycling rate in the EU exceeded was around 73% in all EU Member States (FEVE, 2015). However, much of the above has no impact on the annual use of feldspar, as this recycling does not contribute to the recycling input rate for feldspar. To improve this rate, it would be important to separate glass containers from other kinds of glass such as windows to be separated in different colours to ensure the quality of the cullet product.

8.2.3 EU trade

Due to a high number of deposits and feldspar producing countries, Europe is relatively self-sufficient in the supply of feldspar. There is a trade surplus that has even grown in recent years. Figure 66 shows the development of the international trade in feldspar by the EU.

The supplying countries outside the EU are shown in Figure 67. By far the largest amount of feldspar imported into the EU was from Turkey.

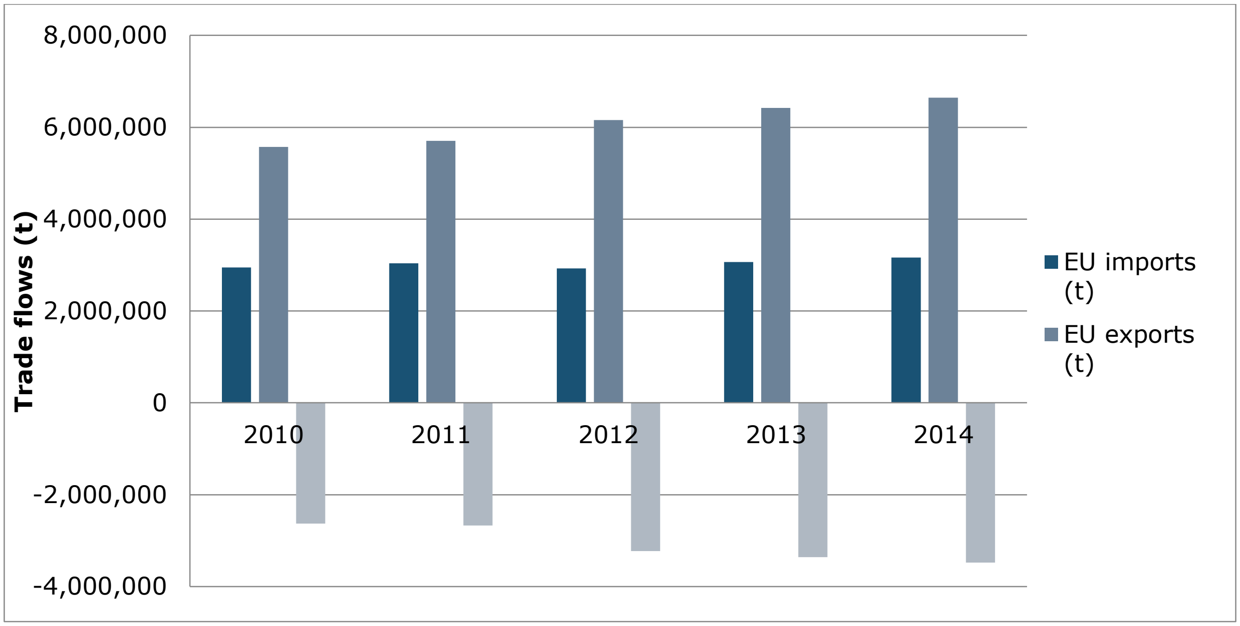


Figure 66: EU trade flows for feldspar. (Data from Eurostat Comext 2016)

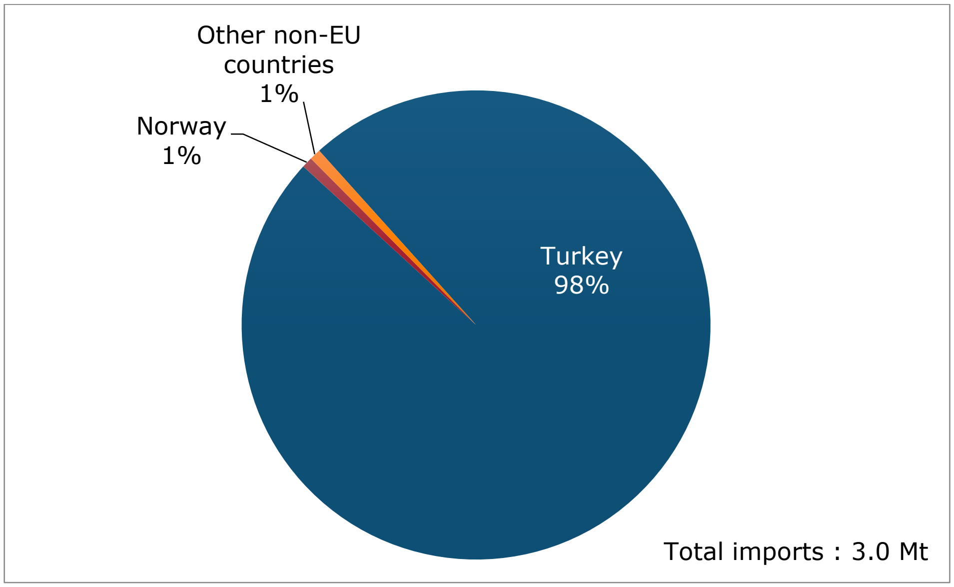


Figure 67: EU imports of feldspar, average 2010-2014. (Data from Eurostat Comext 2016)

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.

There were no trade restriction for feldspar over the 2010-2014 period (OECD, 2016). Some EU free trade agreements are in place with Turkey, Norway, Macedonia and Morocco (European Commission, 2016).

8.2.4 EU supply chain

Germany and Italy are the main producers of feldspar in the EU, but Spain, France, Poland, Czech Republic and Portugal are also important sources of feldspar within the EU. The EU sourcing (domestic production + imports) is shown in the Figure 68. The EU is a net exporter of feldspar, and has a negative import reliance, which is set at 0% in the calculation.

There are no trade restrictions documented, apart from a licensing requirement in Malaysia (OECD, 2016).

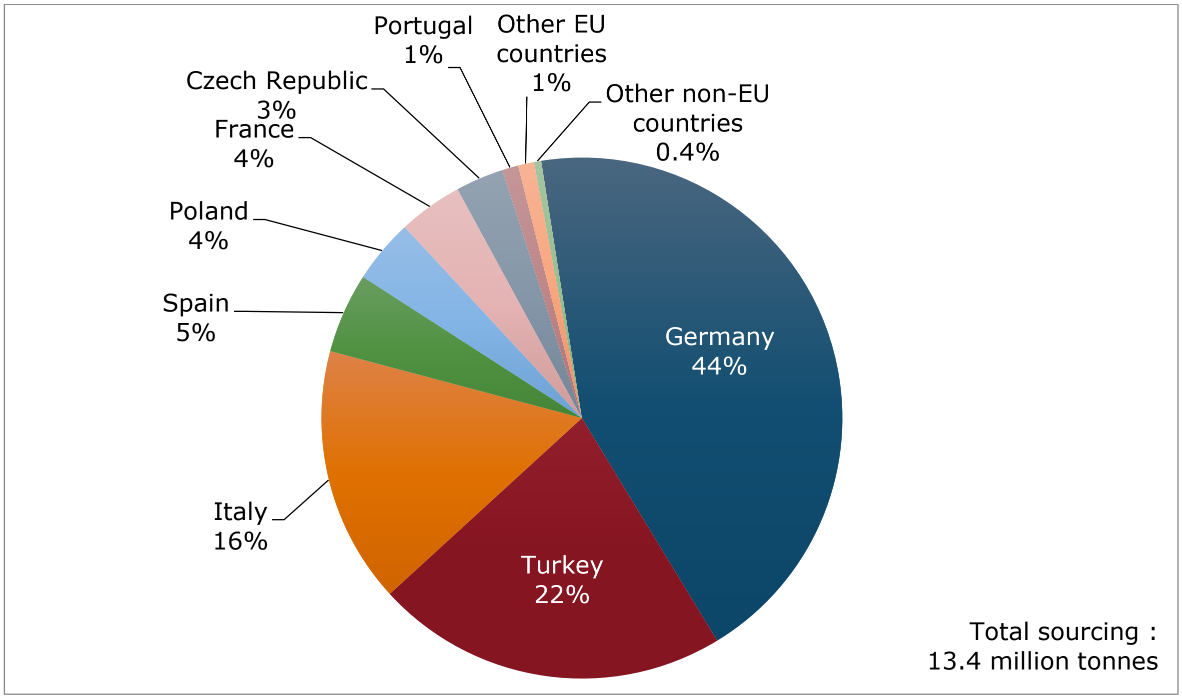


Figure 68: EU sourcing (domestic production + imports) of feldspar, average 2010-2014. (Data from Eurostat - Comext 2016a; BGS, 2016)

The manufacturing of non-metallic mineral products has an annual value added of 59 billion EUR in the EU (Eurostat 2016). The wide range of use of feldspar containing products in the construction sector, and specialized retail (pottery producing shops), represents a sizeable part of the EU GDP in general.

8.3 Demand

8.3.1 EU consumption

The annual consumption of feldspar in the EU was around 13.4 Mt between 2010 and 2014.

8.3.2 Applications / End uses

Basically, the two properties which make feldspars useful for downstream industries are their alkali and alumina content. On those elements we can distinguish three families: Feldspathic sand, Pegmatite and Feldspar. A further distinction can be made between sodium, potassium and mixed feldspars, depending on the type of alkali they contain. Feldspars play an important role as fluxing agents in ceramics and glass applications, and also are used as functional fillers in the paint, plastic, rubber and adhesive industries) (IMA-Europe 2013).

Feldspar is used as a fluxing agent, and is therefore hard, durable and resistant to corrosion. some extent as a filler and extender in paint, plastics, and rubber

In Figure 69 the shares of different feldspar end-uses are shown: the most important applications are:

- Glass: Feldspar is an important ingredient and raw material in glass manufacture. While its alkali content 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.
- Ceramics: Since feldspar melts gradually over a range of temperatures, adding feldspar to ceramics' main ingredient clay in a certain mix enables control of the important step of melting quartz and clay in the ceramic making process. Moreover feldspar supports formation of glazes as well as a glassy phase at low temperatures, and improves the strength, toughness, and durability of the ceramic body.
- Feldspar is also used as filler and extender in applications such as paints, plastics and rubber. Further end-uses are in mild abrasives, urethane, welding electrodes in the production of steel, latex foam and road aggregate.

There is a long term gradual shift from ceramics towards glass markets, due to increasing demand for automotive glass, fiberglass for thermal insulation and solar glass, used in the production of solar cells (USGS, 2016).

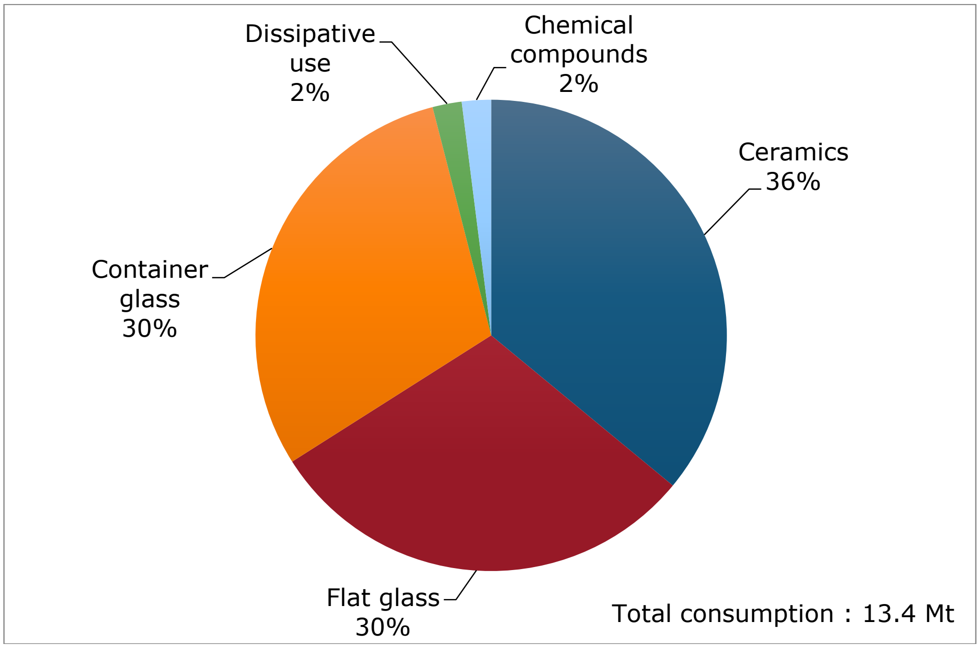


Figure 69: Global/EU end uses of feldspar. Average figures for 2010-2014. (Data from IMA 2013)

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 36). The value added data correspond to 2013 figures.

Table 36: Feldspar applications, 2-digit NACE sectors, associated 4-digit NACE sectors, and value added per sector (Data from the Eurostat database, Eurostat, 2016c).

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (millions €)
Chemical compounds	C20 - Manufacture of chemicals and chemical products	C20.52 - Manufacture of glues	110,000.0
Glasses and ceramics	C23 - Manufacture of other non-metallic mineral products	C23.43 - Manufacture of ceramic insulators and insulating fittings	59,166.0
Dissipative use	C24 - Manufacture of basic metals	C24.10 - Manufacture of tubes, pipes, hollow profiles and related fittings, of steel	57,000.0

The allocation of the use of feldspar to NACE sector "Manufacture of non-metallic mineral products" (23) has been a significant decision. Firstly because this sector is estimated to use 96% of the feldspar (30% flat glass, 30% container glass and 35% ceramic). Secondly because downward activities are thereby excluded. There is no evidence directly linking the use of feldspar to certain construction sectors. Service activities such as retail or hospitality activities are by definition out of scope of the Economic Importance assessment. The other 4% of feldspar is allocated to the chemical industry and base metal production.

8.3.3 Prices

The prices of feldspar minerals have been relatively stable throughout the last decades (Cuddington & Nülle, 2012) at around 45 and 65 EUR per ton.

8.4 Substitution

The possible substitutes for feldspar depend on its end-use. The major alternative material in the USA is nepheline syenite. Feldspar can also be replaced by clays, electric furnace slag, feldspar-silica mixtures, pyrophyllite, spodumene or talc. (USGS, 2016). For the use of feldspar in ceramic and glass industry, the substitution material could be nepheline (a silica-under saturated aluminosilicate).

For glass industry borates can be used but not as substitute (Christidis, 2011). This fact has been used to apply substitution options for the use of feldspar, resulting in a lower supply risk related to the substitution rate.

8.5 Discussion of the criticality assessment

8.5.1 Data sources

The trade of feldspar is analysed by the comext database using the CN code 25291000, a product group aptly named "Feldspar".

Feldspar is one of the few commodities where multiple sources were used to determine the world production. There were significant differences between the BGS World mineral statistics (BGS, 2016), the USGS and the world mining data (WMD). The WMD statistics were used, since it was observed that deviating data for Germany and Italy was present compared to the BGS data.

The data has a very strong coverage, on EU level, is available for time series and updated at regular intervals and is publicly available.

8.5.2 Calculation of Economic Importance and Supply Risk indicators

Feldspar has a refinery process that is usually taking place in the vicinity of the extraction location. (Michaud, 2012). This fact, in combination with the quality of the available data at the extraction phase, has made the decision to assess feldspar at the extraction stage.

The supply risk was assessed on feldspar using both the global HHI and the EU-28 HHI as prescribed in the revised methodology.

8.5.3 Comparison with previous EU assessments

In previous criticality assessments, Feldspar has been allocated to megasector "Plastic", that also comprised of rubber, ceramic and glass products. The value added of this sector is almost twice as high as the value added recorded for NACE sector "Manufacture of non-metallic mineral products" (23). This fact caused the economic importance of feldspar to consequently be lower. See Table 37.

Table 37: Economic importance and supply risk results for tungsten in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Feldspar	5.19	0.23		4.82	0.35		2.4	0.7

8.6 Other considerations

8.6.1 Forward look for supply and demand

Although worldwide production of feldspar increased significantly from 6.25 million tonnes in 1994 to 21.2 million tons in 2011, actual and potential resources of feldspar are likely to be more than adequate to meet anticipated world demand in the future. See Table 38.

Table 38: Qualitative forecast of supply and demand of feldspar

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
Feldspar		x	+	+	+	+	+	+

If the vast stocks of feldspar containing materials (e.g. glass, ceramics) could be recovered in a process that would result in a flow that is of sufficient quality to replace primary feldspar, the supply of feldspar could increase enormously. (FEVE, 2015)

8.6.2 Supply market organisation

The market feldspar producing companies in the EU are organised within Eurofel, the European association of feldspar producers.

8.7 Data sources

8.7.1 Data sources used in the factsheet

BGS (2016) World Mineral Production 2010-2014 [online]. Keyworth, Nottingham British Geological Survey, Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.html

Cuddington, J. T., Nülle, G. (2012) Variable Long-Term Trends in Mineral Prices: The Ongoing Tug-of-War between Exploration, Depletion, and Technological Change. Available at: http://econbus.mines.edu/working-papers/wp201302.pdf

European Commission (2010). 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 (2016)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

Eurostat (2016)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

FEVE (2015). European Container Glass Federation publication. Available at: http://feve.org/wp-content/uploads/2016/04/Press-Release-EU.pdf

IMA-Europe (2013). Feldspar Fact sheet. Available at: http://www.ima-europe.eu/sites/ima-europe.eu/files/publications/Feldspar_An-WEB-2011.pdf .

Michaud, L. D. (2016). Feldspar beneficiation & flotation process. Available at : https://www.911metallurgist.com/blog/feldspar-beneficiation-flotation-process

Minerals4EU (2014). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

USGS (2016) Tanner, A. O.,2014 Minerals Yearbook U.S. Department of the Interior U.S. Geological Survey Feldspar and Nepheline Syenite. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/feldspar/myb1-2014-felds.pdf

8.7.2 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

Christidis, G.E. (2011). Industrial minerals: Significance and important characteristics. European Mineralogical Union Notes in Mineralogy. Vol.9

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 Comext (2016)a. International trade in goods database (COMEXT) Available at: http://ec.europa.eu/eurostat/data/database

IMA-Europe (2013). Feldspar Fact sheet. Available at: http://www.ima-europe.eu/sites/ima-europe.eu/files/publications/Feldspar_An-WEB-2011.pdf .

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

WMD (2016). Reichl, C., Schatz, M., Zsak, G, World mining data. Volume 31. Minerals Production, Vienna. Available at: http://www.wmc.org.pl/sites/default/files/WMD2016.pdf

8.8 Acknowledgments

This Factsheet was prepared by the Netherlands Organisation for Applied Scientific Research (TNO). The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials for their contributions to the preparation of this Factsheet. Specific experts that have contributed their input and feedback to the factsheet and criticality assessments are listed in the data sources section.

9. GOLD

Key facts and figures

Material name and Element symbol	Gold; Au	World/EU production (tonnes)[1]	2,797 / 23
Parent group (where applicable)	n/a	EU import reliance	n.a[2]
Life cycle stage / material assessed	Mine production / Ores and concentrates	Substitution index for supply risk [SI(SR)][1]	0.99
Economic importance (EI) (2017)	2.0	Substitution Index for economic importance [SI(EI)][1]	0.98
Supply risk (SR) (2017)	0.2	End of life recycling input rate	20%
Abiotic or biotic	Abiotic	Major end uses (non-monetary) in EU[1]	Jewellery (83%), Electronics (11%)
Main product, co-product or by-product	Mostly main product, but also by-product or co-product of base metal and silver extraction	Major world producers[1]	China (14%), Australia (9%), USA (8%)
Criticality results	2011	2014	2017 (current)
	Not assessed	Not critical	Not critical

[1] average for 2010-2014, unless otherwise stated; [2] meaningful import reliance cannot be calculated because of complexity of trade flows of gold in diverse forms and uncertainties in reported trade data

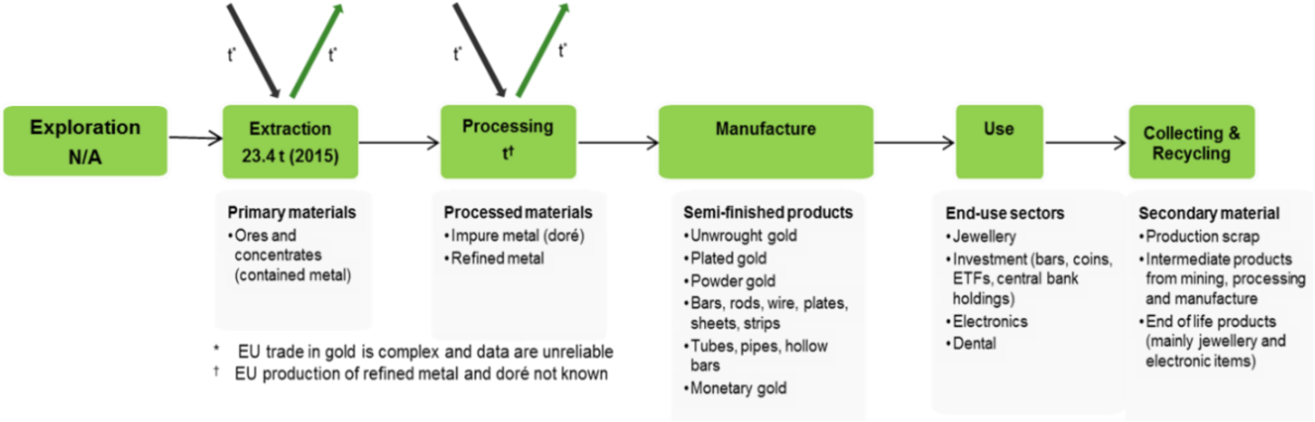


Figure 70: Simplified value chain for gold

The green boxes in the above figure identify activities undertaken within the EU. The thick black arrows represent imports to the EU and the green arrows represent exports from the EU. A quantitative figure on recycling is not included as the EOL-RIR is below 70%. EU reserves are displayed in the exploration box.

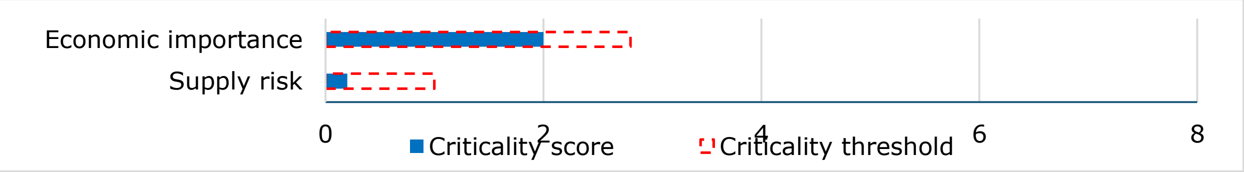


Figure 71: Economic importance and supply risk scores for gold

9.1 Introduction

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. Gold is a dense, soft, malleable and ductile metal with a bright yellow colour and lustre. It has high thermal and electrical conductivity. It is rare in the Earth's crust with an estimated abundance of 1.3 parts per billion (ppb) (Rudnick, 2003). In the uppercrust, its abundance is 1.5 ppb (Rudnick, 2003). It is found chiefly as the native metal, although it commonly occurs in a solid solution series with silver (as electrum) and also 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 in coins and bars as a safe haven for storing wealth, in electrical and electronic equipment, and in dentistry and medicine.

Gold is mined in several European countries but production levels are relatively small on a global scale. 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.

9.2 Supply

9.2.1 Supply from primary materials

9.2.1.1 Geological occurrence

Gold can be concentrated in a variety of geological settings and consequently 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 deposit 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:

1. Greenstone-hosted quartz-carbonate veins
1. Palaeoplacers
2. Epithermal deposits
3. Porphyry gold deposits
4. Carlin type deposits
5. Iron formation hosted deposits
6. Gold-rich massive sulphides.

While extraction from placer deposits remains widespread it is no longer a major contributor to gold supply.

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 tonnes 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 the 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.

9.2.1.2 Exploration

Gold accounts for the major share of global exploration expenditure for non-ferrous metals. From an all-time high in 2012 of US$10.5 billion gold exploration expenditure fell by about 60% to US$4.2 billion 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 million ounces of gold discovered in the period 2010–2013, only one was located in Europe, the Timok copper-gold deposit in Serbia (Schodde, 2015).

9.2.1.3 Mining, processing and extractive metallurgy

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.

The gold ore is crushed and milled to produce a fine powder. The subsequent processing depends on various technical factors the most important of which is whether the gold is free milling or refractory. A free milling ore contains gold in native form which 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. 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. Free milling gold can also be recovered by direct flotation (since Au is naturally hydrophobic).

In a refractory ore the gold is typically very fine grained and is enclosed in a host mineral that is impervious to cyanide leaching, most commonly sulphides or carbonaceous material. 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 (Mining Magazine, 2012).

Gold-silver doré is commonly produced at the mine site in small furnaces. Gold is then recovered from the doré 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.

It must be noted that artisanal mining for gold is not negligible (20% of gold mining according to the World Bank), where gold can notably be recovered by mercury amalgamation process.

9.2.1.4 Resources and reserves

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[8], 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.

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, 2015).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.

USGS (2016) reports known global reserves of gold of approximately 56,000 tonnes. These are widely dispersed on all continents, with the largest amounts in Australia, Russia and South Africa (see Table 39). Resource data for some countries in Europe are available in the Minerals4EU website (see Table 40) but cannot be summed as they are partial and they do not use the same reporting code.

Data on known gold reserves in the EU and adjacent countries were collected in the EU FP7 project Minerals Intelligence Network for Europe (Minerals4EU). Data for gold were obtained from 8 of the countries surveyed (see Table 42). 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 in the Minerals4EU project.

---

[8] www.crirsco.com

Table 39: World reserves of gold (data from USGS, 2016)

Country	Gold Reserves (tonnes)
USA	3,000
Australia	9,100
Brazil	2,400
Canada	2,000
China	1,900
Ghana	1,200
Indonesia	3,000
Mexico	1,400
Papua New Guinea	1,200
Peru	2,800
Russia	8,000
South Africa	6,000
Uzbekistan	1,700
Other countries	13,000
Total	*56,000*

Table 40: Resource data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Quantity	Unit	Grade	Code resource type
Finland	JORC NI43-101	16 363	Mt Mt	0.83 g/t 0.16 g/t	Measured Measured
Sweden	JORC NI43-101 FRB-standard	32.45 0.21 513.4	Mt Mt Mt	1.08 g/t 2.23 g/t 0.12 g/t	Measured Measured Measured
Norway	JORC	7.86	Mt	0.53 g/t	Indicated
Greenland	JORC	5.08	Mt	1.25 g/t	Indicated
UK	JORC NI43-101	0.06 0.161	Mt Mt	15 g/t 9.1 g/t	Measured Measured
Ireland	JORC	4.927	Mt	1.64 g/t	Indicated
Ukraine	Russian Classification	407.7	t	-	P1
Czech Republic	Nat. Rep. Code	60.2	t	-	P1
Slovakia	None	7.335	Mt	1.59 g/t	Verified (Z1)
Hungary	Russian Classification	34.59	Mt	-	C1
Romania	UNFC	760	Mt	Ag + Au	333
Serbia	NI43-101	46.3	Mt	1.56 g/t	Indicated
Macedonia	Ex -Yugoslavian	37.16	Mt	0.64 g/t	A
Albania	Nat. Rep. Code	0.01	Mt	1-4 g/t	A
Greece	USGS	81	Mt	0.06-0.08%	Indicated
Turkey	JORC NI43-101	32.8 96.1	Mt Mt	2.4 g/t 0.97 g/t	Measured Measured
France	None	170.1	t	-	Historic Resource Estimates
Spain	NI43-101	17.3	t	3.99 g/t	Measured
Portugal	NI43-101	4.233	Mt	1.57%	Indicated

Table 41: Reserve data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Quantity	Unit	Grade	Code reserve type
Spain	NI 43-101	8.479	t	-	Proven
Greece	CIM	202.7	t	-	Proved
Turkey	JORC NI43-101	20.51 92.726	Mt Mt	2.51 g/t 0.96 g/t	Proved Proven
Macedonia	Ex -Yugoslavian	37.161	Mt	0.64 g/t	A
Slovakia	None	7.335	Mt	1.59 g/t	Verified (Z1)
Czech Republic	Nat. Rep. Code	48.740	t	0.00019%	Economic explored
Finland	JORC NI43-101	8.9 190	Mt Mt	1.3 g/t 0.92 g/t	Proved Proven
Sweden	JORC NI43-101 FRB-standard	0.41 0.09 517.1	Mt Mt Mt	2.20 g/t 0.71 g/t 0.16 g/t	Proved Proven Proven

9.2.1.5 World mine production

Gold is mined in numerous countries and on every continent apart from Antarctica. Between 2010–2014, global annual production averaged 2797 tonnes. China is the leading producer, accounting for 14 % of global production per annum between 2010–2014 (see Figure 72).

Australia, USA and Russia were the next most important producers during this period. Asia as a whole produces 23 % of all newly-mined gold. Central and South America produce about 17 % of the total, with North America supplying about 16 %. Approximately 19 % of production comes from Africa and 14 % from the CIS region.

Gold production in the EU averaged 23 tonnes per annum between 2010–2014, equivalent to 0.84% of the global total production. The top three EU producers were Finland (33 % of EU total), Bulgaria (27 %) and Sweden (27 %).

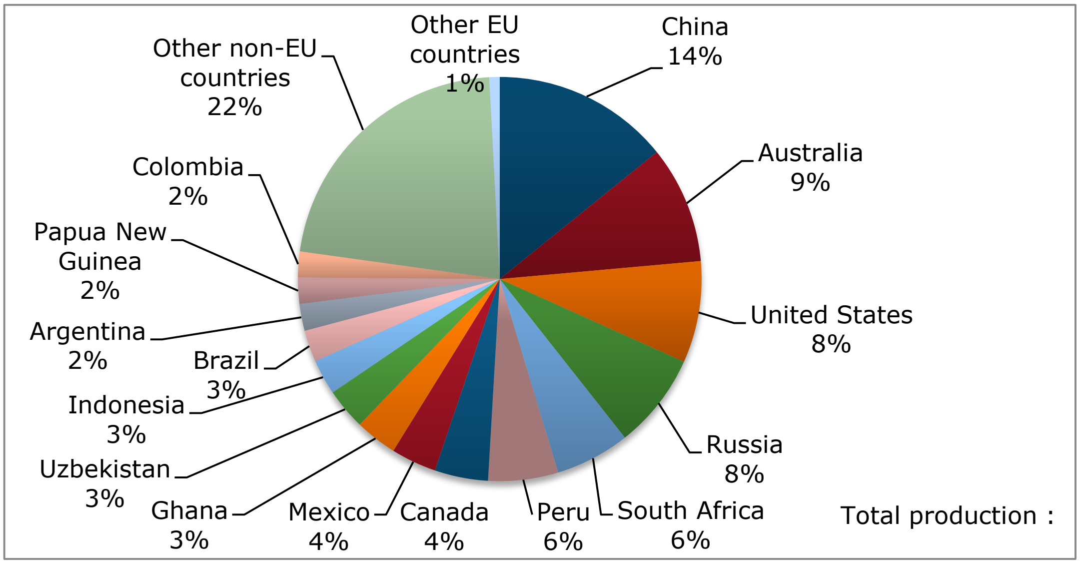


Figure 72: The distribution of global mine production of gold, average 2010–2014 (Data from BGS World Mineral Statistics database - BGS, 2016)

9.2.2 Supply from secondary materials

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 market. 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 life.

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 1728 tonnes, equivalent to 42 % of total gold supply (Boston Consulting Group, 2015). Since then, however, as prices have fallen and global economic recovery began, so 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 WEEE, provides 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 EOL recycling rate for gold to be in the range 15–20 %. This estimate does not include recycling of jewellery and coins because there is typically no end of life management for these products.

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 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 bullion is 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 derive 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 data are available, was examined in the criticality assessment of gold. Trade data were extracted from the Eurostat Comext database using the CN code 26169000 (precious metals ores and concentrates, excluding silver ores and concentrates). It was assumed that the precious metal content of these materials was predominantly due to gold and that the PGM content is very small and can be ignored. However, there is considerable uncertainty in the actual gold content of the material reported under this code.

The Eurostat data also revealed some possible issues with the data held in the Comext database. In particular, in the 2010–2014 period, there were major variations between individual years such as that exports from the EU increased by a factor of about 500 between 2010 and 2014. Further, within that period there were major increases from 2011 to 2012 and from 2012 to 2013. Imports to the EU during the years 2011 to 2014 showed reasonable levels of variation, but the data for 2010 were very much lower, with the quantity of material imported increasing 26 fold between 2010 and 2011. These apparent data issues related to code 26169000 were investigated by Eurostat at the request of BGS. The import data for the year 2010 were considered to be due to misclassification and were therefore ignored in the calculation of average imports to EU used in the criticality assessment for gold. The sharp rises in exports have been explained by Eurostat after checking the data with the governments of Romania and Bulgaria. A major rise in exports from Romania was attributed to the sale to China from 2013 onwards of long-term stocks held by a large company. Another contributing factor to the increased exports during this period was due to major export contracts from Bulgaria to Canada and South Korea from 2012 onwards. On the advice of Eurostat, trade value data are considered to be more reliable than quantities. Accordingly we have used the value data to assess EU trade in precious metal ores and concentrates.

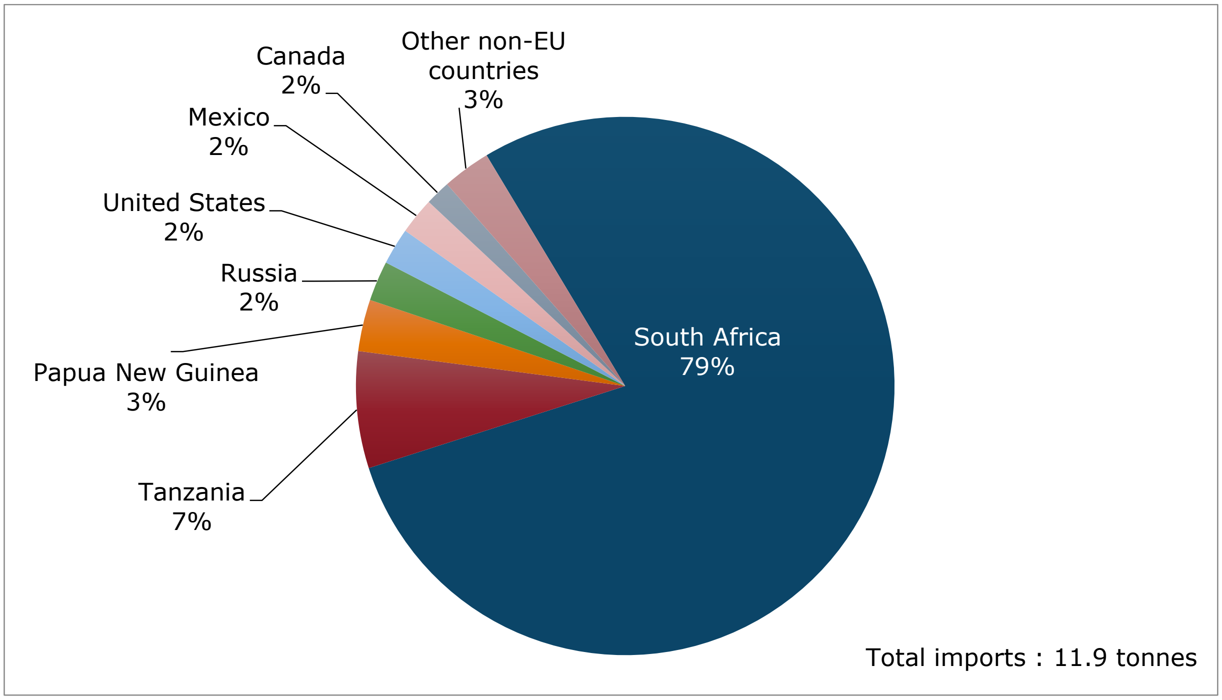


Figure 73: Distribution (%) of EU imports of precious metal ores and concentrates from non-EU countries in 2015, based on their value (Data from Comext database (Eurostat, 2016a))

In the light of the huge variations in trade noted above in various years of the reference period (2010–2014), data presented here cover 2015 only, the most recent year for which data are available. The EU has imported an estimate of 11.9 tonnes of gold, calculated on the basis that the gold content of the ores and concentrates is 0.1%. Imports of precious metals ores and concentrates were dominated in 2015 by South Africa (with close to 79 % of the total by value) (see Figure 73). Tanzania was the second most important source of imports (7 % of total), followed by Papua New Guinea (3 %). Exports of precious metals ores and concentrates from the EU in 2015 were mostly sent to China (69 % of total), followed by Switzerland and the United States each with approximately 15 % of the total.

China has put an export tax up to 25% on precious metal ores and concentrates over the 2010-2014 period (OECD, 2016).

9.2.4 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) 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 in EU is about 23.4 tonnes, derived from mines in nine EU countries, dominated by Finland, Bulgaria and Sweden. Figure 74 represents the EU sourcing (domestic production + imports) for gold.

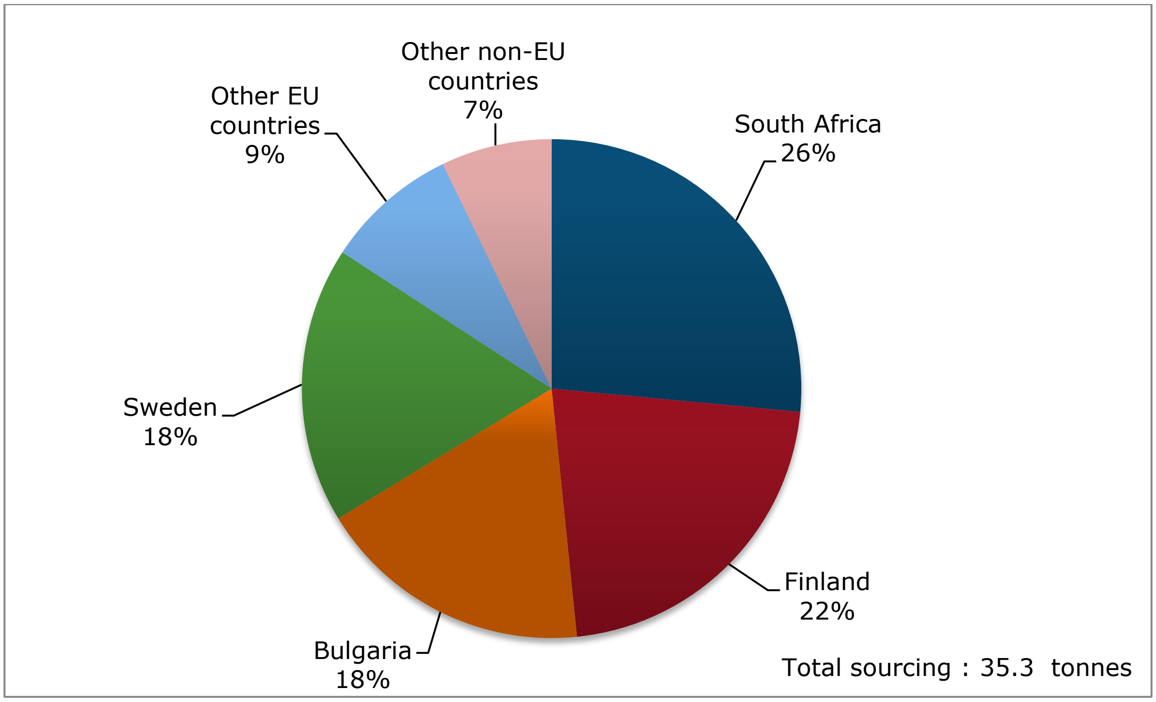


Figure 74: EU sourcing (domestic production + imports) of gold (Data from Comext database - Eurostat, 2016a).

9.3 Demand

9.3.1 Consumption

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. Demand for jewellery, which is by far the largest non-monetary use of gold, is dominated by China and India. Together these two countries accounted for 56 % of global gold demand for jewellery (2042 tonnes) in 2016 (World Gold Council, 2017).

European demand for gold in jewellery was approximately 76 tonnes, or 3 % of the world total (World Gold Council, 2016a). The UK dominates EU demand for jewellery, accounting for about 34 % of the total. Italy accounts for 24 % of the EU total, followed by France (18 %), Germany (13 %) and Spain (11 %).

Technology demand for gold (electronics, other industrial and dentistry) is relatively small. In 2016 global technology demand amounted to 323 tonnes, of which about 76 % was used in electronics (World Gold Council, 2017). Data on the geographical distribution of this demand are not 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 Applications

Gold has a range of uses, both monetary and non-monetary. Monetary uses, comprising investment and holding of gold reserves by central banks, accounted for approximately 39 % of total gold demand between 2010 and 2014 (World Gold Council, 2016c).

Today, investment in gold accounts for around one third of global demand. This demand is made up of direct ownership of bars and coins, or indirect ownership via Exchange-Traded Funds (ETFs) and similar products. Gold plays a prominent role in reserve asset management, as it is one of the few assets that is universally permitted by the investment guidelines of the world’s central banks. Since 2010, central banks have been net buyers of gold, and their demand has expanded rapidly, growing from less than two % of total world demand in 2010 to 14 % in 2014 (World Gold Council, 2016c). Some banks have bought gold to diversify their portfolios, while others have bought gold as a hedge against risks or because of its inflation-hedging characteristics.

For the purposes of criticality assessment, it is the non-monetary, industrial uses that are of interest (EC, 2014). Accordingly, as in 2014, the assessment has been carried on the basis of gold demand for these applications for which GVA data are available.

The most important industrial use of gold is in jewellery which is universally prized for its beauty and value. Between 2010 and 2014 gold jewellery accounted for about 50 % of total gold demand and 83 % of its non-monetary use (Figure 75) (World Gold Council, 2016c).

India and China are the two largest markets for gold jewellery, together representing over half of global consumer demand in 2014. Part of the large appetite for jewellery in these countries is driven by the cultural role gold plays; it is considered auspicious to buy gold at key festivals and events. Limited access to financial assets means gold is also held as a store of value or safe haven. In both India and China, gold jewellery is a desirable possession as well as an investment to be passed down through generations.

About 17 % of the global non-monetary demand for gold is in technical applications (Figure 75). 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 components. Gold is used in connectors, switch and relay contacts, soldered joints, connecting wires and connection strips. Gold is used in dentistry because it is chemically inert, non-allergenic and easily worked.

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 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 autocatalysts and in the manufacture of chemicals.

The relevant industry sectors and their 2- and 4-digit NACE codes are summarised in Table 42.

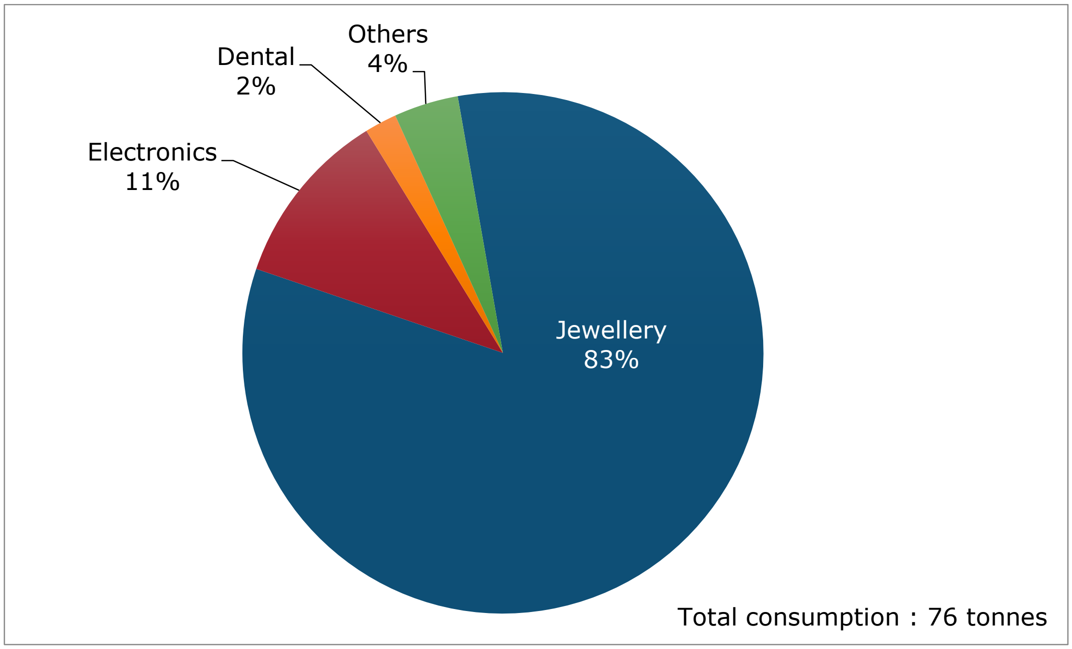


Figure 75: Global non-monetary end uses (%) of gold, 2010–2014 (Data from World Gold Council, 2016c)

Table 42: Gold applications, 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2016c)

Applications	2-digit NACE sectors	Value added of NACE 2 sector (millions €)	4-digit NACE sectors
Jewellery	C32 - Other manufacturing	41,612.6	C3212 - manufacture of jewellery and related articles
Electronics	C26 - Manufacture of computer, electronic and optical products	75,260.3	C2611 - manufacture of electronic components. Application share based on average of 4 years, 2011-2014
Dental	C32 - Other manufacturing	41,612.6	C3250 - manufacture of medical and dental instruments and supplies.

9.3.3 Prices and markets

Most gold is sold as refined gold bullion ranging in purity from 995 to 998 fineness, where fineness refers to the weight proportion of gold in an alloy or in impure gold, expressed in parts per thousand. Thus 1000 fine is pure gold. Most gold bullion is traded on a 24 hour basis, mainly through London, 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.

The gold price is set through the LBMA gold price auction which takes place twice daily at 10:30 and 15:00 with the price set in US dollars per fine troy ounce. The LBMA publishes prices in US dollars, sterling and euros.

After many years in the range US$200–400 per troy ounce, the gold price increased steadily from 2003 onwards up to 2012 when the average annual price was US$1669 (Figure 76). Since 2012 the price has declined with the average annual price in 2015 being US$1160 per troy ounce. In the first half of 2016 the gold price began to recover rapidly and peaked in the third quarter at about US$1335, 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 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 US$1130 at the end of 2016, but recovered to about US$1230 in mid-February 2017.

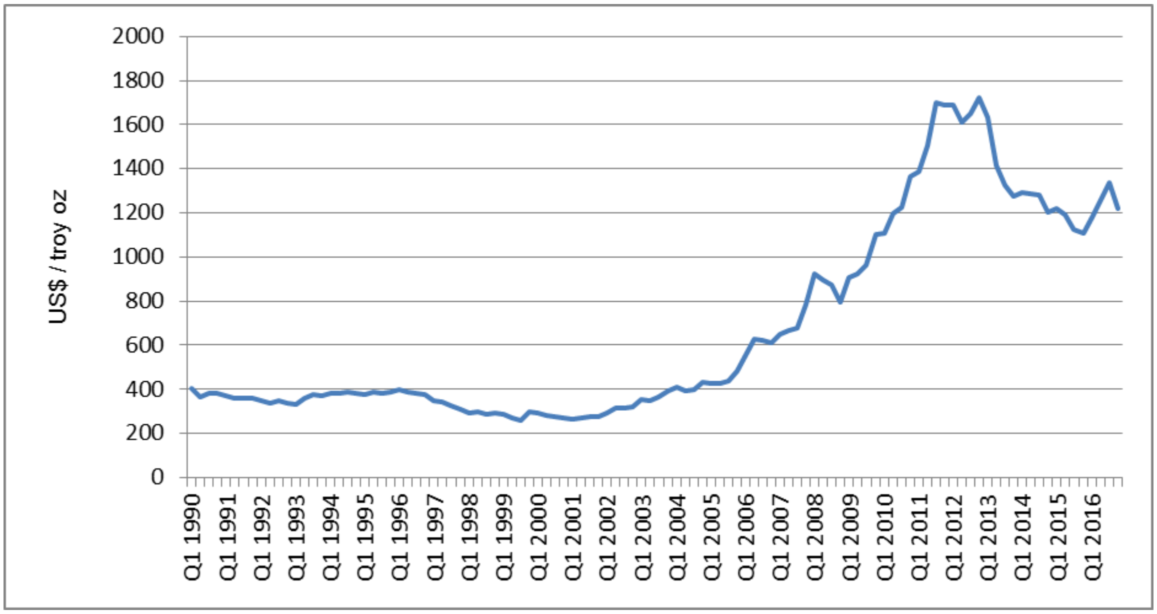


Figure 76: The price of gold, 1990 to end 2016 (quarterly average prices from World Gold Council, 2016b)

9.4 Substitution

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 could theoretically be replaced by other precious metals or by cheaper alloys. However, because the use of gold is so deeply entrenched in many cultures, especially in

China and India, 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 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. 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 dentistry gold is increasingly being replaced by ceramics and cheaper base metal alloys.

9.5 Discussion of the criticality assessment

9.5.1 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 this deals with the global situation and very little data specific to Europe or the EU are available from this sources.

The monetary uses (Investment and central bank gold reserves), which account for about 39 % 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 manufacturing use. Accordingly, as was done in the previous EU criticality assessment (EC, 2014), only the non-monetary uses of gold are included here.

Production data for gold were taken from the British Geological Survey's World Mineral Statistics database and represents global production from primary producing countries.

Trade data for 'precious metal ores and concentrates, excluding silver ores and concentrates' were extracted from the Eurostat COMEXT online database (Eurostat, 2016) 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 gross weight 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 on gold in this form. It is pertinent to note that the USGS states that it is not possible to work out a meaningful gold import reliance figure for the USA (USGS, 2016). It is also important to note that the lack of any information on the gold content of the 'precious metal ores and concentrates, excluding silver' does not impact on the derived Supply Risk and Economic Importance scores. Several estimates of gold content were used to verify this.

EU trade in gold metal is extremely difficult to unravel. It involves metal from numerous sources, both primary and secondary, from EU and non-EU sources, in many forms and with various purities. Numerous codes are used for the reporting of gold trade. Consequently they do not provide a sound basis for assessing the supply risk to the EU.

The recycling rate for gold is difficult to quantify because of the lack of reliable data. It 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 never become available for recycling and will not therefore make a major contribution to 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 15–20 %.

Other data sources are listed in section 9.7.

9.5.2 Calculation of economic importance and supply risk indicators

For the calculation of Economic Importance (EI), the 2-digit NACE sectors shown in Table 42 were used. For information relating to the application share of each category, please see section on applications and end-uses. As required by the methodology, the application shown as 'others' was distributed among the remaining applications. The figures for value added were the most recently available at the time of the assessment, i.e. 2013, and are expressed in thousands of Euros.

The calculation of the Supply Risk (SR) was carried out at the ores and concentrates stage of the life cycle using only the global HHI calculation. Actual supply to the EU cannot be determined from Eurostat because the trade data do not discriminate between gold metal derived from primary and secondary sources. The Eurostat trade data include metal from different life cycle stages and from numerous sources/countries. It cannot therefore be used to calculate the risk to primary gold supply to the EU.

For use in jewellery gold is considered to be largely not substitutable, because in most cultures only gold itself is required for this purpose and no alternatives would be considered to be acceptable. For other industrial uses, such as in electronics and dentistry, alternative materials are available for some applications but there is no data available to quantify the market share of these substitutes for gold.

9.5.3 Comparison with previous EU criticality assessments

In this revision of the EU critical raw materials list a revised methodology for assessing economic importance and supply risk has been used and consequently the results are not directly comparable to the previous EU critical raw materials assessments.

The results of this review and earlier assessments are shown in Table 43.

Table 43: Economic importance and supply risk results for gold in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Gold	*	*		3.78	0.15		2.0	0.2

*Gold was not included in the 2011 criticality assessment

9.6 Other considerations

9.6.1 Forward look for supply and demand

Future demand for gold is likely to continue to be high, especially for investment and national reserves, as global economic and political uncertainties remain at a high level. For many years gold has been the main focus of global exploration for non-ferrous metals. Although there have been few discoveries of major deposits in recent years, gold resources are widespread throughout the world and there is little risk of supply disruption.

Table 44: Qualitative forecast of supply and demand of gold

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
Gold		x	+	+	+	+	+	+

9.6.2 Environmental and regulatory issues

No environmental restriction is known for gold. Regulatory issues are linked with Conflict minerals legislation issues (European Parliament, 2016).

Given widespread concerns over the sourcing of the so-called conflict minerals (tin, tantalum, tungsten and gold; termed '3TG') which have been identified as potential sources of funding for armed groups involved in civil unrest in parts of central Africa, new legislation was enacted in the United States in 2010. Through the Dodd-Frank Act it became obligatory for all companies registered with the U.S. Securities and Exchange Commission to determine whether the products they manufacture, or the components of the products they manufacture, contain tantalum, tin, tungsten or gold. If so, they are required to determine, and to report, whether these minerals were sourced from Congo (Kinshasa province) or its bordering countries.

Similar regulation in the EU is set to ensure sustainable sourcing for more than 95% of all EU imports of tin, tantalum, tungsten and gold, which will be covered by due diligence provisions from 1 January 2021 (EC, 2016). The Regulation (EU) 2017/821 of the European Parliament and of the Council sets up a Union system for supply chain due diligence self-certification in order to curtail opportunities for armed groups and unlawful security forces to trade in tin, tantalum and tungsten, their ores, and gold. It will take effect on 1 January 2021. It is designed to provide transparency and certainty as regards the supply practices of importers, (notably smelters and refiners) sourcing from conflict-affected and high-risk areas. The EU regulation covers tin, tantalum, tungsten, and gold because these are the four metals that are most mined in areas affected by conflict or in mines that rely on forced labour.

The regulation also draws on well-established rules drawn up by the Organisation for Economic Co-operation and Development (OECD) in a document called 'Due Diligence Guidance for Responsible Supply Chains from Conflict-Affected and High-Risk Areas.'

The regulation only applies directly to EU-based importers of tin, tantalum, tungsten and gold, whether these are in the form of mineral ores, concentrates or processed metals.

Given the broad geographical distribution of the global supply base for gold it is considered that the new legislation in the United States and the EU will have minimal impact on global or EU gold supply.

9.7 Data sources

9.7.1 Data sources used in the factsheet

Boston Consulting Group. (2015). The Ups and Downs of Gold Recycling. Boston Consulting Group and World Gold Council. March 2015. Available from http://www.gold.org/supply-and-demand/ups-and-downs-gold-recycling .

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 (EC). (2014). Report on Critical Raw Materials for the EU. Report of the Ad Hoc Working Group on Defining Critical Raw Materials. May 2014.

European Commission (EC). (2016). EU reaches landmark agreement on conflict minerals regulation. http://trade.ec.europa.eu/doclib/press/index.cfm?id=1587

Eurostat (2016)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

Freeport-McMoran. (2016). Proving our Mettle. Freeport-McMoran 2015 Annual Report. Available from http://www.fcx.com/ir/FCX_AR_2015.pdf .

Mining Magazine. (2012). Recovering refractory resources. September 2012.

Robert, F., Poulsen, K.H. and Dubé, B. (1997). Gold deposits and their geological classification. In: Proceedings of Exploration 97, edited by A.G. Gubbins, 1997, 209–220.

Rudnick, R.L. and Gao, S. (2003). The 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, 2003. 1-64.

Schodde, R. (2015). Long term trends in gold exploration. Presented at NewGenGold 2015. Available from 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, 7 June 2016. Available from http://www.minexconsulting.com/publications.html .

USGS. (2016). Mineral Commodity Summary: Gold

World Gold Council. (2016a). Gold Demand Trends Full Year 2015. http://www.gold.org/supply-and-demand/gold-demand-trends/back-issues/gold-demand-trends-full-year-2015

World Gold Council. (2016b). Historical prices. http://www.gold.org/statistics#historical-prices.

World Gold Council. (2016c). Supply and demand data. http://www.gold.org/statistics#supply-and-demand-data

World Gold Council. (2017). Gold Demand Trends Full Year 2016. http://www.gold.org/supply-and-demand/gold-demand-trends/back-issues/gold-demand-trends-full-year-2016

9.7.2 Data sources used in the criticality assessment

BGS. (2016). British Geological Survey World Mineral Statistics database.

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 (EC). (2014). Report on Critical Raw Materials for the EU. Non-critical raw materials profiles. Gold

European Commission. (2016). EU trade agreements webpage [online]. Directorate General for Trade. http://ec.europa.eu/trade/policy/countries-and-regions/agreements/index_en.htm

Eurostat. (2016)a. International trade in goods database (COMEXT) [online]. http://ec.europa.eu/eurostat/data/database

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

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. Graedel, T.E., Allwood, J., Birat, J.-P., Reck, B.K., Sibley, S.F., Sonnemann, G., Buchert, M. and Hagelüken, C.

World Gold Council. (2016). Price and demand statistics available from http://www.gold.org/statistics

9.8 Acknowledgements

This Factsheet was prepared by the British Geological Survey (BGS). The authors would like to thank the following for their contributions to the preparation of this Factsheet: members of the EC Ad Hoc Working Group on Critical Raw Materials; the User Support Team of the European Statistical Data Support, Eurostat and all other relevant stakeholders who contributed to the factsheet.

10. GYPSUM

Key facts and figures

Material name and Formula	Gypsum $CaSO_4\text{-}2H_2O$	World/EU production (million tonnes)[1]	162,8/ 22
Parent group (where applicable)	N/A	EU import reliance[1]	0%
Life cycle stage/ material assessed	Mine production/ natural gypsum	Substitution index for supply risk [SI(SR)]1	0.91
Economic importance (EI) (2017)	2.2	Substitution Index for economic importance [SI(EI)]1	0.83
Supply risk (SR) (2017)	0.5	End of life recycling input rate (EoL-RIR)	1%
Abiotic or biotic	Abiotic	Major end uses in EU[1]	Plasterboard and wallboard (51%), Building plaster (26%), Cement production (17%)
Main product, co-product or by-product	Main product	Major world producers[1]	China (23%), Iran (9%), USA (9%)
Criticality results	2011	2014	2017
	Not critical	Not critical	Not critical

[1] average per annum for 2010-2014, unless otherwise stated;

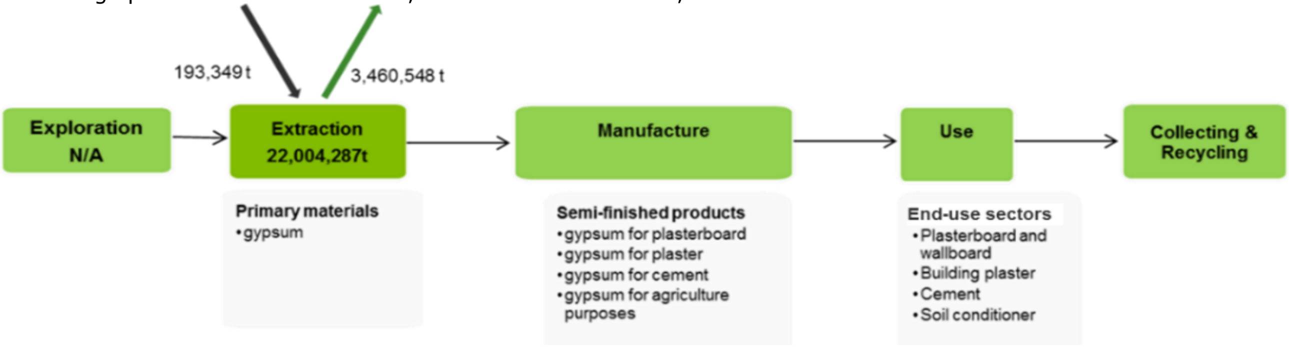


Figure 77: Simplified value chain for gypsum (average data for 2010-2014)

The green box of the production stage in the above figure suggests that activities are undertaken within the EU. The black arrows pointing towards the Extraction stage represent imports of material to the EU and the green arrows represent exports of materials from the EU. A quantitative figure on recycling is not included as the EOL-RIR is below 70%. EU reserves are displayed in the exploration box.

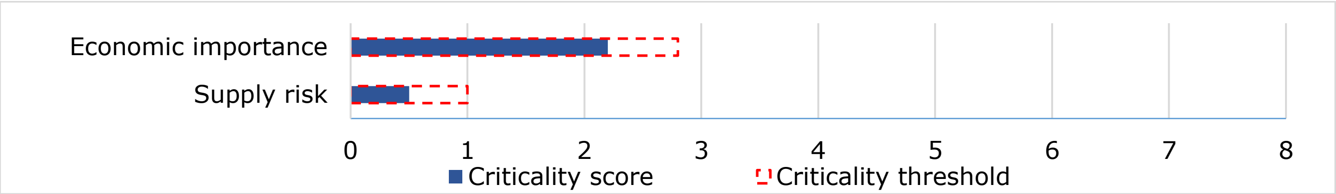


Figure 78: Economic importance and supply risk scores for gypsum

10.1 Introduction

This factsheet is primarily concerned with natural gypsum, but FGD gypsum and recycled gypsum are briefly discussed in the section on supply from secondary materials.

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. 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 USA is a notable exception. The predominant use of gypsum is in plaster and plasterboard, but it is also used in cement to regulate the setting time, agriculture (in fertilizer or as a soil conditioner) and a range of other minor uses (e.g. cat litter, oil absorbent, food additive, cosmetics).

Approximately 14% of the global production of natural gypsum is European. Europe is a net exporter of gypsum hence the sector is a positive contributor to the European economy.

10.2 Supply

10.2.1 Supply from primary materials

10.2.1.1 Geological occurrence

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 ^{o}C. Anhydrite is the thermodynamically stable phase. In sabkhas[9] conditions of gypsum and anhydrite stability switch easily and multiple transformations are often taking place (Pohl, 2011; British Geological Survey, 2006).

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 (Pohl, 2011; British Geological Survey, 2006).

10.2.1.2 Mining and processing

Gypsum/anhydrite are produced predominantly in Europe from open cast mining techniques(80%) and (20%) by underground mining using pillar and stall mining methods that gives extraction rates of up to 75%. This mining method does not give rise to subsidence and no significant waste is produced. The impact of the workings is confined to the surface facilities at the mine. Continuous miners are becoming increasingly common in

---

[9] An area of coastal flats subject to periodic flooding and evaporation which result in the accumulation of clays, evaporites, and salts

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 landfill (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).

10.2.1.3 Gypsum resources and reserves

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 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[10], 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.

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, 2015).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.

Resource data for some countries in Europe are available in the Minerals4EU website (see Table 45) (Minerals4EU, 2014) but cannot be summed as they are partial and they do not use the same reporting code.

---

[10] www.crirsco.com

Table 45: Resource data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

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
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 of mineral resources
Lithuania	Nat. Rep. Code	16.82	Million m^3	-	Mesaured
UK	None	>2,000	Mt	-	Estimate
Ireland	None	8	Mt	78%	Historic Resource Estimates

Some global reserve figures of gypsum in 2016 are shown in Table 46. In addition to the USGS data (USGS, 2016), the gypsum reserves in China are estimated at 17 billion tonnes and in Iran at 2.2 billion tonnes (Roskill, 2014), and have been added to the table. A global reserve figure cannot be estimated as data from several major producing countries are missing (Thailand, Iraq, Turkey, Mexico, etc.). Reserves are believed to be large, but data for most countries are not available. Reserve data for some countries in Europe are available in the Minerals4EU website (see Table 47) but cannot be summed as they are partial and they do not use the same reporting code.

The only country reporting reserve data on gypsum using the United Nations Framework Classification (UNFC) is Romania, which indicated 113 million tonnes of reserves for UNFC 111 code and 200 million tonnes of reserves for UNFC 121 code (Minerals4EU, 2014).

Table 46: Global reserves of gypsum in 2015 (Data from (USGS, 2016; Roskill, 2014)).

Country	Gypsum Reserves (tonnes)
United States	700,000,000
Brazil	290,000,000
Canada	450,000,000
India	39,000,000
Iran	1,600,000
China	17,000,000,000
Iran	2,200,000,000

Table 47: Reserve data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

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	-	-
Macedonia	Ex-yugoslavian	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

10.2.1.4 World mine production

World mine production of gypsum (162.8 million tonnes) is summarised in Figure 79. China is the largest producer of gypsum with a share of 23% of the global production, followed by Iran and the United States that they both have a 9% share of the global production. Many more countries, in total 85, produce gypsum around the world.

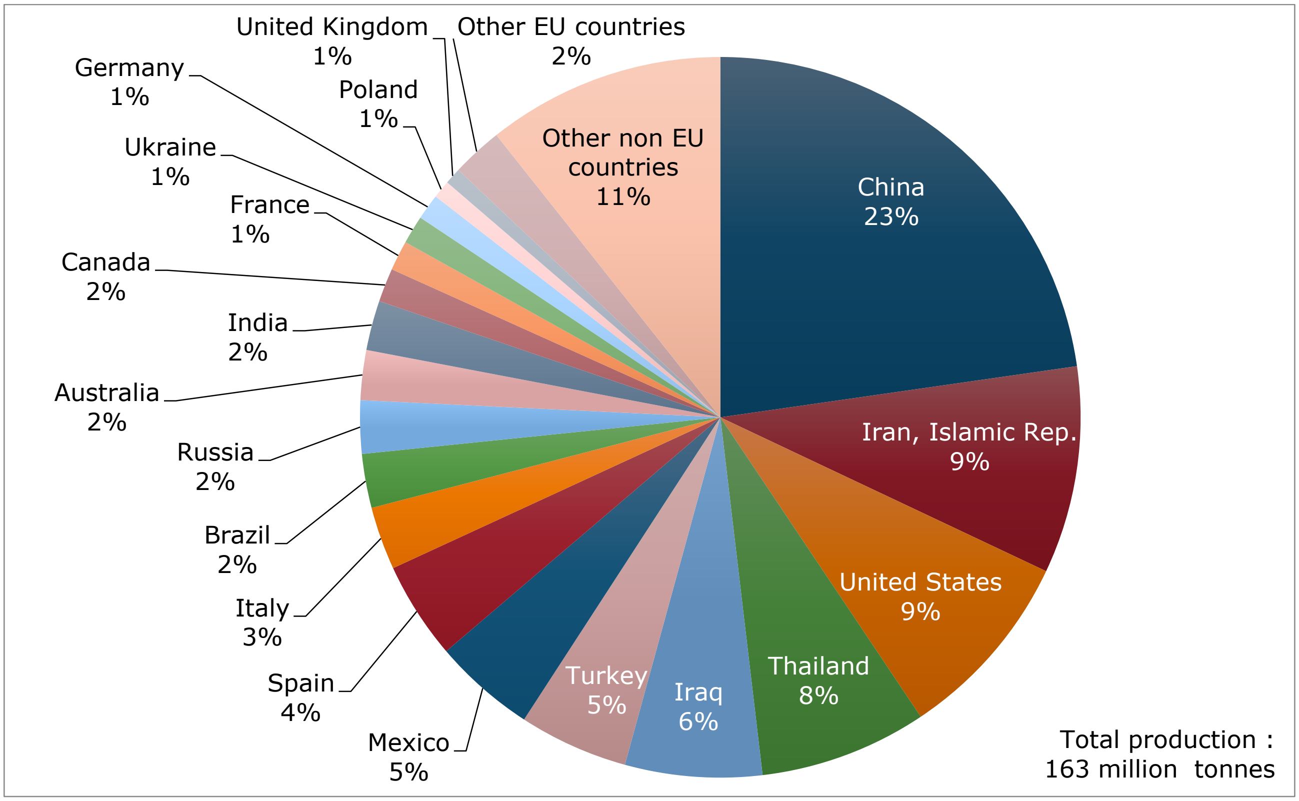


Figure 79: Global mine production of gypsum, average annual 2010–2014 (Data from BGS, 2016).

The European production of gypsum between 2010 and 2014 is estimated at 22 million tonnes and approximately 18 countries are reporting production. According to Eurogypsum, 154 gypsum quarries are currently in operation in Europe (EUROGYPSUM, 2017). Spain and Italy are the largest producers of gypsum in Europe with 7 million tonnes and 4.6 million tonnes production reported respectively.

Spain produces approximately 4% and Italy 3% of the global production. In Spain, gypsum is produced by numerous quarries using open cast mining methods. In Italy too, several different mine and quarries exist that produce gypsum from a variety of locations. The remainder European countries produce in total 14% of the global production.

10.2.2 Supply from secondary materials

The European industry does not solely rely on natural gypsum. The use of FGD (flue gas desulphurisation) gypsum, recycled gypsum and other synthetic gypsum is also important to the sector. Currently the industry uses approximately 38% of FGD gypsum, 3% of recycled gypsum and 2% of other synthetic gypsum is used by the industry, with the remainder 57% representing natural gypsum (EUROGYPSUM, 2015).

10.2.2.1 FGD gypsum

FGD gypsum is a by-product of coal fired power station. Flue gas desulphurisation takes place in the scrubbing towers. When flue gas comes into contact with an aqueous suspension containing limestone or slaked quicklime, then SO_2 in the flue gas is washed out, oxidised to SO_3 and precipitated with calcium from the limestone or quicklime to form gypsum. The gypsum crystals are separated out of the suspension with the use of centrifuges or filtering technology. FGD gypsum production is estimated approximately at 18 million tonnes per annum (EUROGYPSUM and NERA, 2016). FGD gypsum 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. Low sulphur coal will produce lower quantities of FGD gypsum.

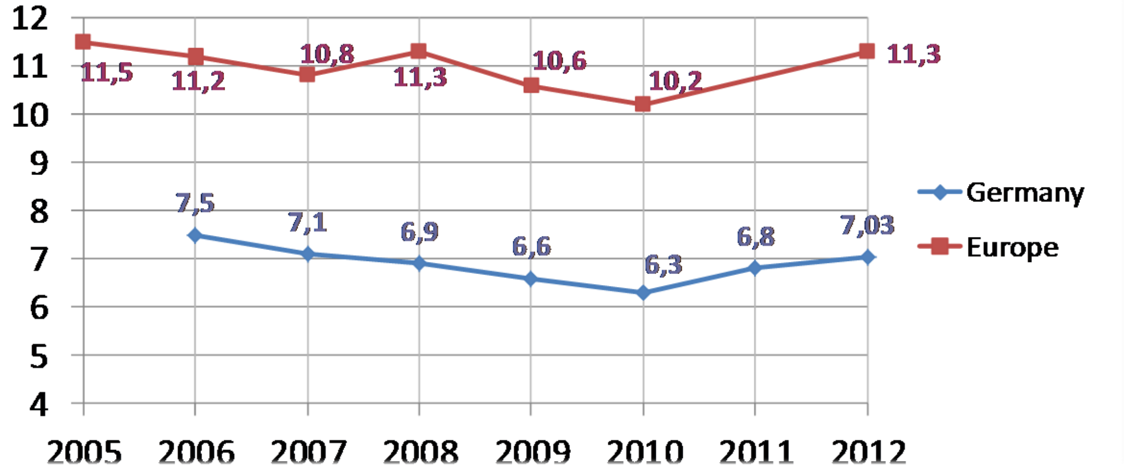


Figure 80: FGD gypsum production figures in million tonnes (2005 – 2012) for Germany and Europe. ^{1}ECOBA figure; ^{2}VGB Powertech figure (Eurogyspum, 2017)

The main country producing FGD gypsum is Germany due to the presence of coal fired power plants stations (around 7 million tonnes produced every year) (Figure 80). Plasterboard plants 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.

10.2.2.2 Recycled gypsum

Recycled gypsum is produced from the 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 resulting from the manufacturing process). The volume of 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 plasters, paints & screeds etc). The demolition waste does not depend on market volumes and its recycling rate is estimated at ca. 1%.

About 1% of the total Construction, Demolition and Deconstruction waste generated can be considered as gypsum waste. 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[11] demonstrates feasibility of re-incorporation (up to 30%) 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.

The recycling of gypsum is controlled by national and commercial specifications, but in reality recycling across Europe varies considerably from country to country. 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 low production and use of recycled gypsum in Europe is not unexpected (only 3% of the total gypsum used).

10.2.2.3 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, 2007).

The most important potential of other synthetic Gypsums than FGD Gypsum lies in the use of purified pPhosphogypsum. Next to that is some potential in the use of purified tTitanogypsum. In the past, both the Phosphoric Acid and the Titanium Dioxide industries have shown a systematic close down of production facilities in Europe (Eurogypsum, 2016).

---

[11] "From production to recycling: a circular economy for the European gypsum Industry with the demolition and recycling Industry" http://gypsumtogypsum.org/

10.2.3 Trade

10.2.3.1 EU trade

Gypsum is a "high place – value" industrial mineral meaning that economic advantages are gained by having access to close proximity markets. The low unit value of gypsum means that transportation cost has a high impact on the final price of the product and therefore most of these products are consumed where they are extracted. This becomes apparent from the trade data reported too (Figure 81). For example, the EU 28 has produced on average, on an annual basis for the period 2010 to 2014 22 million tonnes of crude gypsum, whilst the imports to the EU in the same period were approximately 207,000 tonnes. Therefore imported gypsum represents only a small flow to the EU. Gypsum exported from Europe in the same period accounts for approximately 3.46 million tonnes. As shown in Figure 82, Europe is a net exporter of gypsum. Exports from the EU 28 have increased between 2010 and 2012 and remained quite stable between 2012 and 2014 with a small increase in 2014.

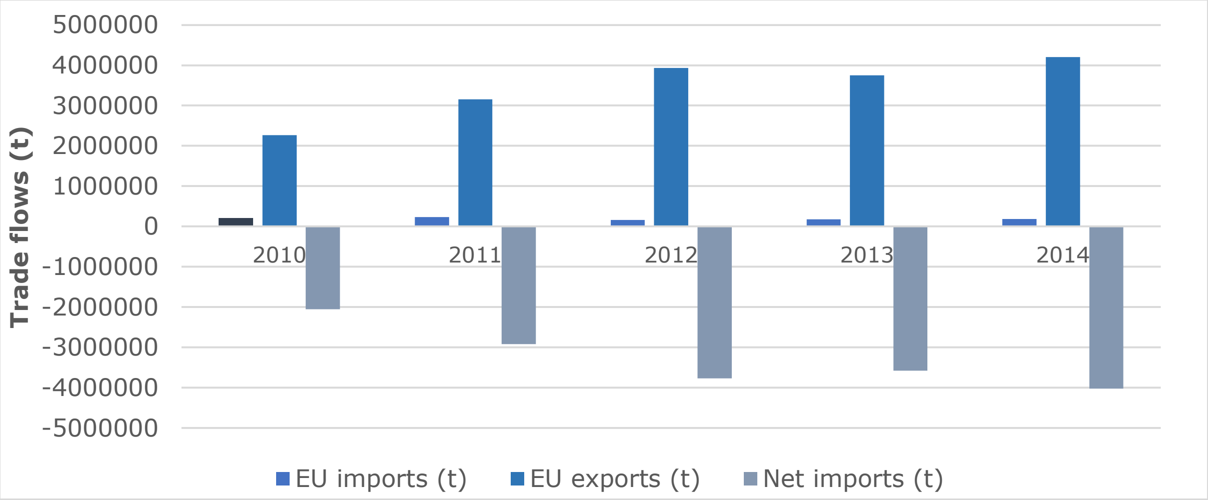


Figure 81: EU trade flows for gypsum (Data from Eurostat, 2016a).

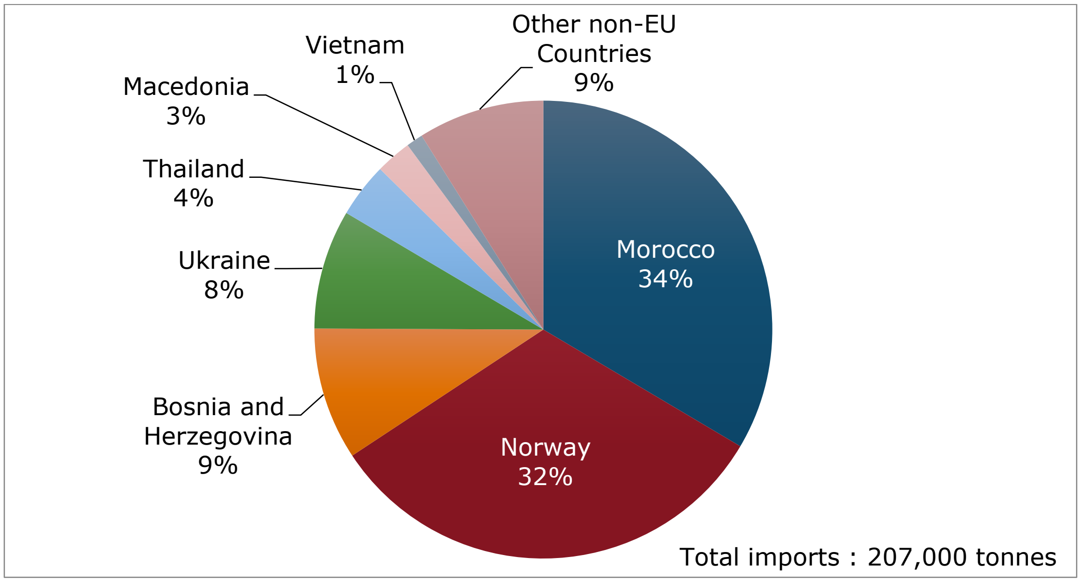


Figure 82: EU imports of gypsum, average 2010-2014. (Data from Eurostat, 2016a)

Spain is the most important exporter of gypsum in EU accounting for 80% of the European gypsum exports. Most of the gypsum produced in Spain is exported to the United States, Nigeria, Colombia and Venezuela. Other important EU exporting countries include Cyprus and Greece. Gypsum from Cyprus is primarily exported to Israel and from Greece to Turkey. Based on Eurostat data, imports of gypsum to the EU appear to be mainly from Morocco and Norway (Figure 82).

10.2.3.2 Global trade

At global level, the United States is the world largest importer of gypsum accounting for 15% of the world imports per annum for the period 2010 to 2014. India and Japan are also major importers with shares equivalent to 14% and 10% of the world total imports in the same period. Thailand, Spain and Canada are the largest exporters of gypsum globally for the period 2010 to 2014.

10.2.4 EU supply chain

The 5 years average European production of gypsum between 2010 and 2014 was 22 million tonnes per year, which accounts for 14% of the global production. Producing countries include Spain, Italy, France, Germany, Poland, the United Kingdom and others [based on data from: (BGS, 2016)]. Gypsum is a "high place – value" industrial mineral therefore most of the gypsum being produced is consumed in the country of production.

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-28.

The Figure 83 presents the EU sourcing (domestic production + imports) for gypsum.

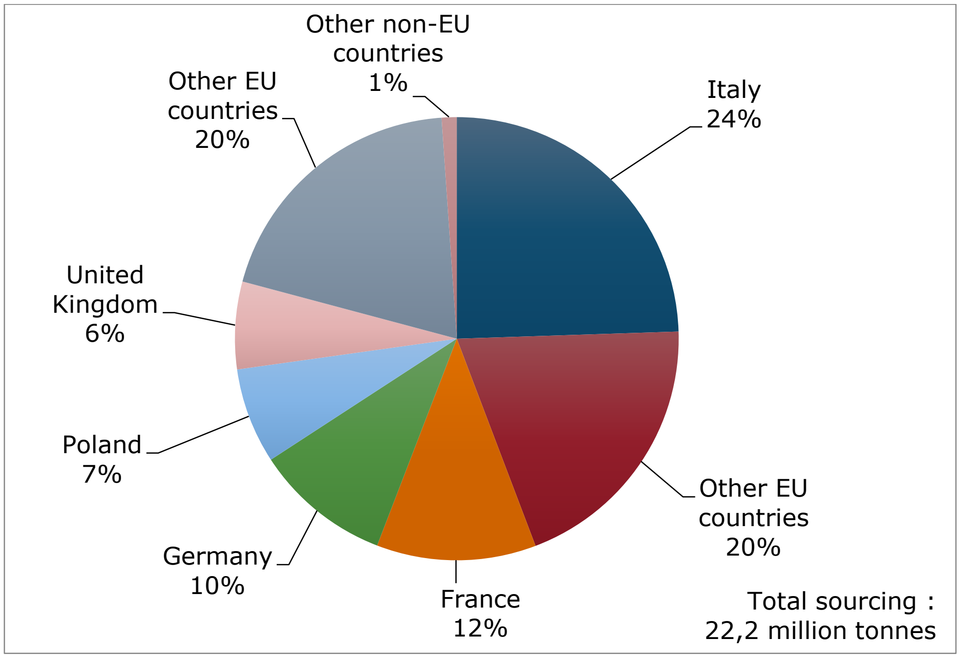


Figure 83: EU sourcing (domestic production + imports) of gypsum, average 2010-2014. (Data from Eurostat, 2016a; BGS, 2016)

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 exporting country in EU 28. About 80% of the European gypsum exports are from Spain. Spain is the second largest exporter of gypsum in the world.

FGD gypsum EU production is estimated approximately at 18 million tonnes per annum. 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 (EUROGYPSUM, 2015).

There are no export restrictions, quotas or prohibitions identified that may impact on the availability of gypsum.

10.3 Demand

10.3.1 EU consumption

The European apparent consumption in the period 2010 and 2014 (5 year average figure) is estimated at 18.75 million tonnes per year, of which 22 million tonnes per annum is the domestic production, 207,000 tonnes per annum is the imports to the EU from extra EU-28 countries and 3.46 million tonnes per annum is the exports from the EU to extra EU-28 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 it can sufficiently satisfy the EU industry demand for gypsum, without import reliance issues.

10.3.2 Applications / 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 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. The EU market shares of the above mentioned applications are presented in Figure 84.

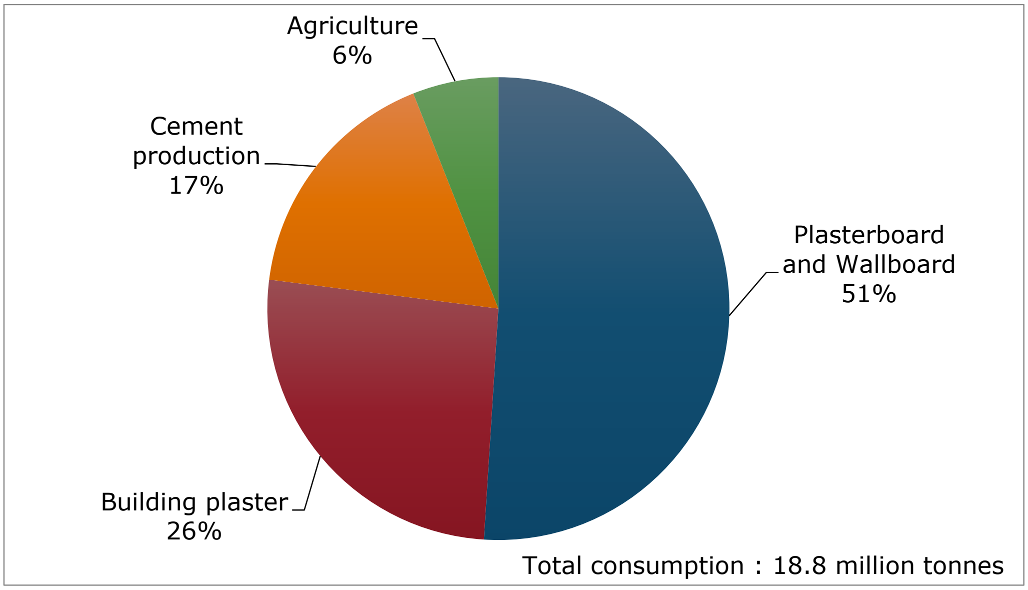


Figure 84: EU end uses of gypsum. Average figures for 2010-2014 (Data from EUROGYPSUM and NERA, 2016

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 plater 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, 2017). Gypsum in cement is used to control the setting rate of cement. In agriculture applications, gypsum finds use as a soil conditioner.

Relevant industry sectors are described using the NACE sector codes in Table 48.

Table 48: Gypsum applications, 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2016c)

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	59,166.0	C2362 - Manufacture of plaster products for construction purposes
Building plaster	C23 - Manufacture of other non-metallic mineral products	59,166.0	C2352 - Manufacture of lime and plaster
Cement production	C23 - Manufacture of other non-metallic mineral products	59,166.0	C2351 - Manufacture of cement
Agriculture	C23 - Manufacture of other non-metallic mineral products	59,166.0	2399 Manufacture of other non-metallic mineral products n.e.c.

10.3.3 Prices and markets

The average unit price of gypsum in 2014 reported by USGS and U.S. producers was $8.91 per metric tonne of crude gypsum. The price of the different gypsum products vary widely depending for example $29.76 per tonne for calcined gypsum, $43 per tonne for gypsum used in agricultural uses and $429 per tonne for plaster (USGS, 2014). The gypsum price may be estimated by the ratio between the value and the quantity of gypsum produced at the EU level (data been provided by Eurostat). This estimation leads to a price of around €12 per tonne.

10.4 Substitution

Substitutes with a similar functionality in comparison to gypsum have been identified for the applications of plasterboard and 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 and literature findings. The literature used to identify substitutes for gypsum is listed in section 10.7.

10.5 Discussion of the criticality assessment

10.5.1 Data sources

Market shares are based on the statistical data provided by EUROGYPSUM and they represent the European market (EUROGYPSUM and NERA, 2016). Production data for gypsum are from World Mineral Statistics dataset published by the British Geological Survey (BGS, 2016). Trade data was extracted from the Eurostat Easy Comext database (Eurostat, 2016a). 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, 2016).

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) (EUROGYPSUM and NERA, 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.

The production figure for China, who is the global leading producer, varies significantly between different data providers. For instance, the BGS Mineral Statistics database reports 37 million tonnes of crude gypsum in 2014 in comparison to USGS reporting 130 million tonnes in the same year. It is believed that the USGS figure most likely includes other forms of gypsum (for example, FGD gypsum). In any case, available figures are based on estimates as actual data is not available.

All data were averaged over the five-year period 2010 to 2014

Other data sources used in the criticality assessment are listed in section 10.7.

10.5.2 Economic importance and supply risk calculation

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 48). The value added data correspond to 2013 figures. The supply risk was assessed on gypsum using both the global HHI and the EU-28 HHI as prescribed in the revised methodology.

10.5.3 Comparison with previous EU criticality assessments

A revised methodology was introduced in the 2017 assessment of critical raw materials in Europe. Both the calculations of economic importance and supply risk are now different therefore the results with previous assessments are not directly comparable. The results of this review and earlier assessments are shown in Table 49.

Table 49: Economic importance and supply risk results for GYPSUM in assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Gypsum	5.04	0.36		5.54	0.47		2.2	0.5

Although it appears that the economic importance of gypsum has been reduced between 2014 and 2017 this is a false impression created by the change in methodology implying refined EI calculation. 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 slightly higher than in the previous assessments. The change observed is not major and should be attributed primarily to the methodological modification and the way the supply risk is calculated. It is not possible to quantify what proportion of this changes is due to the methodology alone, as new data have been used in the assessment.

10.6 Other considerations

The availability of recycled gypsum is accounted as a mitigation factor towards supply risk. In reality however, recycled and secondary materials also have supply issues and are often critical to the European economy. However, this is not taken into account in the current methodology. The assessment is undertaken for a single material and a single life cycle stage.

Ideally the assessment on gypsum should also incorporate synthetic gypsum, in particular FGD gypsum, which is an important contributing material to the sector. However, there is no reliable and sufficient data on FGD gypsum that is public and can cover all stages of the assessment.

10.6.1 Access to natural gypsum deposits

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) (Eurogypsum, 2016). Access to gypsum deposits is also becoming more difficult as Natura 2000 areas expands. The Guidelines on Extraction into Natura 2000 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 in Europe (Eurogypsum, 2016).

In the absence of opening of new quarries, some EU countries are likely to lack gypsum by around 2020 and the EU by around 2040 (Nera study). 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 (Eurogypsum, 2016).

10.6.2 Forward look

The future demand for gypsum is driven by the plasterboard sector. Plasterboards are widely used in buildings nowadays. 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. The same trend is foreseen for building plaster and cement production, as they closely align to the construction sector (British Geological Survey, 2006; DG Environment, 2010).

The future supply of gypsum is more complicated to predict due to interlinkages of the flows of natural gypsum and synthetic gypsum. 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 reduce substantially over the future. According to the NERA study, FGD gypsum production is expected to decrease by 40% to 50% in the next 15 years (NERA, 2016) (Figure 85).

Boosting the recycling of waste gypsum (e.g. waste plasterboard) may compensate for part of the FGD gypsum reduction, but not for all. In that case the requirement for natural gypsum may grow to satisfy the expected demand (British Geological Survey, 2006; Demmich, 2015).

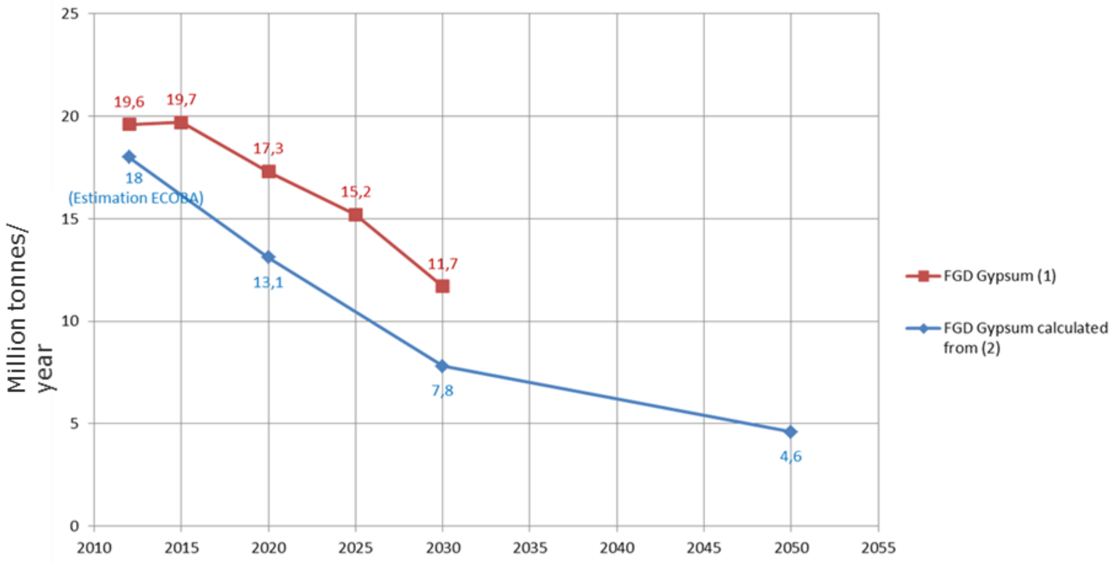


Figure 85: Prospective development of FGD gypsum production (in tonnes) in the EU. (1) Prognos-report: Supply of gypsum to industry in the context of energy turnaround in Europe, Ashtrans Europe 2014, Berlin; (2) European Commission: EU trends to 2050 – EU reference scenario (2013) (EUROGYPSUM, 2017)

Table 50: Qualitative forecast of demand and supply of gypsum

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
Gypsum		X	+	+	?	+	+	+

10.7 Data sources

10.7.1 Data sources used in the factsheet

Demmich, J. (2015). The Future of FGD Gypsum in Europe. ASHTRANS EUROPE 2015, Copenhagen KNAUF.

British Geological Survey (2006). Gypsum - Mineral Planning Factsheet [online] Available at: http://www.bgs.ac.uk/mineralsuk/planning/mineralPlanningFactsheets.html

BGS (2016). World Mineral Production 2010-2014. [online] Keyworth, Nottingham British Geological Survey, Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.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 (2017). Additional data and information on FGD gypsum provided by EUROGYPSUM during expert consultation within the 'Study on the review of the list of critical raw materials'

EUROGYPSUM (2017). EUROGYPSUM Publications [online] Available at: http://www.eurogypsum.org/library/publications/

EUROGYPSUM and NERA (2016). Data and information on gypsum provided by EUROGYPSUM during stakeholder workshops and expert consultation within the 'Study on the review of the list of critical raw materials'.

EUROGYPSUM (2016) Personal communication during the review.

EUROGYPSUM (2015). Position letter Re: Assessment of FGD gypsum as a separate material in the list of raw materials to be evaluted as critical by the Commission in 2016.

EUROGYPSUM (2007). Factsheet on: What is Gypsum? [online] Available at: http://www.eurogypsum.org/library/gypsum-factsheets/

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

GypsumtoGypsum (2016). Gto G Project - EU Life programme. [online] Available at: http://gypsumtogypsum.org/

Minerals4EU (2014). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

NERA (2016). The access to gypsum raw material by 2050: challenges, obstacles and levers. Report prepared for Eurogypsum.

OECD (2016). 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.

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/

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/

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 productio nand use of recycled gypsum from waste plasterboard. [online] Available at: http://www.wrap.org.uk/sites/files/wrap/Gypsum_Quality_Protocol_0.pdf

10.7.2 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

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 and NERA (2016). Data and information on gypsum provided by EUROGYPSUM during stakeholder workshops and expert consultation within the 'Study on the review of the list of critical raw materials'.

EUROGYPSUM (2015). Position letter Re: Assessment of FGD gypsum as a separate material in the list of raw materials to be evaluted as critical by the Commission in 2016.

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 (2016). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

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

GypsumtoGypsum (2016). Gto G Project - EU Life programme. [online] Available at: http://gypsumtogypsum.org/

Katz, T., P. N. Martens and K. Sakamornsnguan (2013). The Minerals Industry of Thailand. Current status and Mineral Regulatory Framework. [online] Available at: http://stan.bbk1.rwth-aachen.de/BBK1/en/download?name=138

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

Ministry of Industry (2004). Minerals Act B.E. 2510 and the related Ministerial Regulations. [online] Thailand: Available at: http://www.dpim.go.th/en/media/002_2510.pdf

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

USGS (2016). 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

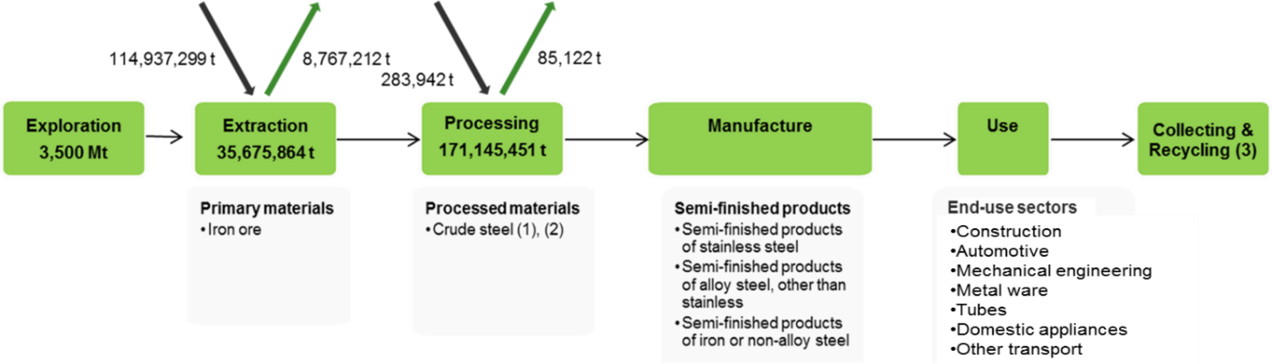
This Factsheet was prepared by the British Geological Survey (BGS). The authors would like to thank the following for their contributions to the preparation of this Factsheet: EUROGYPSUM and NERA Economic Consulting, members of the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders.

11.IRON ORE

Key facts and figures

Material name and Element symbol	Iron ore, Fe	World/EU production (million tonnes)[1]	3,036 /35.7
Parent group	-	EU import reliance[1]	74%
Life cycle stage/ material assessed	Mine production/ Ore	Substitution index for supply risk [SI(SR)][1]	0.97
Economic importance score (EI)(2017)	6.2	Substitution Index for economic importance [SI(EI)][1]	0.94
Supply risk (SR) (2017)	0.8	End of life recycling input rate (EOL-RIR)	24%
Abiotic or biotic	Abiotic	Major end uses in EU[1]	Construction (33%), Automotive (20%), Mechanical Engineering (15%)
Main product, co-product or by-product	Main product	Major world producers[1]	China (44%), Australia (18%), Brazil (13%)
Criticality results	2011	2014	2017
	Not critical	Not critical	Not critical

[1] average for 2010-2014, unless otherwise stated;



(1) Crude steel includes the following materials: ingots of iron and non-alloy steels, in ingots or other primary forms, steel stainless in ingots and other primary forms: steel, alloy, other than stainless, in ingots and other primary forms

(2) Between the extraction and processing stages there is an intermediate phase that corresponds to the production of pig iron. Due to simplified value chain diagram this is not shown.

(3) Recycling of ferrous scrap is common practice in Europe.

Figure 86: Simplified value chain for iron ore

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU. A quantitative figure on recycling is not included as the EOL-RIR is below 70%. EU reserves are displayed in the exploration box.

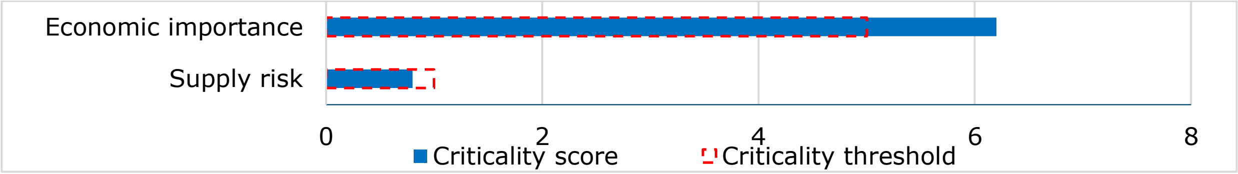


Figure 87: Economic importance and supply risk scores for iron ore

11.1 Introduction

Iron, chemical symbol Fe, is an abundant element in the Earth's crust, with 557 parts per million in the upper crust (Rudnick & Gao, 2003). Metallic iron is produced by refining iron ores in which iron is concentrated in a variety of minerals, the most important of which are hematite, magnetite, limonite, goethite and siderite. Approximately 98% of the ore shipped in the world is used in iron and steel manufacturing. Pure iron is rarely used because it is soft and oxidises rapidly in air to produce rust. Iron is generally used in the form of various alloys, where it is mixed with other elements to make stronger, more useful materials. Pig iron and cast iron contain around 3-4 per cent carbon and very small amounts of other elements such as silicon, manganese and phosphorus. Pig iron and cast iron are hard but brittle and consequently are much less useful than steel, which can contains up to about 2 per cent carbon (usually, around 0.25-0.5%). Numerous types of steel are produced to provide the physical properties, such as strength, hardness and toughness, required for particular applications. These steels vary not only in their levels of contained iron and carbon but also in their contents of alloying elements such as chromium, nickel, molybdenum, tungsten, copper, manganese, silicon, niobium and vanadium (European Commission, 2014b; Kuck, 2016).

Iron ore production in Europe (EU28) accounts for 1% of the global production (BGS, 2016). European (EU28) apparent steel consumption of all finished steel products in 2015 was estimated at 10.2% of the global consumption (worldsteel, 2016c). The steel industry in Europe is an important contributor to the region’s economy. It has a turnover of €170 billion, produces on average 170 million tonnes of steel per year and employs 320,000 people. There are more than 500 steel production sites across the EU Member States and the sector is integrated with European manufacturing and construction industries (European Steel Association, 2016a).

11.2 Supply

11.2.1 Supply from primary materials

11.2.1.1 Geological occurrence

Iron ore deposit types include primarily sedimentary iron deposits (banded iron formations-BIF) and volcanic-associated massive sulphide deposits. The most important types are sedimentary deposits, which are commonly divided into the Precambrian Banded Iron Formations (BIF) and the Phanerozoic ironstones.

The BIF –hosted iron ore system represents the world’s largest and highest grade iron ore deposits (>60% Fe) and is responsible for the majority of iron ore production undertaken at the moment worldwide. BIF are the precursors to low and high grade BIF hosted iron ore (Hagemann et al., 2016). They are stratigraphical units hundreds of metres thick that extend for hundreds or even thousands of kilometres in length. BIF comprise finely laminated to thin bedded sedimentary rocks with distinct chert layers that contain more than 15% by weight iron of sedimentary origin (Beukes and Gutzmer, 2008). The host rock (i.e. BIF) is already rich in Fe, often containing 30% - 35%wt Fe. BIF alone however are not economically viable and therefore do not represent iron ore (Hagemann et al., 2016). The upgrade to BIF-hosted iron ores through complex geochemical processes that lead to the formation of high grade iron ore There are three main types of settings for BIF (Hagemann et al., 2016):

- Archean and Paleoprotezoic Algoma-type BIF, for example the Serra Norte iron ore district in the Carajas Mineral Province (Brazil)
- Proterozoic Lake Superior-type BIF, such as the deposits in the Hamersley Province (Australia), and
- Neoproterozoic Rapitan-type BIF, for example the Urucum iron ore district (Brazil).

Some major BIF-hosted iron ore deposits are listed in Table 51.

Table 51: Major BIF-hosted iron ore deposits with average ore grade above 60% (Hagemann et al., 2016)

Deposit name	**Country**	**Fe (Mt) contained**
Hamersley District	Australia	12,288
Quadrilatero Ferrifero	Brazil	11,200
Carajas	Brazil	10,080
Noamundi	India	2,013

Phanerozoic ironstones are of two types, Clinton and Minette. Both nowadays are of insignificant economic importance due to their low grade and complicated silicate mineralogy, which does not allow for efficient beneficiation to take place (Evans, 1993).

Volcanic-associated massive sulphide deposits predominantly consist of iron sulphide (over 90%) in the form or pyrite and often pyrrhotite. They are stratiform bodies developed at interfaces between volcanic units or at volcanic-sedimentary interfaces. 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 (Evans, 1993). In Sweden, there are two types of iron ore: the Iron Apatite Oxide (IOA-Kiruna type) which stands for about 95% of European iron production, and the Iron Skarn deposits.

Iron ores vary considerably in iron content. In average the iron content of Chinese iron ores is between 30 to 40%, whilst the content of Brazilian and Australia iron ore is above 60% (BGR, 2012). The Fe content of the Kiruna deposit in Sweden is 60%.

11.2.1.2 Mining and processing of iron ore

Mining of iron ore is undertaken either through surface mining or underground mining. Surface mining is the most popular method for extracting iron ore resources, as many deposits are situated near the surface. Overburden is removed during the life of the mine to permit deepening of the pit. Ore benches are developed during the mining stage to allow for drilling, blasting and transport of the ore to the processing facilities.

The first step of the extraction process is the removal of overburden material, such as surface vegetation, soil and rock to reach the deposit. Following that, drilling and blasting of the ore takes place, which exposes the ore body and breaks it up. Subsequently the broken ore is hauled to the crushing plant, using a combination of equipment, such as shovels and excavators and large dump trucks.

In the crushing and washing plant, iron ore is crushed and screened and separated into various size fractions. The different size fractions undergo further processing that removes impurities utilising gravity separation, density separation and sizing methods. The processed iron ore is blended and stockpiled to meet product quality requirements and before it reaches the refining stage (Sarna, 2014). Agglomerated iron ore (pellets) can be fed directly into the blast furnace. Finer material, up to 6 mm in diameter, is fed into a sintering plan, often located with the steel plant, to produce suitable feed for the blast furnace. Very fine material, below 6 mm in diameter, is pelletised for direct use in the blast furnace (Vale, 2016).

A good example of underground mining of iron ore is the Kiruna mine situated in Sweden. Ore in the Kiruna deposit is extracted using the sub-level caving method, which uses gravity to get ore to fall into underground tunnels. The extraction starts by developing transport roads and tunnels underground by directly drilling and blasting the ore body. Reinforcement of walls and ceilings is undertaken and subsequently additional drilling and blasting is performed to liberate the iron ore. The iron ore is removed by electrically driven underground loaders (operator controlled or remotely controlled vehicles) and tipped into vertical shafts (ore passes). Iron ore is collected in rock bins, above the main level. The ore is transported from the rock bins to the crusher (e.g. by train, trucks etc.) and from there it is conveyed to skips, which are hoisted to the surface (LKAB, 2016).

Apart from the Kiruna iron ore mine in Sweden, there are two additional underground mines the Malmberget and Svappavaara. There is also a newly opened open pit mine called Gruvberget in Svappavaara (LKAB, 2016). In Austria, iron ore is mined from the Erzberg open pit mine located in the state of Styria, which contains the largest siderite deposit in the world (Hastorun, 2016). In Germany, only low-grade iron ore is produced, which finds use as a construction additive (Perez, 2016).

11.2.1.3 Refining of iron ore and steel making

Iron ore is the primary raw material used in the production of steel, which is an alloy of iron with less than 2% carbon. There are two different ways followed to produce steel (Worldsteel, 2016a; Worldsteel, 2016b):

- The blast furnace-basic oxygen furnace (BF-BOF) route. The majority of steel production is based on the use of the blast furnace route (approximately 73% of steel produced). In the blast furnace iron ore along with coal, limestone and recycled steel are used. First iron ore is reduced to iron, often called pig metal. Subsequently pig iron is converted to steel in the basic oxygen furnace where steel is produced. Overall, the BF-BOF route uses 1,450 kg of iron ore, 450 kg of coking coal, 200-300 kg of limestone and 100-200 kg of recycled steel (depending on the steel quality) to produce 1,000 kg of crude steel.
- The electric arc furnace (EAF) route relies predominantly on ferrous scrap and, depending on the plant configuration, varying amounts of other sources (e.g. direct-reduced iron - DRI, pig iron, granulated iron). The EAF route uses approximately 1000-1070 kg of ferrous scrap - depending on the scrap quality and the presence of tramp elements -(sometimes combined with other sources of DRI, pig iron etc. depending on the quality of the final steel), and 50-100 kg of limestone to produce 1,000 kg of crude steel.

Downstream processes, such as casting and rolling are similar in the BF-BOF route and the EAF route and steel is delivered as coil, plate, sections or bars (worldsteel, 2016b).

There are numerous different types of steel products, with different grades, different physical, chemical and environmental properties. According to World Steel, there are approximately 3,500 different types of steel (worldsteel, 2016a).

11.2.1.4 Iron ore resources and reserves

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[12], 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.

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 at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU, 2015).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.

According to USGS, world known resources of iron ore are estimated to be greater than 800 billion tons of crude ore containing more than 230 billion tons of iron (USGS, 2016). Resource data for some countries in Europe are available in the Minerals4EU website (see Table 52) but cannot be summed as they are partial and they do not use the same reporting code.

Table 52: Resource data for Europe compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Quantity	Unit	Grade	Code resource type
Finland	NI43-101	190	Mt	30%	Measured
Sweden	JORC FRB-standard NI43-101	17.5 157 169.14	Mt Mt Mt	39.5% 39.46% 30.66%	Measured Measured Measured
Norway	JORC	250	Mt	32%	Indicated
Greenland	JORC	380	Mt	33%	Indicated
Lithuania	State reporting code	61.69	Million m^3	-	Indicated
Ukraine	Russian Classification	233,440	kt	-	P1
Slovakia	None	4.02	Mt	33.81%	Z1
Hungary	Russian Classification	1.75	Mt	24.4%	B
Serbia	JORC	3.98	Mt	37.5%	Total
Greece	USGS	7	Mt	45% Fe_2O_3	Measured
Albania	Nat. rep. code	238.052	Mt	44-52%	Category A
Turkey	None	82.5	Mt	-	Total
Spain	None	282	Mt	-	Identified
Portugal	None	790.65	Mt	38.25%	Historic Resource Estimates

Known global reserves of iron ore estimated by the USGS amount to 190 billion tonnes, with 28% located in Australia (Government of Western Australia, 2016; USGS, 2016), see

---

[12] www.crirsco.com

Table 53. In addition to the reported figures by USGS, Guinea holds important iron ore deposits with the Simandou and Nimba deposits being reported as the most significant at present. Iron ore reserves in Simandou are reported at 1,844 million tonnes with a Fe grade of 65.5%. The Nimba reserves are estimated at 53.96 million tonnes (initial JORC reserve figure) with a Fe grade of 60 to 63% (RioTinto, 2015; Sable Mining Africa, 2016). The Swedish Geological Survey announces lower reserves in Sweden (1039 million tonnes) compared to USGS figures. Reserve data for some countries in Europe are available in the Minerals4EU website (see Table 53) but cannot be summed as they are partial and they do not use the same reporting code.

Table 53: Global reserves of iron ore (Data from USGS, 2016)

Country	Iron ore Reserves (million tonnes)	Iron content (million tonnes)
Australia	54,000	24,000
Russia	25,000	14,000
Brazil	23,000	12,000
China	23,000	7,200
United States	11,500	3,500
India	8,100	5,200
Ukraine	6,500	2,300
Canada	6,300	2,300
Sweden	3,500	2,200
Iran	2,700	1,500
Kazakhstan	2,500	900
South Africa	1,000	650
Other countries	18,000	9,500
World total	190,000	85,000

In addition to Table 53, the iron ore reserves in Sweden in 2015 are estimated at 1,138 million tonnes (SweMin reporting code) with an average Fe grade of 45.3% (LKAB, 2015). The company reported figure is much lower than the one reported for Sweden from USGS, which showcases the deficiencies of reserves data in global estimates.

Table 54: Reserve data for Europe compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Quantity	Unit	Grade	Code reserve type
Sweden	JORC NI43-101 FRB-standard	29.1 81.9 804	Mt Mt Mt	34.2% 32.97% 45.41%	Probable Proven Proven
Finland	JORC NI43-101	64 114	Mt Mt	10% 31%	Proved Proven
Norway	JORC	135.1	Mt	30%	Probable
Ukraine	Russian Classification	633,915	kt	-	A
Slovakia	None	4.02	Mt	33.81%	Z1
Romania	UNFC	57	Mt	-	121
Italy	None	3.5	Mt	-	Estimated

According to the Minerals4EU website (Minerals4EU, 2014), there is some exploration for iron ore in Greenland, Ireland, Sweden, Portugal, Spain, Ukraine, Romania, Slovakia, Kosovo and Albania.

11.2.1.5 World mine production

World mine production of iron ore is summarised in Figure 88. Global supply of iron ore is dominated by China with about 44% of the total mine production, equivalent to 1,336 million tonnes of gross ore (average of 2010-2014). Australia and Brazil are the second and third largest single producing countries accounting for 18% [557,758,348t (gross ore; average of 2010-2014)] and 12% [379,180,000t (gross ore; average of 2010-2014)] respectively of the global iron ore production.

Iron ore production in China takes place from numerous medium to small sized mines with only a few large mines, overall including over 4,133 iron mines in 2014 (Zhaozhi et al., 2016). Small to medium sized mines represent 96% of the total number of mines with large mines accounting for the remainder 4%. Iron ore from China is of lower grade (30-40%) than Australian, Brazilian and other ores (commonly with an ore grade above 60%).

Production has jumped from 75 million tonnes in 1980 to 1.5 billion tonnes in 2014. Iron ore production has been increasing steadily with an average global year on year growth between 1980 and 2014 of 4%, and 9% between the years 2000 to 2014 (BGS, 2016). This growth is attributed to the industrial expansion of China which is clearly documented from year 2000 onwards with a steep increase in production.

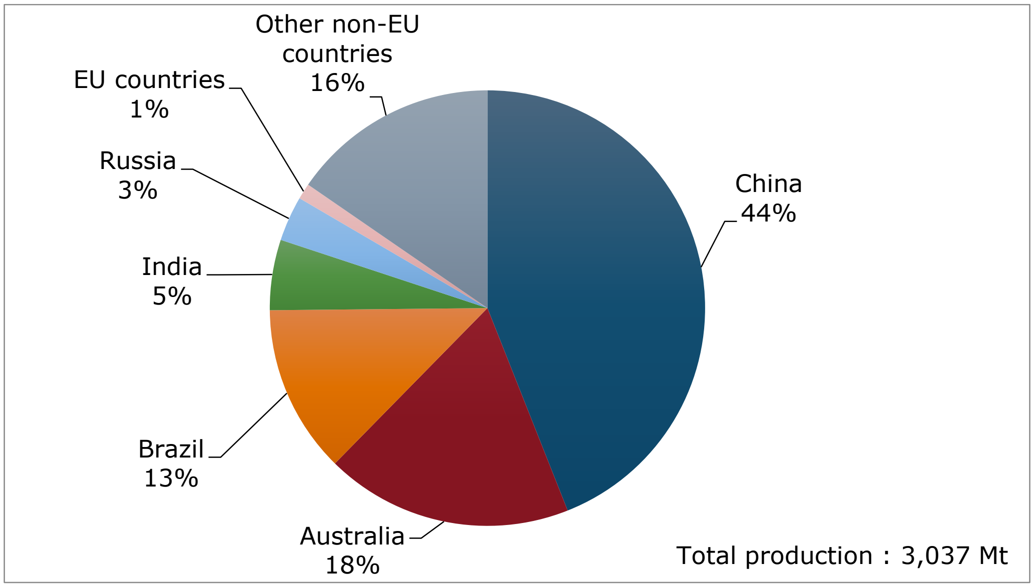


Figure 88: Global mine production of iron ore, average 2010–2014 (Data from BGS World Mineral Statistics database)

The three largest iron ore mining companies are Vale, Rio Tinto and BHP Billiton. Together they controlled 39% of the world production in 2014, while the top 10 companies accounted for 61% of world production in 2014. This is the highest concentration figure recorded so far. The recorded increase over 2013 is attributed to new production mainly from Rio Tinto and BHP Billiton, but also to closures elsewhere, particularly in China. Vale remains the world's largest producer at 319 million tonnes in 2014 (Ericsson and Lof, 2015).

In the EU, Sweden was the leading producer of iron ore with an average 5 years (2010-2014) annual figure of 33 million tonnes representing a share of 93% of the total European production. Austria produced in the same period approximately 2.2 million tonnes and Germany 439 thousand tonnes. Important iron producers in Europe (but not in the EU) are Ukraine, Norway and Bosnia And Herzegovina, with in average respectively 71, 34 and 2 Mt of annual production in 2010-2014 (BGS, 2016).

11.2.1.6 Global crude steel production

Average annual global crude steel production between 2010 and 2014 is estimated at 1,564 million tonnes. Leading producers are presented in Figure 89. China has been the leading producer of crude steel, followed by EU-28, Japan and the United States of America. EU-28 represents a region rather than a single country, but it has been included in that form to showcase the important status of the European steel production globally. Within the EU, Germany is the leading producer (3% of global production), followed by Italy (2% of global production) and France, Spain, the United Kingdom and Poland (1% of global production each). Most of EU-28 countries are steel producers.

The proportional difference between China's steel production figures and the EU-28 is remarkable and once again it illustrates the rapid and large scale industrialisation underway in China. Crude steel production in China is geographically dispersed with an excess in production capacity at present. Except Beijing and Tibet, the remaining 29 provinces all produce crude steel in varying quantities and with varying degrees of capacity (Zhaozhi et al., 2016). China's crude steel production has shown a steady increase over the years. In 2005, the Chinese share of the world total production was 31% in comparison to 49.6% in 2015 (Worldsteel, 2016c).

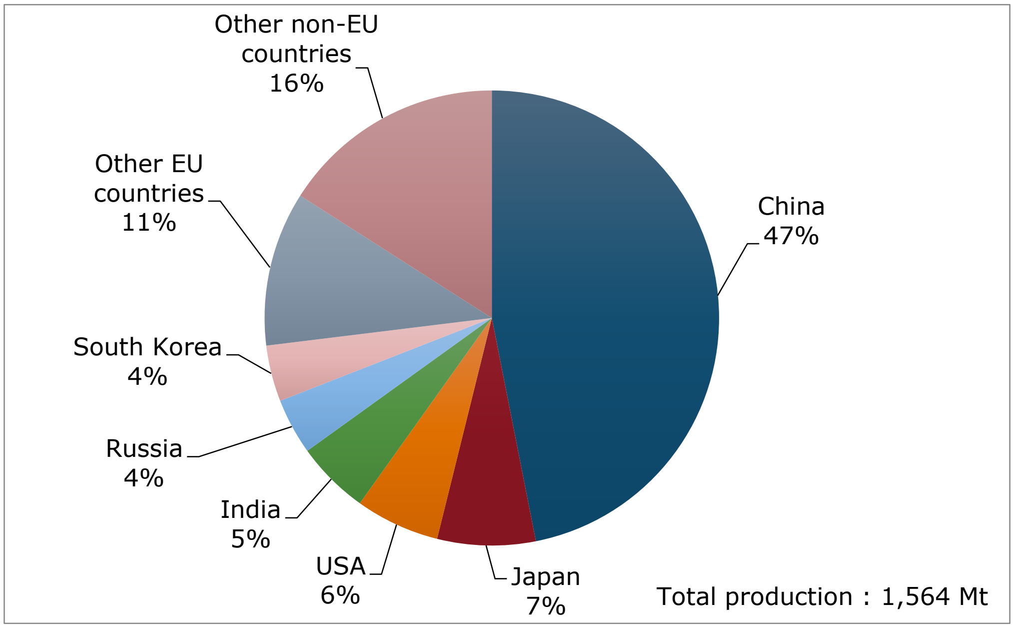


Figure 89: Global crude steel production 2010-2014 (Data from BGS World Mineral Statistics database)

11.2.2 Supply from secondary materials

Iron is recovered from secondary sources (pre-consumer and post-consumer waste) through steel recycling. The recycling process of steel is well established globally and an integral part of steel manufacturing. It is estimated that approximately 650 million tonnes of steel are recycled every year globally, including pre-consumer and post-consumer waste (Worldsteel, 2016c).

Ferrous scrap is recovered from a diverse range of products with a varying degree of complexity in their composition. Steel is found in construction (buildings and infrastructure), automotive (e.g. cars, trucks, ships), industrial equipment and machinery (e.g. mechanical and electrical equipment), and metal goods (e.g. packaging, appliances) (Allwood, 2016). 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% (UNEP, 2013). 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 recycling of steel, especially from products such as electronics which currently include over 50 different elements in their composition. The lower recycling rate for electronic products for instance, is attributed to the complex product composition and inefficient collection rates. The recovery from waste electrical and electronic equipment of steel and other metals often poses significant challenges to metallurgy, if the products are not designed for recyclability and disassembling. If steel is recycled together with other metals, it is substantially downgraded and in some cases might not be recycled at all (UNEP, 2013).

At present, more than half of the ferrous scrap collected is from the manufacturing process, rather than end-of-life products (Allwood, 2016). This suggests that the collection rates of post-consumer ferrous scrap could be improved further to enhance access to more end-of-life products. In addition, improving the recovery of steel from end-of-life products is essential, as at the moment end-of-life steel scrap is often of lower quality and it is normally downcycled.

The average lifetime of steel in different applications and end products is another factor to be taken into consideration when examining secondary supply sources. With construction being the largest consumer of steel, it means that this is not available for recovery for several decades. Overall, the average lifetime of steel is between 35 and 40 years.

There is a synergic interlink between ferrous scrap and primary iron ore. Ferrous scrap is highly sought after by industry due to its reduced environmental impacts (e.g. lower embodied energy and water) and is traded globally. Statistics indicate that the EU-28 ferrous scrap exports over the period 2010 to 2014 were on average 18.3 million tonnes and the EU-28 ferrous scrap imports over the same period were 3.3 million tonnes (Eurostat, 2016a).

Steel is easy to separate from waste streams due to its magnetic properties, whilst the recycling of steel through the electric arc furnace route does not discriminate between different steel types. The use of recycled steel reduces the demand for primary ore and at the same time offers substantial environmental gains and material savings (worldsteel, 2016b). For every tonne of steel scrap turned into new steel on average 1,450kg of iron ore, 450kg of coal and 200-300kg of limestone are saved (worldsteel, 2016b), whilst the total greenhouse gas emissions associated with the production of steel components from recycled steel are around half of those when making steel from iron ore (Allwood, 2016).

In Europe, ferrous scrap plays an important role in steel making. Over 39% of the crude steel production is from the EAF route that uses up to 100% ferrous scrap and Europe has an important role in scrap trade.

11.2.3 Global trade

At the global level, China accounts for 67% of imports of iron ore and the increase of 14% in imports recorded in 2014 is primarily from China. Imports to Japan have remained stable, whilst the Republic of Korea reported a substantial increase in imports of iron ore by 15% in 2014 (Ericsson and Lof, 2015). World exports have increased by 140% between 2003 and 2014, due to China's industrialisation and demand for iron ore. Australia, Brazil, India and South Africa have been the largest exporting countries over this period. In 2014, exports from Australia increased by 24% to 717 million tonnes. Exports from Brazil have shown a lower growth at 4.5%, whilst South Africa has now become the third largest exporter in 2014 with recorded exports of 66 million tonnes. Exports from India in the same year were under 10 million tonnes. Political constraints on exports and shrinkage in new projects have impacted on the growth of the Indian iron ore sector (Ericsson and Lof, 2015).

At the global level, excess capacity in the steel industry has presented a continuous increase since 2014. In 2014, the capacity utilisation rate was estimated at 73% and the Organisation for Economic Cooperation and Development projects that the gap between capacity and production may widen further in the coming years (European Steel Association, 2016a). This excess capacity has been built up in certain third countries, notably China, with Europe being one of the destinations of its exports. In 2014, the overcapacity in China was estimated at around 350 million tonnes, almost the double of the EU annual production (European Commission: COM(2016)155).

11.2.4 EU trade

Europe is a net importer of iron ore with an average annual net import figure in the period 2010-2014 of 106 million tonnes (Figure 90). EU imports iron ore from several countries outside Member States, but the majority of iron ore, approximately 48% of the total imports to the EU originates from Brazil, followed by Ukraine and Canada, with 13% and 12% share respectively in the total iron ore supply to the EU (Figure 91). Imports to the EU between 2013 and 2014 show a slight decrease of 0.6%, with a larger decrease shown between years 2010 and 2014 of 5%. Net imports of iron ore from extra EU countries have been quite stable over the period 2010 and 2014, but have reduced substantially since 2000, on average by 22%. The net import reduction is attributed to the economic recession with the lowest figure reported for 2009 at 73 million tonnes.

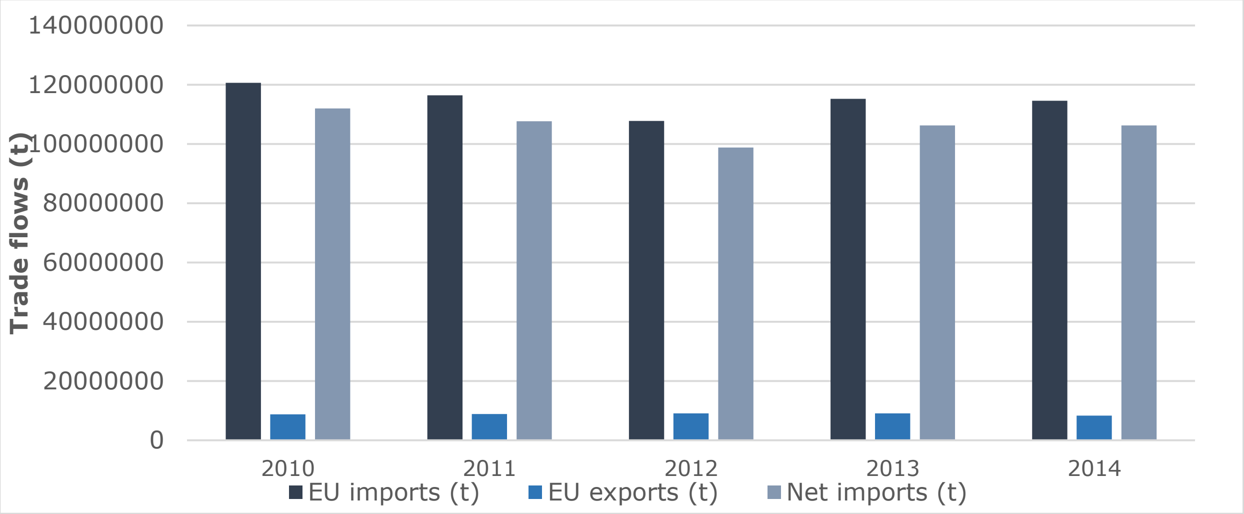


Figure 90: EU trade flows for iron ore (Data from Comext Eurostat)

In the EU28, total steel imports (all types, including semi-manufactured products) increased by 23% in 2015 to 32.3 million tonnes. Total exports in the EU fell by 9% in the same period to 26.4 million tonnes. EU is now a net importer of steel, while historically it has been a net exporter. However, the trade of steel takes place on a dynamic market and the change in status in the EU from a net exporter to a net importer is due to the accelerating rise in imports observed fuelled by global overcapacity. Market distortions from third players had affected the European steel trade and the EU is imposing a record number of trade defence measures on steel products, with a majority of them concerning China, and new investigations over unfair trade practices are currently underway (European Commission: COM(2016)155, Steel: preserving sustainable growth and jobs in Europe). Key destinations for exports of steel from the EU include Turkey, the US, Algeria and Switzerland (European Steel Association, 2016a).

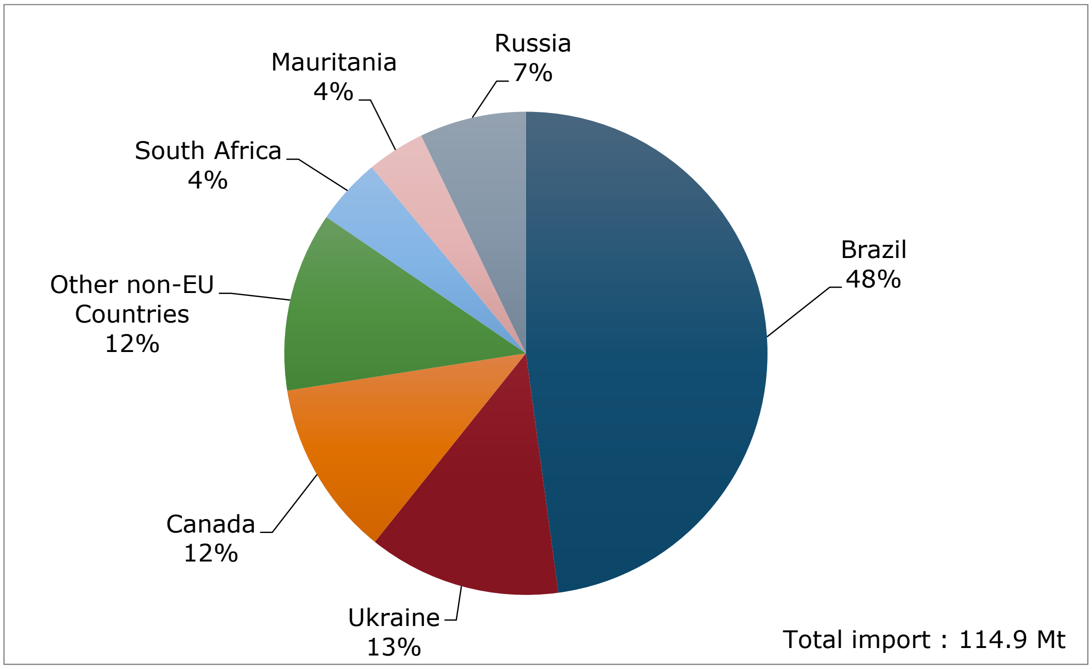


Figure 91: EU imports of iron ore from extra-EU28 countries, average 2010-2014. (Data from Eurostat Comext database)

11.2.5 EU supply chain

The EU supply chain can be described by the following key points:

EU production:

- The 5 year average European production of iron ore between 2010 and 2014 was 35.7 million tonnes per year, which accounts for 1% of the global production. Producing countries include Sweden, Austria and Germany (based on data from BGS, 2016).
- The average European crude steel production between 2010 and 2014 was 171 million tonnes per year, with Germany (25%), Italy (15%), France (9%) and Spain (9%) representing the major producing countries in Europe. European steel production accounts for 11% of the global production (based on data from BGS, 2016).
- The average European production of finished steel products (all qualities) between 2010 and 2014 was 155 million tonnes per year. Finished steel products include flat and long hot rolled products (based on data from European Steel Association, 2015).
- Based on data from the European Steel Association, Europe produced 69.7 million tonnes of steel through the EAF route that uses up to 100% ferrous scrap. According to the European Steel Association, the average ferrous scrap input into the EU total steel production (primary and secondary routes, between 2010 and 2014) equal to 95 million tonnes (European Steel Association, 2017).

Trade balance:

- The traded quantities of iron ore suggest that Europe is a net importer of iron ore. Domestic production cannot satisfy the European demand for steel. Brazil is the main country supplying iron ore to Europe, accounting for 48% of the total European imports (Eurostat, 2016a).
- Europe imports iron in the forms of crude steel, semi-finished steel products and finished steel products. Europe is a net importer of crude steel and semi-finished

steel products (all qualities) and the 5 years average (2010 – 2014) net import figure from extra-EU28 countries was 198,821 tonnes per year (crude steel) and 4.6 million tonnes per year (semi-finished steel) respectively. The statistical data for finished steel products suggest that Europe is a net exporter of finished products with a net export figure in the same 5 year period being 9.9 million tonnes per year (based on data from European Steel Association, 2015). This suggests that the imports of iron ore and semi-finished products are turned into finished products that are exported outside the EU.

- The import reliance for iron ore in Europe is estimated at 74%, which is not an unexpected figure considering the relatively small EU production, high imports and low exports figures. Figure 92 presents the EU sourcing (domestic production + imports) for iron ores.
- Europe is a net exporter of scrap with an average 5 year figure of 14.7 million tonnes per year. Around 40% of the crude steel production in Europe relies on the availability of ferrous scrap. Its importance to the European economy is clearly major.

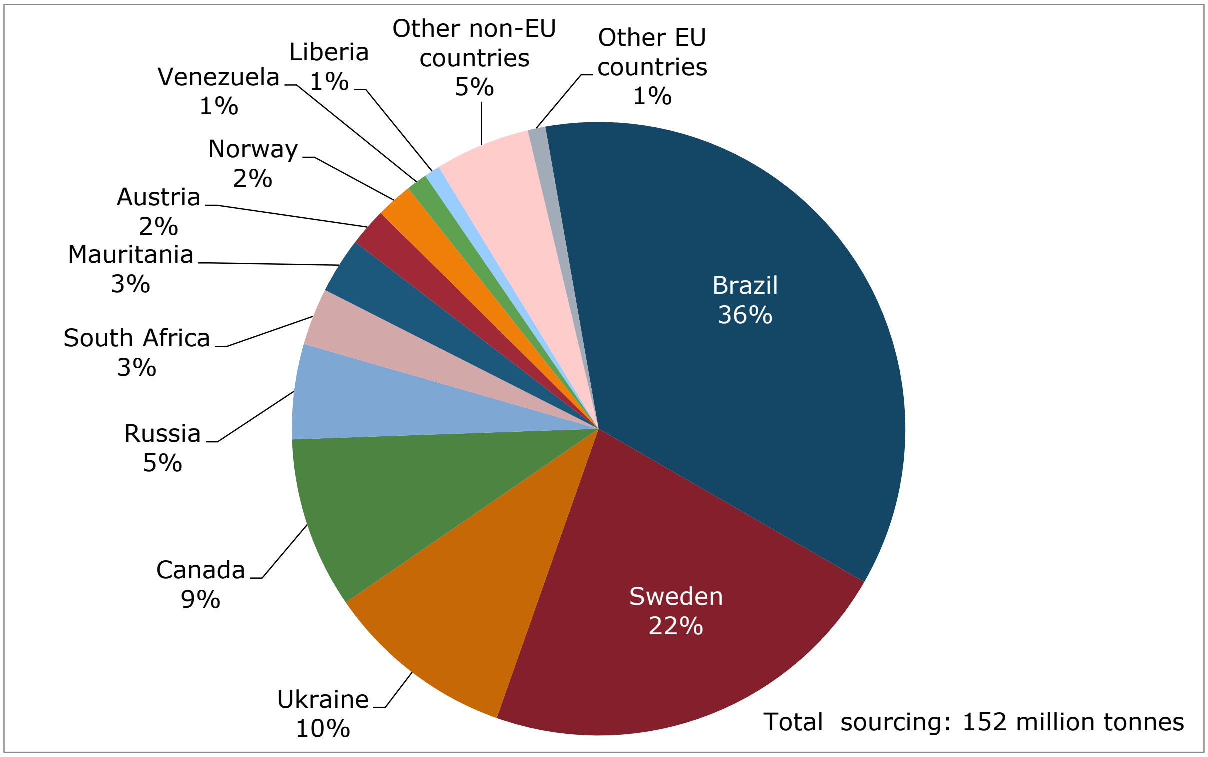


Figure 92: EU sourcing (domestic production + imports) of iron ore, average 2010-2014 (Data from Eurostat Comext database)

Export restrictions:

- China imposes a 10% export tax for iron ore and concentrates and roasted iron pyrites. India has imposed a 25% average 5 years (2010 – 2014) tax. In both cases the export tax restrictions have been introduced to safeguard domestic production, and to expand domestic steelmaking. Both China and India are emerging economies and steel is a fundamental raw material contributing to their industrialisation.

11.3 Demand

11.3.1 EU consumption

Apparent consumption of iron ore in the EU is estimated at 141.8 million tonnes per year (2010-2014 average), of which 35.7 million tonnes are provided by domestic production and 114.9 million tonnes through imports to the EU. Iron ore produced and imported to Europe is utilised in the production of various steel products. The dependency on imports is substantial hence the import reliance of 74% is not surprising. Between 2010 and 2014, apparent consumption showed a substantial drop in 2012 to 133.5 million tonnes, but picked up thereafter and in 2014 apparent consumption is estimated at 144.9 million tonnes. The drop seen in 2012 is attributed to the economic climate and the weakening of emerging economies. Since 2012, demand in Europe has increased, which is an indicator of the recovery in the developed world. In the future this increase is not expected to continue, as the slowdown of emerging economies, such as China will impact on EU exports of steel products (European Steel Association, 2016a). EU apparent steel consumption has also increased by 3.5% in 2015, but real consumption of steel products is estimated at 1.7% only, which suggests an oversupply of steel that currently ends up in stocks. According to the European Steel Association, the increase in steel inventories in 2015 was higher than in previous years (European Steel Association, 2016a).

11.3.2 Applications / end uses

Iron ore is the key component of steel manufacturing. Figure 93 presents the main applications of steel in EU-28. Steel is a vital material found in numerous products: in construction applications, in automotive, in mechanical engineering, domestic appliances, tubes, other transport media and many more applications (European Steel Association, 2016b). Relevant industry sectors are described using the NACE sector codes in Table 55.

In construction, steel performs numerous functions in buildings and infrastructure. In buildings, steel finds use as a structural material in the building frame, as reinforcing bars in conjunction with concrete, in sheet products (e.g. roofing material, ceilings), in non-structural uses, for example heating and cooling equipment and in interior fixtures and fittings, such as rails and stairs. Steel is used in the development of major infrastructure including bridges, tunnels, rail track, in ports and airports and in utilities, for example pipelines, rebar for power stations and others (European Steel Association, 2016b; Worldsteel, 2016d).

Steel is used in all motor vehicles, with an average of 900kg of steel per vehicle. Steel is found in the body structure, panels, doors, engine, gears, suspension, wheels, tyres and many more. High-strength steels are used in all new vehicles, which enables them to be lighter and enhance their safety (European Steel Association, 2016b; Worldsteel, 2016d).

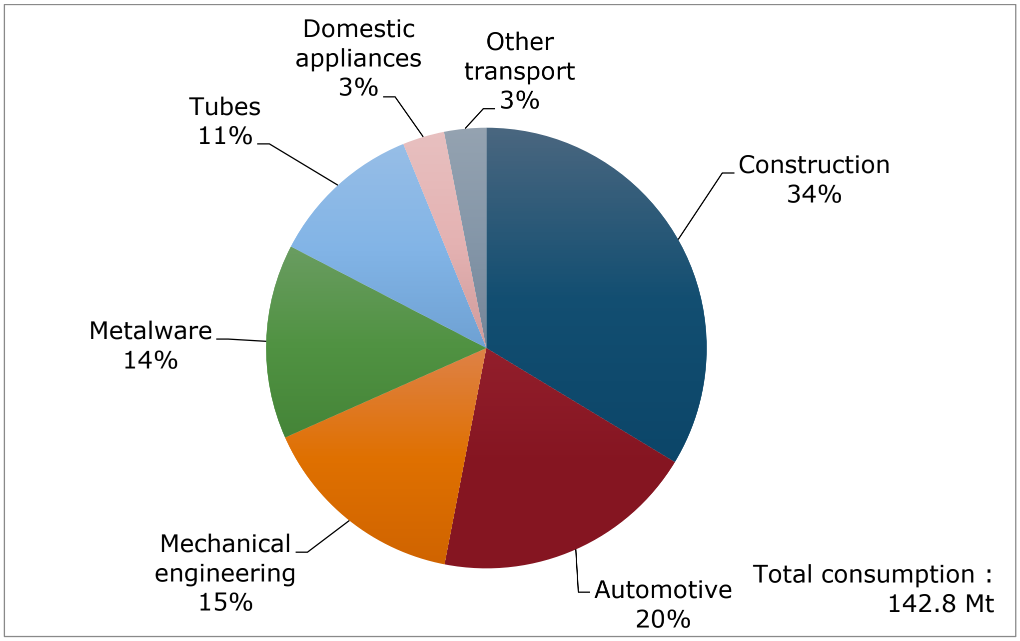


Figure 93: EU end uses of steel. Average figures for 2010-2014. (Data from European Steel Association, 2015)

Table 55: Steel applications, 2-digit and associated 4-digit NACE sectors

Applications	2-digit NACE sector	4-digit NACE sectors	Value added of sector (millions €)
Steel in Construction	C25 - Manufacture of fabricated metal products, except machinery and equipment	C2511 - Manufacture of metal structures and parts of structures	159,513.4
Steel in Automotive	C29 - Manufacture of motor vehicles, trailers and semi-trailers	C2920 - Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semi-trailers	158,081.4
Steel in Mechanical Engineering.	C28 - Manufacture of machinery and equipment n.e.c.	C2811 - Manufacture of engines and turbines, except aircraft, vehicle and cycle engines	191,000.0
Steel in metalware	C25 - Manufacture of fabricated metal products, except machinery and equipment	C2571 - Manufacture of cutlery	159,513.4
Steel in tubes	C24 - Manufacture of basic metal	C2420 - Manufacture of tubes, pipes, hollow profiles and related fittings, of steel	57,000.0
Steel in domestic appliances	C28 - Manufacture of machinery and equipment n.e.c.	C2821 - Manufacture of ovens, furnaces and furnace burners	191,000.0
Steel in other transport	C30 - Manufacture of other transport equipment	C3011 - Building of ships and floating structures	53,644.5

The mechanical equipment and machines used to make numerous products are steel based. Tools and machinery include a wide range of equipment ranging from cranes, bulldozers, drills and scaffolding used in construction, to tools used by the manufacturing sector, to small products such as pens and tools we all have in our households (European Steel Association, 2016b; Worldsteel, 2016d).

Steel metalware includes a variety of products used for packaging, cutlery, cookware and others. Steel is used for the production of pipes and tubes used primarily in the energy sector for the transport of oil and natural gas. It also finds application in numerous domestic appliances ranging from fridges to washing machines and other smaller equipment. Finally, steel is used in the manufacture of other transport equipment, including ships and shipping containers, trains and rail cars and aeroplanes (European Steel Association, 2016b; Worldsteel, 2016d).

11.3.3 Prices and markets

Iron ore is traded in a variety of forms, ore grades and currencies. Transactions often take place in closed-door negotiations hence pricing data transparency and accuracy can be an issue. Spot prices of iron ore are calculated using a variety of methodologies, therefore they can differ depending on who is the data provider (Reserve Bank of Australia, 2015).

Figure 94 presents spot prices for iron ore between the years 1980 and 2015. The price of iron ore between 1980 and 2005 varied from below US$20/tonne to US$30/tonne. The spot market started to emerge in 2003 due to the growing demand for steel from China. From 2005 to 2015, the price of iron ore averaged US$96/tonne due to substantial global demand (Wilson, 2015). The industrialisation of China has had a distinct effect on the iron ore price and it is often used as a proxy to monitor China's economic growth. The price of iron ore peaked in 2011 at more than US$180/tonne, a level never recorded in the past (Wilson, 2015). The average price of iron ore (62% material content, cost insurance freight, from China) between 2011 and 2015 was 110,01 US$/tonne (DERA, 2016).

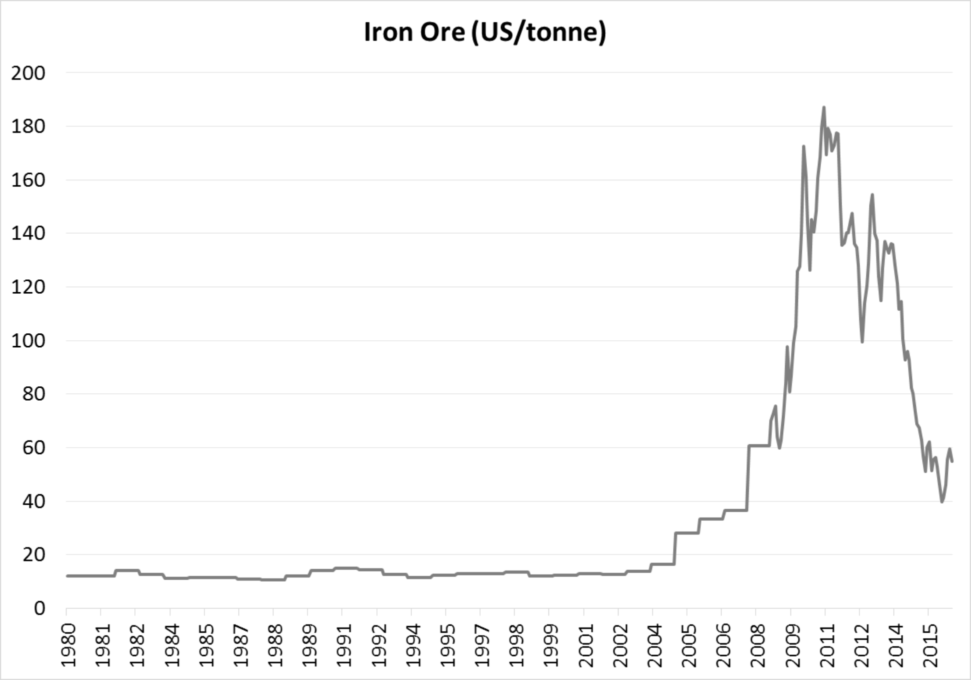


Figure 94: Iron ore spot price (in US$/tonne) based on standard NYMEX traded 62% Fe, CFR (Cost and Freight) China in $US/metric tonne (Market Index, 2016)

The global demand for iron ore was met by low cost supply from the three major producing countries, which increased their capacity to 115 million tonnes in 2014 (Ericsson and Lof, 2015). However, this fast expansion in capacity, in combination with a slowdown in demand in China and no reduction in supply from higher cost producers resulted in a substantial decline in iron ore prices in particular from 2013 onwards (Ericsson and Lof, 2015).

11.4 Substitution

Substitutes are identified for the applications and end uses of the commodity of interest. In the case of iron ore, substitutes have been identified for the applications of steel in construction, automotive and mechanical engineering. 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 concrete, timber, masonry and other construction products that are often used for construction purposes. These alternative materials do not necessarily have the same performance as steel or used for the same purposes. 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 the purposes of this assessment information corresponding the UK construction industry and the use of steel in structural construction have been used as a proxy. On that basis steel in construction is considered the dominant material.

Potential substitutes for the use of steel in automotives include aluminium and plastic composites. The sub-shares used for the substitute materials are based on an average car composition and the current percentages of these materials used. None of the identified substitutes have the same performance as steel.

Substitutes for steel used in mechanical engineering include composites, aluminium, magnesium and titanium. Sub-shares for these substitutes are not known and have been estimated for the purposes of the criticality assessment. Titanium could be an effective substitute for stainless steel in products such as medical devices, in marine applications and aircraft applications.

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. Exact sub-shares for the substitute materials are unknown and have been estimated. Substitutes for none of the other applications of steel have been identified as their market shares are not significant.

The literature used to identify substitutes for iron ore is listed in section 11.7.

11.5 Discussion of the criticality assessment

11.5.1 Data sources

Market shares are based on the statistical data produced by the European Steel Association presented in the *European Steel in Figures* publication (European Steel Association, 2015). Production data for iron ore are from World Mineral Statistics dataset published by the British Geological Survey (BGS, 2016) and the Eurostat Statistics on the production of manufactured goods (PRODCOM NACE Rev.2) (Eurostat, 2016b). Trade data were extracted from the Eurostat Easy Comext database (Eurostat, 2016a). 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 derived from the OECD Export restrictions on the Industrial Raw Materials database (OECD, 2016).

For trade data the Combined Nomenclature (CN) code 2601 'iron ores and concentrates (incl. roasted iron pyrites)' have been used. For Prodcom data the code 07101000 'Iron ores and concentrate' was used. These data were averaged over the five-year period 2010 to 2014. Other data sources used in the criticality assessment are listed in section 11.7.

11.5.2 Economic importance and supply risk calculation

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 55 in previous paragraph).

The supply risk was assessed on iron ore using both the global HHI and the EU-28 HHI as prescribed in the revised methodology.

11.5.3 Comparison with previous EU criticality 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 56.

Table 56: Economic importance and supply risk results for iron ore in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014a) and 2017.

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Iron ore	8.11	0.35		7.40	0.50		6.2	0.8

Although it appears that the economic importance of iron has reduced between 2014 and 2017 this is a false impression created by the change in methodology. 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 but also due to changes in the supply of iron ore to Europe and the increased reliance on imported material. It is not possible to quantify what proportion of these changes is due to the methodology alone, as new data have been used in the assessment.

11.6 Other considerations

The criticality assessment of iron ore is not straightforward due to its complicated value chain. The assessment of economic importance undertaken is based on the availability of data for steel rather than iron ore, as all iron ore finds use in the production of steel. However for the assessment of supply risk, data on iron ore only were used. The intermediate stage of pig iron is not taken into consideration in the assessment process due to data and literature being available primarily for steel.

Iron ore and steel have been a driving force for emerging economies and consumption figures are often reported as a proxy to monitor growth in developing economies, such as China. In that sense, steel is more critical to countries such as China that undergo industrialisation rather than Europe. For instance, apparent consumption in China in 2015 is estimated at 44.8% in comparison to 10.2% in EU-28 (Worldsteel, 2016c). Nevertheless, the import dependency of iron ore in Europe is significant. This is why the status of iron ore has been assessed in the 2017 criticality assessment.

11.6.1 Forward look

Growth in the iron ore market is expected in the coming years but in a much slower pace. The position of China and the activities to be undertaken in dealing with excess capacity for instance will determine the steel market. It is suggested that it is not the slowdown of China's growth that would affect the demand for steel, but the reduced share of investment in Chinese GDP (Ericsson and Lof, 2015). Therefore, steel demand in China is expected to be weak over the next few years. In terms of the outlook for supply, the reduced iron ore prices seen in the last few years imply that it is possible to supply world steel producers with cheaper iron ore. This has initiated major restructuring in the mining sector and the world iron ore market, which includes closure of inefficient production capacity and brought a stop to mines that required excess capital. Major producers have been able to respond to this and brought new capacity into the market, which could not be absorbed and means additional closures for their competitors. China has invested in additional infrastructure to be able to deal with steel scrap and it is expected that in the future the utilisation of scrap will rise (Ericsson and Lof, 2015).

Overall, it is expected that the iron ore market will be characterised by oversupply for a few years and the price of iron ore will remain low (Ericsson and Lof, 2015).

Table 57: Qualitative forecast of supply and demand of iron ore

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
Iron (iron ore)		X	+	+	+	+	+	+

11.7 Data sources

11.7.1 Data sources used in the factsheet

Allwood, J. M. (2016). A bright future for UK steel [online] Cambridge Available at: https://www.cam.ac.uk/system/files/a_bright_future_for_uk_steel_2.pdf.

Beukes, N. J. and J. Gutzmer (2008). Origin and Paleoenvironmental Significance of Major Iron Formations at the Archean-Paleoproterozoic Boundary. Reviews in Economic Geology, 15(2008), 5-47.

BGR (2012). Polinares. Fact Sheet: Iron (Fe).

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

Ericsson, M. and A. Lof (2015). Iron ore 2015: Market Review and Forecast [online] Available at: http://www.e-mj.com/features/5724-iron-ore-2015-market-review-and-forecast.html

EU (2016). Investigations. [online] Available at: http://trade.ec.europa.eu/tdi/completed.cfm

European Commission (2010). Critical raw materials for the EU. [online] Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission (2014)a. 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 (2014)b. 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 Steel Association (2015). European Steel in Figures. Covering 2010-2014. 2015 Edition. [online] Brussels European Steel Association (EUROFER), Available at: http://www.eurofer.org/News%26Events/Publications.itpl

European Steel Association (2016)a. EUROFER Annual Report 2016. [online] Brussels: European Steel Association (EUROFER), Available at: http://www.eurofer.org/News%26Events/Publications.itpl

European Steel Association (2016)b. Made of Steel: omnipresent and indispensable. [online] Available at: http://www.eurofer.org/About%20us/About%20Steel/Made%20of%20Steel.fhtml

European Steel Association (2017). Data and information on iron ore provided by Eurofer during expert consultation within the 'Study on the review of the list of critical raw materials'.

Eurostat (2016)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

Evans, A. M. (1993). Ore Geology and Industrial Minerals. An Introduction. Third Edition. Oxford and Northampton: Blackwell Science.

Ghilotti, D. (2016). India's shift towards monolithic refractories. Industrial Minerals 2016 (October).

Government of Western Australia (2016). Western Australia Iron ore Industry Profile [online] Available at: http://www.dsd.wa.gov.au/

Hagemann, S. G., T. Angerer, P. Duuring, C. A. Rosière, R. C. Figueiredo e Silva, L. Lobato, A. S. Hensler and D. H. G. Walde (2016). BIF-hosted iron mineral system: A review. Ore Geology Reviews, 76, 317-359.

Hastorun, S. (2016). 2013 Minerals Yearbook. Austria. [online] Available at: http://minerals.usgs.gov/minerals/pubs/country/europe.html#au

Kuck, P. (2016). Iron Ore. Statistical Compendium. [online] Available at: http://minerals.usgs.gov/minerals/pubs/commodity/iron_ore/stat/

LKAB (2015). Annual and Sustainability Report 2015. [online] Available at: https://www.lkab.com/en/investors/financial-reports/

LKAB (2016). Sub-level Caving [online] Available at: http://www.lkab.com/en/About-us/Overview/Mining/Sub-Level-Mining/

Market Index (2016). Fe-Iron Ore. [online] Available at: http://www.marketindex.com.au/iron-ore

Minerals4EU (2014). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

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

Perez, A. A. (2016). 2013 Minerals Yearbook. Germany [online] Available at: http://minerals.usgs.gov/minerals/pubs/country/europe.html#gg

Reserve Bank of Australia (2015). Statement on Monetary Policy – February 2015. Box A: The Effects of Changes in Iron Ore Prices. [online] Available at: http://www.rba.gov.au/publications/smp/2015/feb/box-a.html

RioTinto (2015). RioTinto 2015 Annual report. [online] Available at: http://www.riotinto.com/documents/RT_Annual_Report_2015.pdf

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.

Sarna, S. K. (2014). Mining of iron ores [online] Available at: http://ispatguru.com/mining-of-iron-ores/

Tuck, C. A. (2015). 2013 Minerals Yearbook. Iron ore. [online] United States U.S. Geological Survey, Available at: http://minerals.usgs.gov/minerals/pubs/commodity/iron_ore/

UNEP (2013). Metal Recycling - Opportunities, limits, 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. Iron ore. [online] Available at: http://minerals.usgs.gov/minerals/pubs/commodity/iron_ore/

Vale (2016). Iron ore and Pellets [online] Available at: http://www.vale.com/en/business/mining/iron-ore-pellets/pages/default.aspx

Wilson, J. (2015). Iron ore fundamentals [online] Available at: http://www.bhpbilliton.com/media-and-insights/reports-and-presentations/2015/06/iron-ore-fundamentals

worldsteel (2016)a. About steel [online] Available at: https://www.worldsteel.org/media-centre/About-steel.html worldsteel (2016)b. FACT SHEET. Steel and raw materials [online] Available at: http://www.worldsteel.org/steel-by-topic/raw-materials.html

worldsteel (2016)c. World Steel in Figures 2016. [online] Available at: http://www.worldsteel.org/publications/bookshop/product-details.~World-Steel-in-Figures-2016~PRODUCT~World-Steel-in-Figures-2016~.html

worldsteel (2016)d. Markets [online] Available at: http://www.worldsteel.org/steel-by-topic/Markets.html

Zhaozhi, Z., J. Guangyu, W. Xianwei and Z. Jianfeng (2016). Development and Utilization of the World's and China's Bulk Mineral Resources and their Supply and Demand Situation in the Next Twenty Years. Acta Geologica Sinica - English Edition, 90(4), 1370-1417.

11.7.2 Data sources used in the criticality assessment

American Chemistry Council (2016). Plastics and Polymer Composites in Light Vehicles. [online] Available at: https://plastics-car.com/lightvehiclerepor

American Institute of Steel Construction (2016). Structural Steel: An Industry Overview. [online] Available at: https://www.aisc.org/globalassets/why-steel/steel-industry-overview.pdf

AZO MATERIALS (2012). Medical Applications of Stainless Steel 304 [online] Available at: http://www.azom.com/article.aspx?ArticleID=6641

Copper Development Association Inc. (2016). Copper Alloys [online] Available at: https://www.copper.org/applications/architecture/arch_dhb/technical-discussion/copper_alloys/

Ducker Worldwide (2009). 2009 Worldwide Light Vehicle Material Content.

European Aluminium (2016). Aluminium in use [online] Available at: http://european-aluminium.eu/about-aluminium/aluminium-in-use/

European Commission (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

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 (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 (2016). Annexes to the background report on the assessment of the methodology on the list of critical raw materials.

European Steel Association (2015). European Steel in Figures. Covering 2010-2014. 2015 Edition. [online] Brussels European Steel Association (EUROFER), Available at: http://www.eurofer.org/News%26Events/Publications.itpl

European Steel Association (2016). EUROFER Annual Report 2016. [online] Brussels: European Steel Association (EUROFER), Available at: http://www.eurofer.org/News%26Events/Publications.itpl

Eurostat (2016)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

Infomine (2016). Magnesium Prices and Magnesium Price Charts [online] Available at: http://www.infomine.com/investment/metal-prices/magnesium/

Mining Journal (2016). Commodities [online] Available at: http://www.mining-journal.com/

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

PlasticsEurope (2013). Automotive - The World moves with plastics [online] Available at: http://www.plasticseurope.org/Document/automotive---the-world-moves-with-plastics-brochure.aspx?FolID=2

The American Foundry Society (2016). Magnesium Alloys [online] Available at: http://www.afsinc.org/content.cfm?ItemNumber=6895

The Construction Index (2012). Steel grows market share in key sectors. [online] Available at: http://www.theconstructionindex.co.uk/news/view/steel-grows-market-share-in-key-sectors

The Silver Institute (2016). Silver, You & Your Home [online] Available at: http://www.silverinstitute.org/site/silver-you-your-home-2/

Total Materia (2005). Titanium and Its Alloys: Selection of Materials and Applications. [online] Available at: http://www.totalmateria.com/page.aspx?ID=CheckArticle&site=ktn&NM=125

UNEP (2013). Metal Recycling - Opportunities, limits, 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

11.8 Acknowledgments

This Factsheet was prepared by the British Geological Survey (BGS). The authors would like to thank Eurofer, Euromines, SGU, 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. KAOLIN

Key facts and figures

Material name and Formula	Kaolin, $Al_2O_{3}\text{-}2SiO_{2}\text{-}2H_2O$	World/EU production (tonnes)1	35,086,441/10,830,073
Parent group (where applicable)	-	EU import reliance[1]	5%
Life cycle stage assessed	Extraction	Substitution index for supply risk [SI (SR)][1]	0.93
Economic importance (EI)(2017)	2.3	Substitution Index for economic importance [SI(EI)][1]	0.89
Supply risk (SR) (2017)	0.5	End of life recycling input rate	0%
Abiotic or biotic	Abiotic	Major end uses in the EU[1]	Mineral products: 60% Plastics products: 18% Paper: 17%
Main product, co-product or by-product	Co-product	Major world producers[1]	United States: 17% Germany: 13% India: 11%
Criticality results	2011	2014	2017 (current)
	Not critical	Not critical	Not critical

[1] average for 2010-2014, unless otherwise stated;

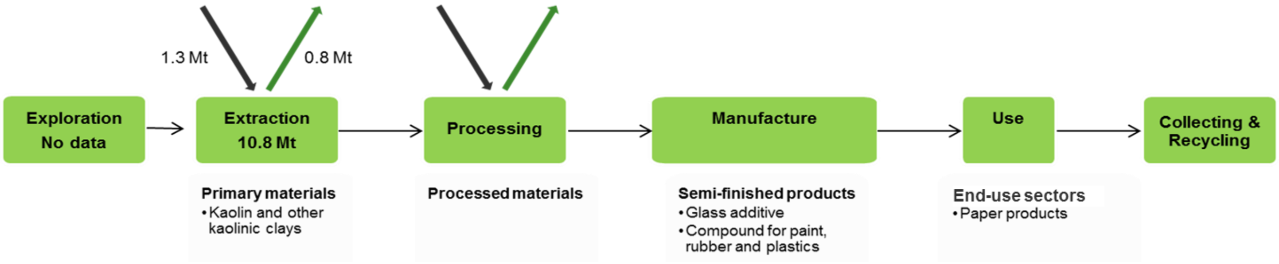


Figure 95: Simplified value chain for kaolin

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU.

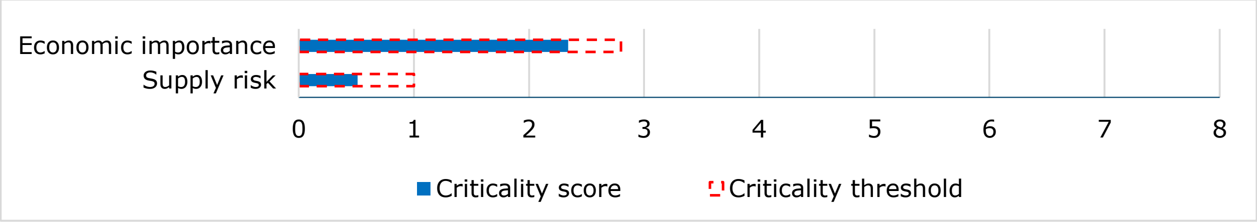


Figure 96: Economic importance and supply risk scores for kaolin

12.1 Introduction

Kaolin as discussed in the 2017 criticality assessment are natural, earthy, fine grained raw materials mainly composed of hydrous aluminium, magnesium and iron silicates. These silicates are called clay minerals. The specific clay mineral discussed here is kaolin. Kaolin is the market name for the clay mineral kaolinite. Kaolin is both a rock term and a group minerals name for kaolinite, dickite, nacrite, and halloysite (Murray, 2006). They are derived primarily from the alteration of alkali feldspar and micas. Kaolin is a white, soft, plastic clay mainly composed of fine-grained plate-like particles. (IMA, 2011). The name kaolin is derived from the Chinese word kauling meaning high ridge, the name of a hill near Jauchau Fu in China; a synonym "China Clay" is sometimes used for kaolin for that reason.

In the EU, kaolin is used industrially, primarily as filler based on its optical, mechanical and chemical characteristics.

12.2 Supply

12.2.1 Supply from primary materials

12.2.1.1 Geological occurrence/exploration

Kaolin deposits, in all sizes, can be found all over the world. Kaolin may occur as primary or secondary ore, where the primary type is hydrothermally altered igneous or metamorphic rocks, and the secondary type is of sedimentary origin formed through transportation and deposition of mineral particles. Kaolin is formed when the anhydrous aluminium silicates which are found in feldspar rich rocks, like granite, are altered by weathering or hydrothermal processes. The process which converted the hard granite into the soft matrix found in kaolin pits is known as "kaolinisation". The quartz and mica of the granite remain relatively unchanged whilst the feldspar is transformed into kaolinite. Smectite may also form in small quantities in some deposits. (IMA, 2011)

12.2.1.2 Processing

The refining and processing of the fine fraction of the kaolinised granite yields predominantly kaolinite with minor amounts of mica, feldspar, traces of quartz and, depending on the origin, organic substances and/or heavy minerals (IMA, 2011). Separation of the fine kaolinite particles from the coarser waste quartz mainly) requires a series of techniques. These include blending, fine grinding and chemical reductive bleaching. Finally, kaolin is dried to a powder. Kaolin extraction and processing creates large quantities of sand and other aggregates arising as by-products (BGS, 2009).

12.2.1.3 Resources and reserves

Kaolin is one of the clays that can be found in nearly pure occurrence or at least be beneficiated to high purity. Major kaolin reserves are located in the USA (Georgia), Australia, Brazil (Jari, Capim), Germany (Bavaria, Saxony), the UK (Cornwall, Devon), Czech Republic (Karlovy Vary and Pilszen area), France (Bretagne), Ukraine, Poland, China and India. Many countries' reserves are large, and resources of kaolin and all clays are considered to be extremely large (USGS, 2015).

There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of kaolin 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[13], 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.

For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for kaolin. 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. 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 kaolin at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU, 2015).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.

12.2.1.4 World production

The global production of kaolin clay between 2010 and 2014 was annually 35.1Mt on average. Figure 97 shows the USA was the largest single producer of kaolin with an output of 17% of the world’s production, million tonnes in 2010, followed by Germany (13%), India (11%), and the Czech Republic (10%). The UK follows with a production just over 1 Mt, and Spain and Italy both with production levels between 0.3 and 0.4 Mt.

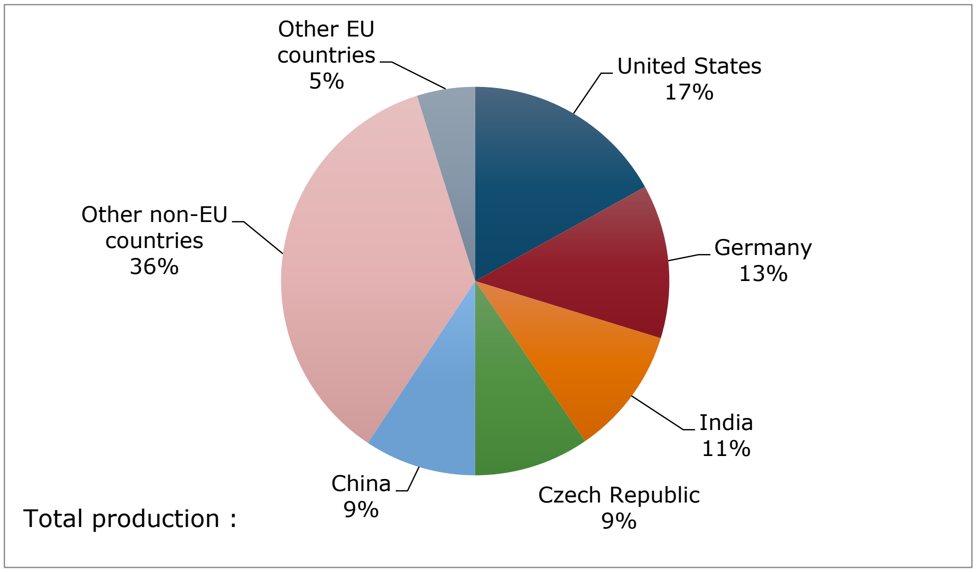


Figure 97: Global mine production of kaolin, average 2010–2014 (Data from BMWFW 2016)

12.2.2 Supply from secondary materials

End of life recycling input rate for kaolin is estimated to be 0%.

---

[13] www.crirsco.com

The recycling of kaolin as used in ceramics (end-of-life input rate) is not possible for quality reasons. In spite of the insignificant recycling, kaolin secondary input could be considered to come indirectly through the recycling of paper or tiles and bricks which allows some of the mineral components to be recovered. Based on market analysis and estimated recycling rates, IMA considers that about 49% of all kaolin and clay used is recycled. As said, this does not affect the end-of-life recycling input rate. As indicated above, this figure is an EU-wide average figure and regional disparities do exist. (IMA-Europe, 2013).

12.2.3 EU trade

A minor share of the EU consumption is imported from outside the EU. The trend in recent years (see Figure 98) shows that the EU increasingly reducing the already small share of kaolin from outside the EU.

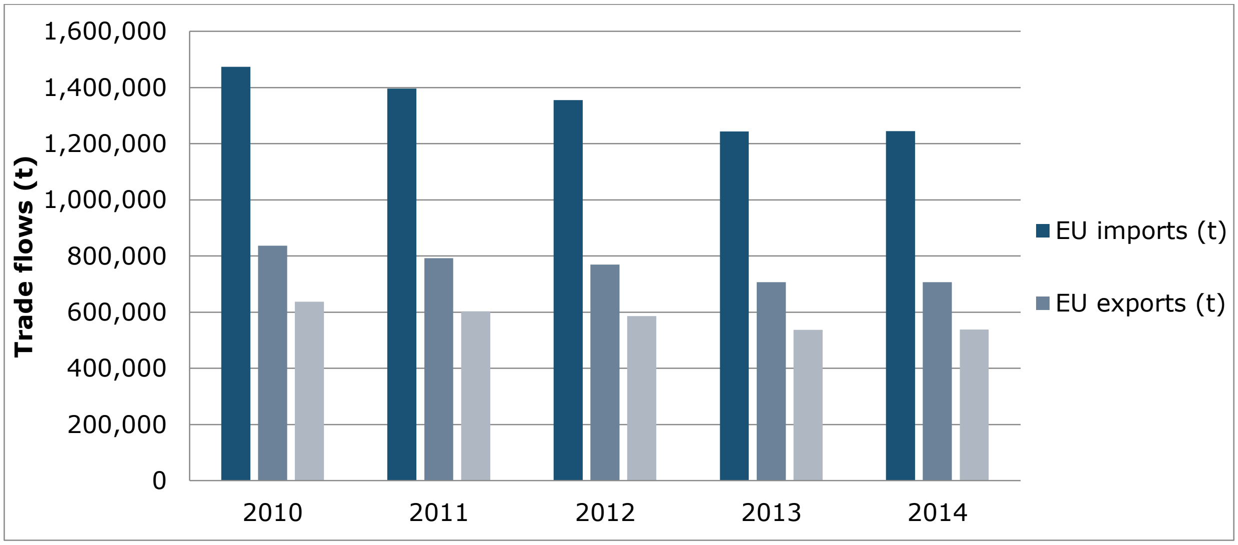


Figure 98: EU trade flows for kaolin (Data from Eurostat 2016)

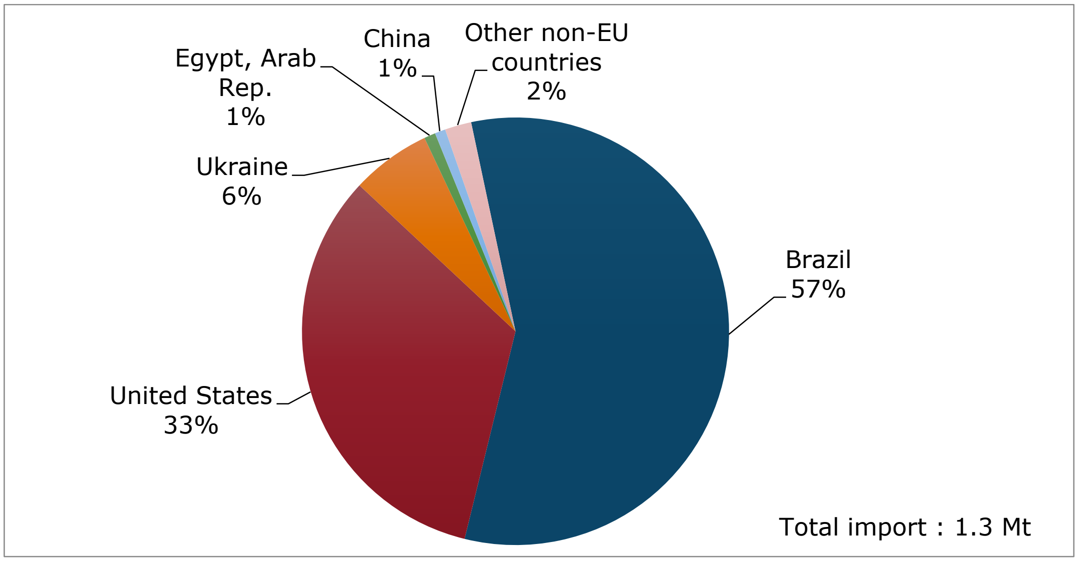


Figure 99: EU imports of kaolin, average 2010-2014 (Data from Eurostat 2016)

Main importers of kaolin to the EU are United States and Brazil (see Figure 99). The abundance of kaolin in the world is reflected in a large number of suppliers that deliver small volumes, mostly shipped together with other commodities.

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.

12.2.4 EU supply chain

The EU has still a significant manufacturing ceramic, mineral products and paper/paper products producing sector. These industries take in the refined kaolin directly from the extractive industry. The total value added of these sectors is over 150 billion EUR.

The EU relies for the supply of kaolin for 5% on its imports.

Vietnam is the only country to impose an export tax, at an average of 10% between 2010 and 2014. Egypt and Malaysia require a specific license to export kaolin clay (OECD, 2016).

Figure 100 shows the EU sourcing (domestic production + imports) for kaolin.

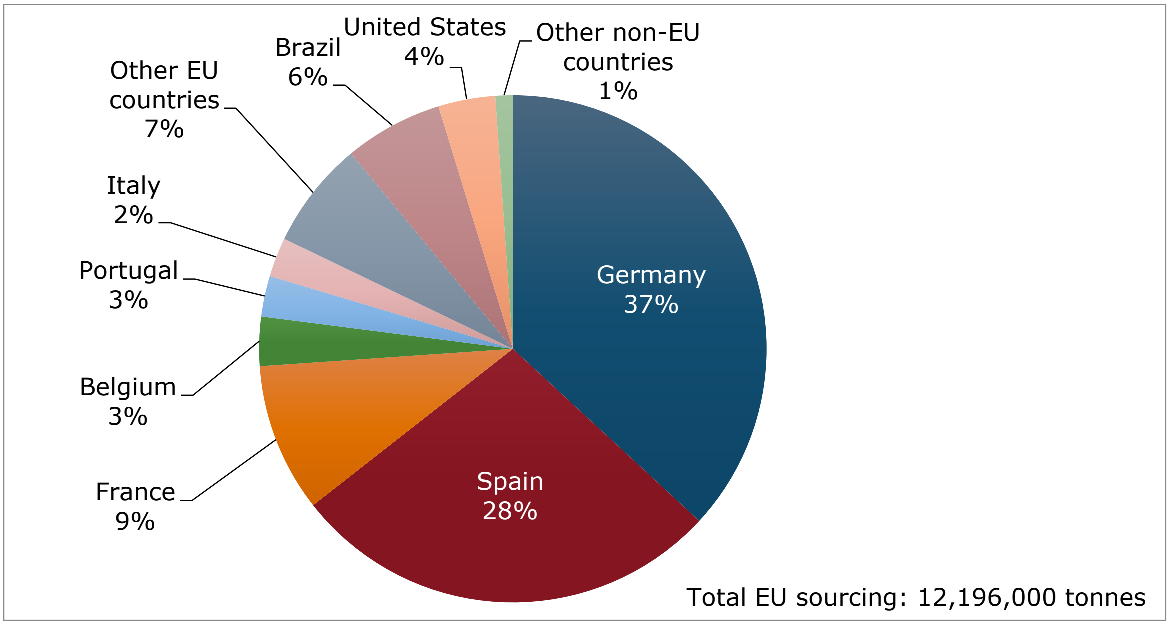


Figure 100: EU sourcing (domestic production + imports) of kaolin, average 2010-2014 (Eurostat, 2016; BGS, 2016)

12.3 Demand

12.3.1 EU consumption

On average, the EU consumption was around 12.1 Mt between 2010 and 2014.

12.3.2 Applications / End uses

Individual kaolin variances vary in many physical aspects, which in turn influence their end use. Of particular commercial interest is the degree of crystallinity which influences the brightness, whiteness, opacity, gloss, film strength, and viscosity (IMA-Europe, 2011).
The main industrial applications of kaolin are in the manufacture of paper, ceramics, rubber, plastics, paint, cement and glass-fibres. More detailed descriptions of applications are adhesives, insecticides, sanitary ware, cosmetics, sealants, pharmaceuticals, glazes, refractories, fertilizers and tiles.

In Europe, the most important uses of kaolin and clays are as follows (see Figure 101):

- Ceramics: 60% of total kaolin and clay consumption is used by the ceramics industry for white wares, which consists of tableware, sanitary ware, and wall and floor tiles. It provides strength and plasticity in the shaping of these products and reduces the amount of pyroplastic deformation in the process of firing.
- Paper: The paper industry uses kaolin both as filler in the bulk of the paper and to coat its surface, and consumes another 17%.
- Fibreglass: For the production of fibre glasses 5% of total kaolin consumption is necessary.
- Other: Other uses are in paints, rubber, plastics, refractory industries and cosmetics/pharmaceuticals. These applications have mainly been linked to the rubber and plastic product manufacturing.

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 58). The value added data correspond to 2013 figures.

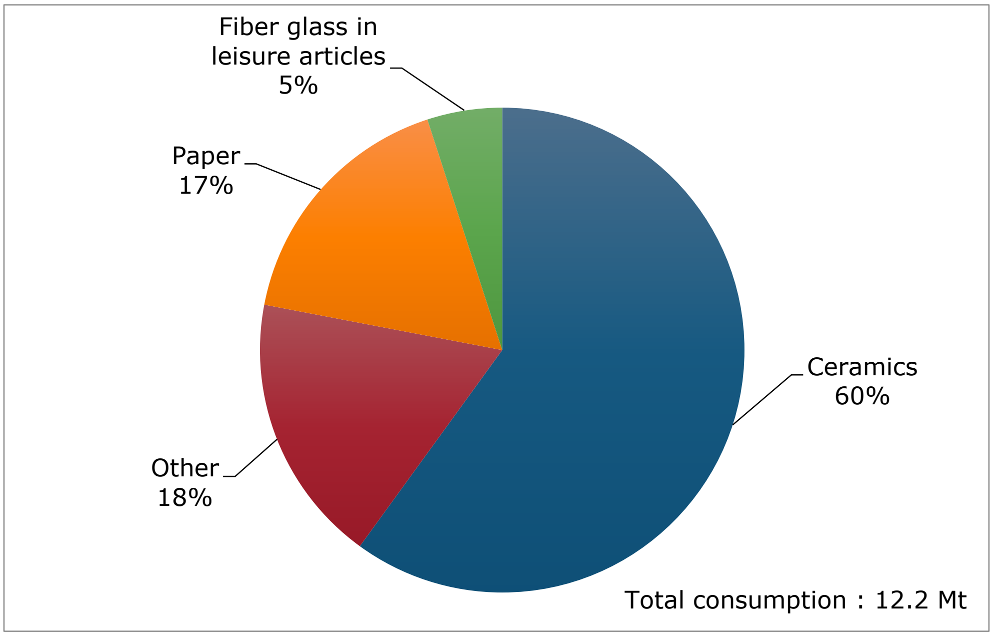


Figure 101: Global/EU end uses of kaolin. Average for 2010-2014 (Data from European Commission 2014)

Table 58: Kaolin applications, 2-digit NACE sectors and value added per sector (Data from the Eurostat database, Eurostat, 2016)

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (millions €)
Paper	C17 - Manufacture of paper and paper products	C17.09 - Manufacture of paper stationery	41,281.5
Additives	C22 - Manufacture of rubber and plastic products	C22.21 - Manufacture of plastic plates, sheets, tubes and profiles	82,000.0
Ceramics	C23 - Manufacture of other non-metallic mineral products	C23.42 - Manufacture of ceramic sanitary fixtures	59,166.0
Glass in leisure articles	C32 - Other manufacturing	C32 – C32.30 Manufacture of sports goods	41,612.6

12.3.3 Prices

The price of clays, kaolin among them, has been constant for decades (see Figure 102). The price spike from 2011 was induced by the demand for higher quality clays, with a corresponding higher price (USGS, 2016). The average price of kaolin paper #1 coating grade between 2011 and 2015 was 190.68 US$/t (DERA, 2016).

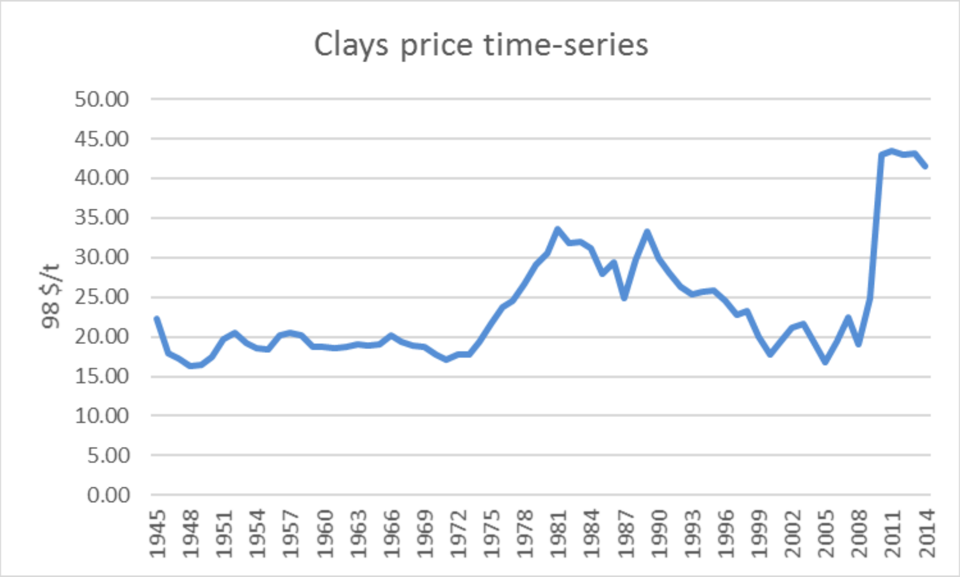


Figure 102: Global developments in price of kaolin. Average for 1945-2014. (Data from USGS, 2015)

12.4 Substitution

Data on market shares and recycling rate comprise both kaolin and other ceramic clays; the latter will to a large extent find their way into fired clay bricks and tiles. Research has shown that replacement of primary clay by clean brick rubble from Construction & Demolition Waste up to 75 % may be feasible (Van Dijk et al., 2001). Actual use is limited by the mismatch in availability of clean brick rubble from CDW waste and new construction volumes and techniques to separate brick and mortar in masonry rubble. Replacement of kaolinite (and other ceramic clays) may affect about 30% of the kaolinite market, as this is the share finding its way to ceramic industry (BGS, 2009).

Note that in several cases, kaolin, talc and calcite compete as potential substitutes for each other in many purposes.

It may be speculated that, if alkali activated binders (e.g. Provis, 2014; Vinai et al., 2015) find their way in to building and construction to replace conventional cements, e.g. as a way to reduce CO_2, the demand for kaolinite will significantly increase as a raw material for metakaolin is one of the most suitable precursors for the geopolymer-type of alkali activated binders. Most industrial waste products have not enough reaction potential to be used exclusively as a precursor (i.e. without addition of e.g. metakaolin).

An important substitute for kaolin in paper applications is calcium carbonate ($CaCO_3$), however substitution rates are sometimes overestimated and should be around 15% (IMA, 2016). In the paper industry, calcium carbonate substitutes for kaolin and has become a strong competitor of kaolin in coating paper and as filler. However, as the plate-structure of kaolin is highly desired for many applications, substitution by calcium carbonate may have reached a limit. (BGS, 2009)

Diatomite, polymers, silica gel, and zeolites can replace kaolin as absorbents; and various siding and roofing types in building construction (USGS, 2016).

Talc in paper is used as well, but for a different functionality as compared to kaolin; therefore it is not substitution.

12.5 Discussion of the criticality assessment

12.5.1 Data sources

The CN product group code for kaolinites is 2507 00 20, and is aptly labelled "Kaolin". The other clays are covered in CN product group with code 2507 00 80, but these clays are not part of the assessment.

The trade and production data come from Eurostat and BGS respectively (BGS, 2016). 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.

12.5.2 Calculation of Economic Importance and Supply Risk indicators

As with most industrial minerals, refining of kaolinites takes place near the extraction site. Therefore, the extraction phase in the supply chain is taken for the criticality analysis.

The supply risk was assessed on kaolin using both the global HHI and the EU-28 HHI as prescribed in the revised methodology.

12.5.3 Comparison with previous EU assessments

The criticality assessment of kaolin in the 2017 assessment has shown different results compared to the previous assessments. The economic importance is reduced given the modest size (compared to the mega sector size of over 140 billion in the previous analysis) of value added in the mineral products manufacturing sector (e.g. ceramics), plastic products and paper products. The increase in supply risk is due to the weight that the new methodology places in very low end-of-life recycling input rates, even though the 2017 assessment has the same stance as recycling opportunities considered in the previous assessments. The input values relate to substitution are also similar to previous assessments, which indicates that the change in supply risk is due to the new methodology. See Table 59.

Table 59: Economic importance and supply risk results for Kaolin in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Kaolin	4.44	0.3		4.77	0.27		2.3	0.5

12.6 Other considerations

12.6.1 Forward look for supply and demand

Developments in the construction sector in developed economies may result in slightly increased sales of common clay for heavy clay products and ball clay for ceramic tile and sanitary ware manufacture. Decreased kaolin sales for paper markets is proven to be balanced by increased sales for ceramics. Despite the variability in sales from year to year, the underlying trend in sales has been relatively flat for the past seven years and probably will remain so for the near future (USGS, 2016). See Table 60.

Table 60: 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	0/+	0/+	0/+	0/+	0/+	0/+

12.6.2 Environmental and regulatory issues

Restoration of tips and pits is put in practice near European extraction sites. Backfilling can be done, but needs to be weighed against possible needs in the future. New permissions for tipping provide opportunities to tackle the legacy of degraded landscapes and lack of alternate land uses. (BGS, 2009)

12.7 Data sources

12.7.1 Data sources used in the factsheet

BGS (2009). Mineral planning factsheet. Available at: https://www.bgs.ac.uk/downloads/start.cfm?id=1362

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

Dill, H. G. (2010). The "chessboard" classification scheme of mineral deposits: Mineralogy and geology from aluminum to zirconium. Earth Science Reviews, Volume 100, Issue 1, p. 1-420. Available at: http://adsabs.harvard.edu/abs/2010ESRv..100....1D

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 (2016)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

Minerals4EU (2014). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

Murray, H. H. (2006). Clays. Ullmann's Encyclopedia of Industrial Chemistry. Available at: http://onlinelibrary.wiley.com/doi/10.1002/14356007.a07_109.pub2/abstract

Provis, J.L., (2014). Geopolymers and other alkali activated materials: Why, how, and what ? Materials & Structures 47:11-25.

USGS (2015). Virta, R. L . USGS Mineral Yearbook 2013 Clay and Shale. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/clays/myb1-2013-clays.pdf

Van Dijk, K., Van der Zwan, J., Fraaij, A.L.A., Mulder, E. & Hendriks, C.F., (2001). 'Closing the clay-brick cycle', options for the recycling or reuse of masonry debris. CIB World Building Congress, Wellington, 12 pp.

Vinai, R., Panagiotopoulou, C., Soutsos, M., Taxiarchou, M., Zervaki, M., Valcke, S., Chozas Ligero, V., Couto, S., Gupta, A., Pipilikaki, P., Larraza Alvarez, I., Coelho, D. & Branquinho, J., (2015). Sustainable binders for concrete: A structured approach from waste screening to binder composition development. Heron 60:27-48.

12.7.2 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

BMWFW (2016). World Mining Data. Kaolin. Pp. 119-120 of the PDF file. http://www.en.bmwfw.gv.at/Energy/Documents/WMD2016.pdf

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 (2016). Expert consultation.

IMA-Europe (2011). Kaolin Fact sheet. Available at: http://www.ima-europe.eu/sites/ima-europe.eu/files/minerals/Kaolin_An-WEB-2011.pdf

IMA-Europe (2013). Recycling sheet: Kaolin and Clay. Pp. 13-14. Available at: http://www.ima-europe.eu/sites/ima-europe.eu/files/publications/IMA%20Recycling%20Sheets%20FULL%20published%20on%2024.10.2013_0.pdf

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

12.8 Acknowledgments

This Factsheet was prepared by the Netherlands Organisation for Applied Scientific Research (TNO). The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials for their contributions to the preparation of this Factsheet. Specific experts that have contributed their input and feedback to the factsheet and criticality assessments are listed in the data sources section.

13. LEAD

Key facts and figures

Material name and Element symbol	Lead, Pb	World/EU production (mining production, metal content)[1]	5 million tonnes/ 213,173 tonnes
Parent group (where applicable)	N/A	EU import reliance[1]	18%
Life cycle stage assessed	Ores & concentrates	Substitution index for supply risk [SI (SR)][1]	0.97
Economic importance score EI(2017)	3.7	Substitution Index for economic importance [SI(EI)][1]	0.97
Supply risk SR (2017)	0.1	End of life recycling input rate	EU: 75%
Abiotic or biotic	Abiotic	Major end uses in EU (2012)	Batteries (85%), lead compounds (6%), rolled and extruded products (4%)
Main product, co-product or by-product	Co-product and main product	Major world producers[1]	China (49%), Australia (14%), United States (7%)
Criticality results	2011	2014	2017
	Not assessed	Not assessed	Non Critical

[1] Average for 2010-2014, unless otherwise stated.

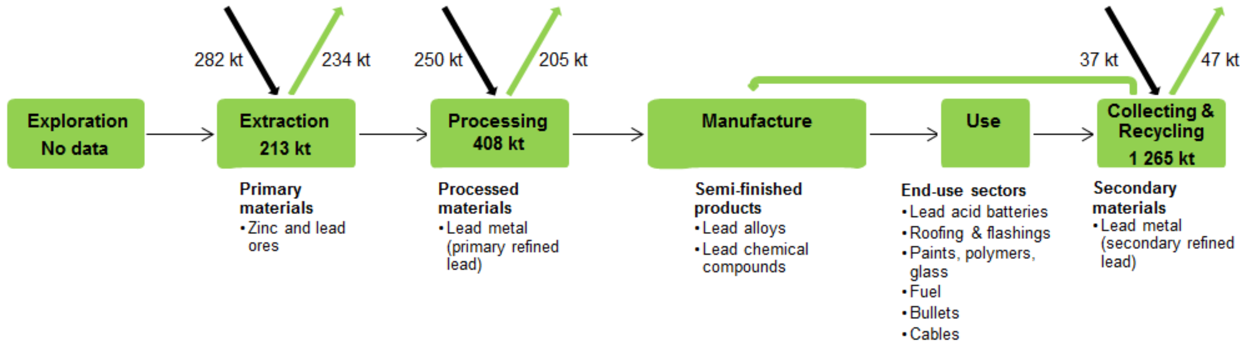


Figure 103: Simplified value chain for lead

Green boxes in the above figure represent stages of the supply chain which take place in the EU-28. The black and green arrows represent imports and exports to and from the EU respectively. EU reserves are displayed in the exploration box.

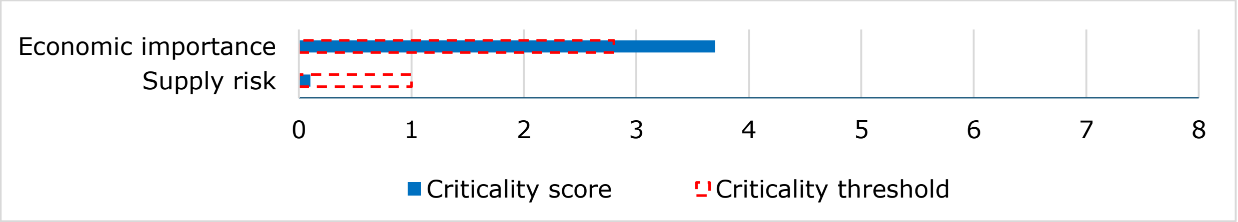


Figure 104: Economic importance and supply risk scores for lead

13.1 Introduction

Lead (Pb) has an atomic number of 82 and belongs to Group 14 (IVa) of the periodic table. It is a soft, malleable, darkish grey metal with a low melting point of 327.3°C and a boiling point of 1740°C. Lead has a high density of 11.3 g/cm3 and a poor electrical conductivity and a good resistance to corrosion under a wide variety of conditions, especially to most acids including sulphuric and chromic acids. It can be used as a pure metal, an alloy or in the form of a chemical compound. Lead concentration in the Earth continental upper crust is estimated to be 17 ppm (Rudnick & Gao, 2003), which is relatively low compared to the other base metals.

Lead is usually found in ore with zinc, silver and copper and is extracted together with these metals. The main lead mineral is galena (PbS), which contains 86.6% lead. Cerussite ($PbCO_3$) and anglesite ($PbSO_4$) commonly occur in the near-surface weathered or oxidized zone of a lead orebody.

Lead-acid batteries are the largest end-use sector now accounting for about 85 % of global lead demand. Lead is also used in a wide range of applications including plastics, paint additives, roofing material and soldering alloys.

Lead and its compounds can be toxic to humans and animals and their use is regulated in many countries.

13.2 Supply

13.2.1 Supply from primary materials

13.2.1.1 Geological occurrence

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), Zn-Pb 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 to 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 Co, Sn, Se, Mn, Cd, In, Bi, Te, Ga, and Ge.

13.2.1.2 Exploration

Global zinc-lead exploration expenditure fell by 56% to US$380.3 million in 2016 from US$865.4 million in 2012 (SNL, 2017). Countries with the largest exploration budgets for lead/zinc in 2016 were Peru, China, Australia, and Canada which together accounted for 50% of the total budget, followed by Mexico, Brazil, USA and India. About 5% of the total budget (US$19 million) was spent in the EU, primarily in Sweden, followed by Ireland, Poland, Romania, France, Portugal, Spain and Greece. Based on SNL data, 39% of the global exploration budget was spent on late-stage and feasibility activity, 38% on minesite exploration work, and 23% on grassroots exploration.

13.2.1.3 Mining, processing and extractive metallurgy

The ore undergoes various processes. The lead concentrate is produced by milling and flotation. The lead concentrate is then processed by the smelter. The smelting stage 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 concentrates) 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., Cu, As, Sb, Sn, Bi, Zn, Ag, Au) and needs to be refined.

13.2.1.4 Resources and reserves

There is no single source of comprehensive evaluations of resources and reserves that apply the same criteria to lead-zinc deposits 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[14], 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.

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 lead, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes

---

[14] www.crirsco.com

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 at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU, 2014). 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 USGS estimated the world (identified) lead resources at more than 2,000 million tonnes. Global reserves of lead at the end of 2015 were estimated at around 89 million tonnes (USGS, 2016), with Australia, China and Russia, collectively accounting for 67% of the global total (Table 61).

Resource/reserve data for some countries in Europe are available in the Minerals4EU website (Minerals4EU, 2014) but cannot be summed as they are partial and they do not all use the same reporting code (Table 62 and Table 63).

Table 61: Global lead reserves in year 2015 (USGS, 2016)

Country	Estimated Lead Reserves (thousand tonnes)
Australia	35,000
China	15,800
Russia	9,200
Peru	6,700
Mexico	5,600
United States	5,000
India	2,200
Poland	1,700
Bolivia	1,600
Sweden	1,100
Turkey	860
Ireland	600
South Africa	300
Other countries	3,000
World Total (rounded)	*89,000*

Table 62: Lead resource data for the EU-28 compiled in the European Minerals Yearbook (Minerals4EU, 2014)

Country	Reporting code	Code resource type	Quantity	Unit	Weighted average Grade
Czech Republic	Nat. rep. code	Potentially economic	0.2	Mt	0.67%
		P1	0.8	Mt	-
		P2	5.3	Mt	-
France	None	Historic resource estimate	0.8	Mt	Metal content
Greece	USGS	Measured	35.3	Mt	4.12%
Hungary	Russian Classification	A	0	Mt	-
		B	0.5	Mt	-
		C2	4	Mt	-
Ireland	JORC	Measured, Indicated & Inferred	57.4	Mt	1.28%
Italy	None	Sub-economic	0.1	Mt	-

Country	Reporting code	Code resource type	Quantity	Unit	Weighted average Grade
Poland	Nat. rep. code	A+B+C1	1.3	Mt	0.08
		C2 + D	0	Mt	0.02
		Total	1.3	Mt	0.07
		A+B+C1	0.6	Mt	1.84
		C2 + D	0.7	Mt	1.78
		Total	1.3	Mt	1.8
Portugal	NI43-101	Measured	33.9	Mt	1.40%
		Indicated	112.2	Mt	0.90%
		Inferred	47.2	Mt	0.64%
Slovakia	None	Probable (Z2)	0	Mt	1.17%
		Anticipated (Z3)	1.6	Mt	1.17%
Spain	NI43-101	Measured	10.8	Mt	0.01%
Sweden	JORC	Measured	0.5	Mt	0.40%
		Indicated	3	Mt	2.05%
		Inferred	1.5	Mt	1.60%
	NI43-101	Measured	8.5	Mt	4.80%
		Indicated	6.4	Mt	4.20%
		Inferred	5	Mt	3.20%
	FRB-standard	Measured	5.2	Mt	0.91%
		Indicated	26.2	Mt	1.23%
		Inferred	39.5	Mt	1.26%
United Kingdom	JORC	Indicated	2.1	Mt	2.18%
		Inferred	4.1	Mt	1.20%

"-": not known

Table 63: Lead reserve data for the EU compiled in the European Minerals Yearbook (Minerals4EU, 2014)

Country	Reporting code	Code reserve type	Quantity	Unit	Weighted average grade	Included in resources
Ireland	JORC	Proven & Probable	14.77	Mt	1.61%	Yes
Italy	None	Estimated	4	Mt	-	-
Poland	Nat. rep. code	Total	0.9	Mt	-	Yes
		Total	0.14	Mt	-	Yes
Portugal	NI43-101	Proven	16.521	Mt	1.43%	Yes
		Probable	33.77	Mt	0.72%	Yes
Slovakia	None	Probable (Z2)	0.049	Mt	1.17%	Yes
		Anticipated (Z3)	1.574	Mt	1.17%	Yes
Sweden	FRB-standard	Proven	17.19	Mt	1.96%	No
		Probable	31.56	Mt	1.34%	No
	NI43-101	Proven	8.508	Mt	4.00%	No
		Probable	3.301	Mt	2.70%	No

"-": not known.

13.2.1.5 World mine production

During the period 2010-2014, 5 million tonnes of lead (metal content in ore) were mined on average annually, in the world. The output increased by 23% from 2010 to 2014 to reach 5,368 kt (metal content, BGS data) in 2014, due to a sharp increase in Chinese production

(+36%). China was the leading producer and accounted for 49% of the global mine production (average 2010-2014), followed by Australia (14%) (Figure 105). However, mine production growth has slowed down since 2011 and global output was down to around 4765 kt in 2015 (ILZSG, 2017) as a result of a fall in Chinese and Australian production mainly.

With an annual average production of 213 kt (2010-2014), the EU accounted for 4% of world production. Poland (68 kt), Sweden (64 kt) and Ireland (44 kt) together contributed to more than 80% of EU production. Lead was also mined in Bulgaria and Greece (about 15 kt each) and very small quantities were extracted in Spain, Portugal, Slovakia and Romania where production stopped in the latter in 2014. Lead produced in the UK was a by-product of fluorspar processing (BGS, 2010).

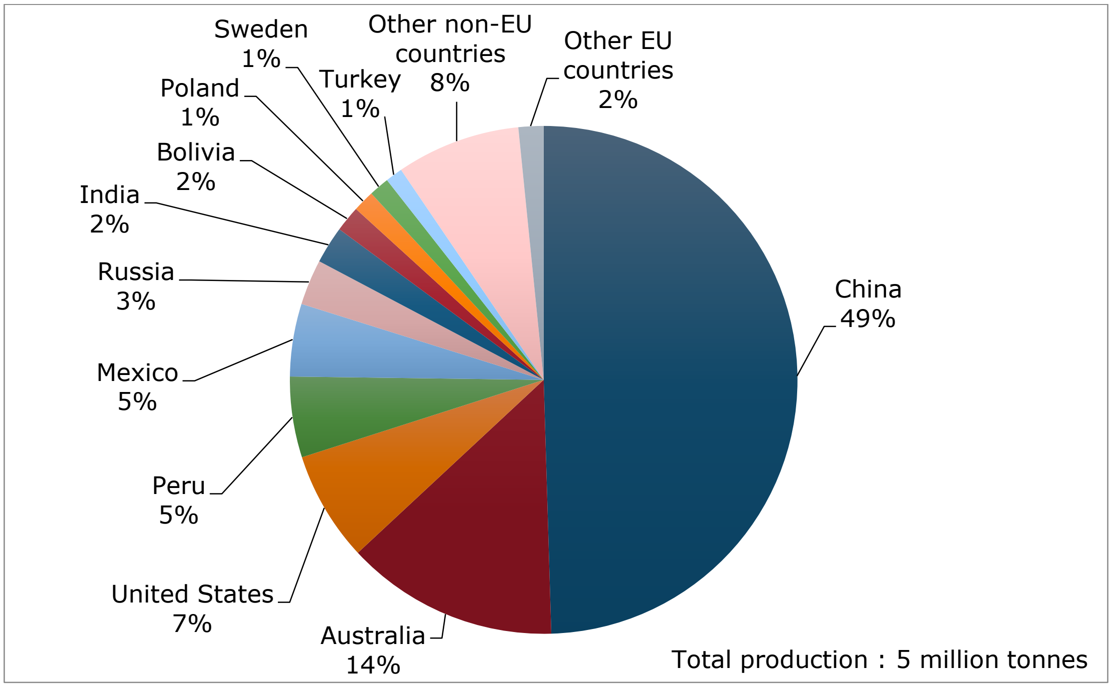


Figure 105: Global mine production of lead, average 2010–2014 (BGS, 2016)

13.2.1.6 World refinery production

World refined lead metal production amounted to 10.6 million tonnes on average during the period 2010-2014 (BGS, 2016). China was the world leading supplier with 43% (4.6 million tonnes) of the global production, followed by the United States contributing 1.2 million tonnes/year, and South Korea (463,000 tonnes). Production of refined lead metal from secondary raw material accounted for 57% of global output (6 million tonnes).

13.2.2 Supply from secondary materials

Today more refined lead is produced by recycling than is mined. World annual secondary lead production amounted to 6 million tonnes on average over the period 2010-2014, representing 60% of the total metal output.

Lead was recycled in 18 EU countries EU: Austria, Belgium, Bulgaria, Czech Republic, Estonia, France, Germany, Greece, Ireland, Italy, Netherlands, Poland, Portugal, Romania, Slovenia, Spain, Sweden and United Kingdom. The EU secondary lead production remained fairly flat on the period 2010-2014 with an average output of about 1,250 kt/year, which was 75% of the total refined lead production. Germany was the largest producer with about 20% of the total production of the Union, followed by Spain, United Kingdom and Italy.

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). In the EU, 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.

13.2.3 EU trade

EU lead ore imports, which have increased by more than 70 % over the period 2010-2014, amounted to 282 kt per year on average (Figure 106). 25% of the ores imported to the EU-28 came from European countries: Macedonia (19%) and Serbia (6%) (Figure 107). Australia was the other major supplier (19 %) to the EU during that period, followed by Peru (15%).

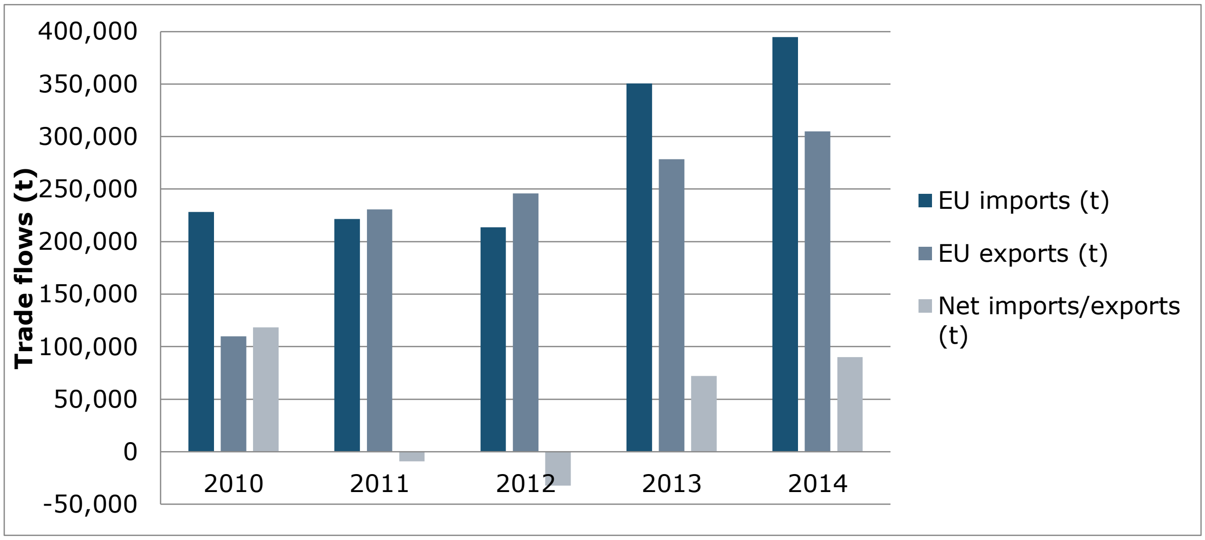


Figure 106: EU trade flows for lead (Eurostat, 2016a)

EU lead ore exports almost tripled from 2010 to 2014. China imported 90% of all EU lead ore exports which amounted to 233,942 tonnes per year on average during the period 2010-2014. EU exports to China increased to 97 % of the total EU exports in 2014. The EU was a net exporter in 2011 and 2012. The EU industry reliance on imports of lead concentrates was 18% during the period 2010-2014.

Australia has put an export tax up to 25% over the period 2010-2014 (OECD, 2016). Several EU free trade agreements exist with suppliers such as Turkey, Macedonia, Morocco, Mexico, Peru, Serbia, Chile, Montenegro, Bosnia and South Africa (European Commission, 2016).

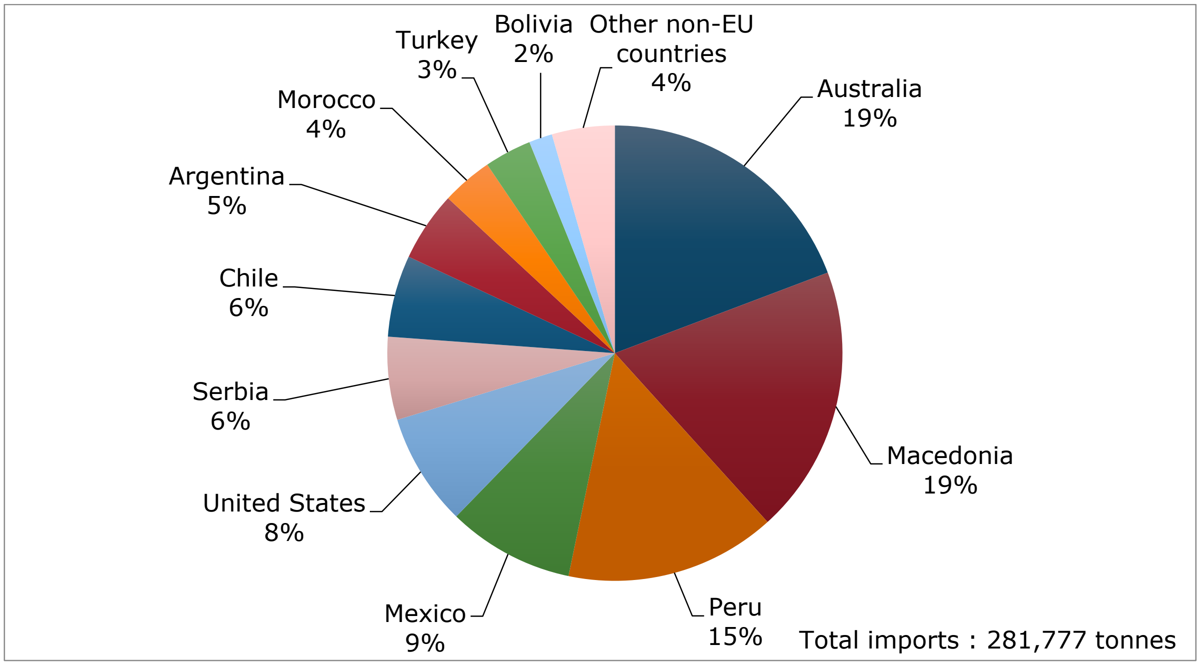


Figure 107: EU imports of lead ores & concentrates, average 2010-2014 (Eurostat, 2016a)

13.2.4 EU supply chain

The Figure 108 shows the EU sourcing (domestic production + imports) for lead.

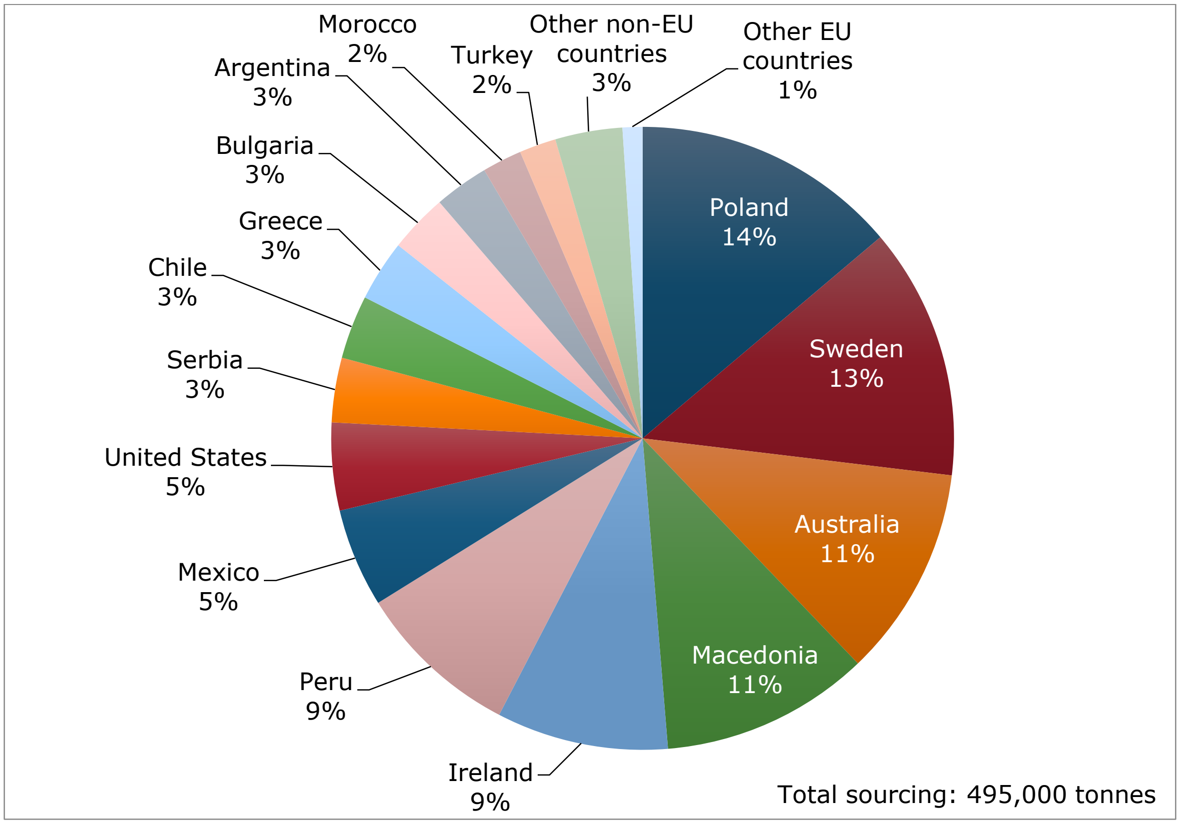


Figure 108: EU sourcing (domestic production + imports) of lead, average 2010-2014. (Eurostat, 2016; BGS, 2016)

Lead ore is extracted and processed in the EU. There is a small and stable production of refined primary lead - from imported ores and from ores produced within the EU - that amounted to about 400 kt/year, on average over the period (2010-2014). Germany and the UK are the main producers with 136 kt/year each, followed by Bulgaria (58 kt), Poland (41 kt), Sweden (19 kt) and Italy (16 kt). The EU was a net exporter of refined lead – primary or secondary– from 2010 to 2014, with average imports and exports amounting to 250 kt and 205 kt of metal, respectively.

As described above, the production of refined metal by processing lead scrap represents 75 % (1,265 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 was a net exporter of lead scrap, with average annual imports and exports amounting to 37 kt and 47 kt, respectively, during the period 2010-2014.

13.3 Demand

13.3.1 EU consumption

The EU net lead consumption amounted to 261,000 tonnes per year on average during the period 2010-2014.

13.3.2 Global end uses

Lead is used as a pure metal, alloyed with other metals or as chemical compounds in a wide range of applications. 85% of all lead produced is used in lead-acid batteries (Figure 109).

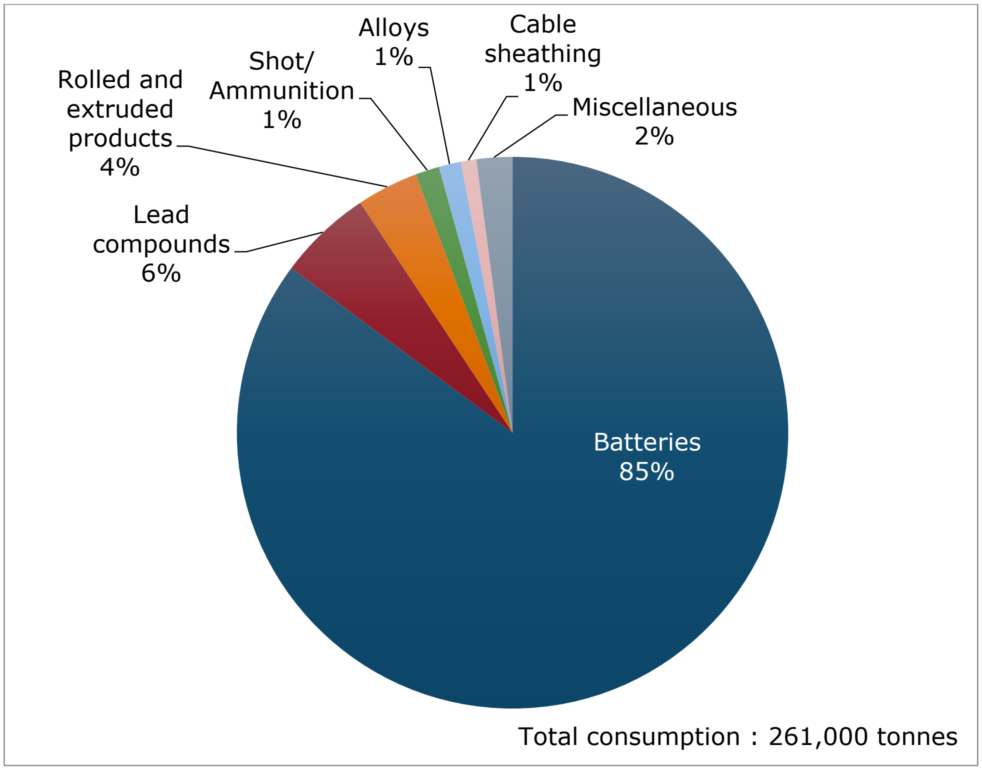


Figure 109: Global end uses of lead in 2012. (International Lead Association, 2016)

Relevant industry sectors are described using NACE sector codes in Table 64.

Table 64: Lead applications, 2-digit NACE sectors, associated 4-digit NACE sectors, and value added per sector (Eurostat, 2016b)

Applications	2-digit NACE sector	Value added of sector (millions €)	4-digit NACE sector
Batteries	C27 - Manufacture of electrical equipment	84,609	C27.2.0 - Manufacture of batteries and accumulators
Lead compounds	C20 - Manufacture of chemicals and chemical products	110,000	C20.1.6 - Manufacture of plastics in primary forms
Rolled and extruded products	C24 - Manufacture of basic metals	57,000	C24.4.3 - Lead, zinc and tin production
Shot/Ammunition	C25 - Manufacture of fabricated metal products, except machinery and equipment	159,513	C25.4.0 - Manufacture of weapons and ammunition
Alloys	C24 - Manufacture of basic metals	57,000	C24.4.3 - Lead, zinc and tin production
Cable sheathing	C27 - Manufacture of electrical equipment	84,609	C27.3.2 - Manufacture of other electronic and electric wires and cables

Lead-acid batteries: The largest application for lead by far is the manufacture of lead acid batteries which accounted for about 85% of global lead consumption in 2012 (ILA). Lead is also used as lead alloys and various types of oxides. The three major types of batteries are automotive, motive and stationary batteries. Automotive batteries (or starter batteries) found in every gasoline or diesel-engine vehicle provide electric power for starting, lighting, and ignition. Motive batteries (or traction batteries) are used to propel electric cars and bikes, fork-lift trucks, airports vehicles etc. Stationary batteries are used for applications where power is necessary only on a standby or emergency basis such as electrical load levelling, backup emergency power, telecommunications equipment etc. About 40% of the batteries produced in China are traction batteries used to power electric bicycles mostly, whereas automotive starter batteries account for 53% of the European market (Mineralinfo, 2016; ILZSG, 2017).

Lead compounds: Lead compounds are used as stabilisers in PVC to prevent the material degrading rapidly during manufacture, to improve resistance - especially in outdoor applications, weathering and heat ageing - and physical properties of the finished articles. A number of different lead compounds are used in PVC formulations in order to enhance performance in a particular application (stability to heat and UV light, dielectric properties etc.). The main compounds, which contain from 30 to 85% lead, are lead sulphates, phthalates, stearates and phosphites. Lead-based stabilisers have been voluntarily phased out within the EU-28 under the Vinyl 2010/VinylPlus voluntary commitments of the PVC industry, and their sales ceased in late 2015 (see section on “substitutions”) (The European council of vinyl manufacturers, 2016; the European stabiliser producers association, 2016).

Lead compounds are also used in solvent-based paints as pigments, drying and anti-corrosion agents (lead chromates and oxides). Toxic lead-based paints are still widely sold in all developing regions of the world (IPEN, 2016), but their use is limited to a few specific applications (artist paints, some industrial paints) in the rest of the world.

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.

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.

Other applications - soldering alloys, shots, fishing weights: 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. Shot lead is an alloy of lead, antimony, and tin.

13.3.3 Prices

Figure 110: Lead metal prices (US$/t fob) from January 2007 to December 2016 (LME)

During the period 2010-1014, average annual lead metal prices fluctuated between 2,000 US$/tonne to US$2,402/tonne. Price rally in 2016 reflected the perception of supply issues following the closure of the Century mine in Australia and Lisheen mine in Ireland (Figure 110).

13.4 Substitution

- *Batteries*: Lead-acid batteries are the predominant technology option, due to their low cost, reliability and well-established supply chain. They represented 90% of the global battery market in 2014 (Avicenne, 2015). Lithium-ion (Li-ion) batteries are increasingly replacing lead-acid batteries for some applications (almost 10% of the 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-28 since 31 December 2016.

- *Lead compounds*: Lead based PVC stabilisers can be replaced by calcium-based stabilisers (Ca-Zn and Ca-organic). Pb-based stabilisers have been voluntarily phased out within the EU under the Vinyl 2010/VinylPlus voluntary commitments by the PVC industry and the replacement was completed by the end of 2015. Stabilisers containing lead have not been sold within the EU since 1st January 2016. 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.).
- *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.
- *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 (PA) 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-28, 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 Sn based alloys commercially available as lead-free solders which are generally specific to a certain applications such as SnAgCu, SnAgCuBi, SnIn alloys etc.

13.5 Discussion of the criticality assessment

13.5.1 Data sources

Production data for lead ore and concentrates are from BGS (2016). Trade data were extracted from the Eurostat Easy Comext database (Eurostat, 2016a). 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 derived from the OECD Export restrictions on the Industrial Raw Materials database (OECD, 2016). For trade data, the Combined Nomenclature CN8 codes 26070000 'Lead ores and concentrates" 25111000' and 78020000 'lead waste and scrap' have been used.

13.5.2 Economic importance and Supply Risk Calculation

The calculation of economic importance (EI) 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 2013 figures. The calculation of the Supply Risk (SR) was carried out at the extraction stage (i.e. lead ores) of the life cycle using both the global HHI and the EU-28 HHI.

Lead is being assessed for the first time in 2017 with the EI and SR results presented in the following table. Lead was not assessed in 2011 or in 2014, therefore, it is not possible to make any comparisons with the previous assessments.

Table 65: Economic importance and supply risk results for lead in the assessments of 2011, 2014 (Commission European 2011; Commission European 2014) and 2017

Assessment	2011		2014		2017	
Indicator	EI	SR	EI	SR	EI	SR
Lead	Not assessed		Not assessed		3.7	0.1

13.6 Other considerations

13.6.1 Environmental and regulatory issues

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 European Commission amended the lead restrictions under REACH Annex XVII (Entry 63). Under the amended restriction, consumer products that can be 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).

13.6.2 Forward look for supply and demand

Lead-acid battery production is expected to be the main drivers 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 battery and stationary batteries. Stationary are used to provide backup power for continuous power supply in telecommunications systems, UPS, etc. as well as in power storage systems for the fast-growing renewable energy industry.

Table 66: Qualitative forecast of supply and demand of Lead

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
Lead		X	+	+	+	+	+	?

13.7 Data sources

13.7.1 Data sources used in the factsheet

BGS (2010). Mineral planning factsheet: Fluorspar. [online] Available at: https://www.bgs.ac.uk/downloads/start.cfm?id=1357

BGS (2016). World Mineral Production 2010-2014. [online] Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.html

ECHA (2016). Registered substances. [online] available at: https://echa.europa.eu/

European Commission (2016). Free 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

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. https://eurobat.org/sites/default/files/ihs_eurobat_report_lead_lores_final.pdf

International lead association (2016). [online] Available at: http://www.ila-lead.org/

ILZSG (2017). [online] 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.

Mineralinfo (2016). [online] Available at: http://www.mineralinfo.fr/ecomine/marche-plomb-en-chine-lindustrie-automobile-telecommunications-prennent-relai-demande

Minerals4EU (2014). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

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.

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.

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/

USGS (2016). Mineral Commodity Summaries. Lead. [online] Available at: https://minerals.usgs.gov/minerals/pubs/commodity/lead/mcs-2016-lead.pdf

13.7.2 Data sources used in the criticality assessment

Association of European Automotive and Industrial Battery Manufacturers (Eurobat) (2014). Battery Materials Analysis. [online] Available at: http://www.eurobat.org/sites/default/files/resource_availability-final_long_version.pdf

Avicenne Energy (2015). Battery Market Development for Consumer Electronics, Automotive, and Industrial: Materials Requirements and Trends, C. Pillot Presentation at 5th Israeli Power Sources, Herzelia, Israel, May 2015. [online] Available at: http://www.avicenne.com/articles_energy.php

Batteryspace (2016). [online] Available at: http://www.batteryspace.com/batteryknowledge.aspx

BGS (2016). World Mineral Production 2010-2014. [online] Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.html

Ecomass (2016). Lead replacement. [online] Available at: http://www.ecomass.com/lead-replacement/

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). Free 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

IPEN (2014). Alternatives to lead in paint. [online] Available at: http://www.unep.org/chemicalsandwaste/Portals/9/CEE_CAsia/10%20Alternatives%20to%20lead%20in%20paint.pdf

ILZSG (2006). Estimated Global RER for Lead in 2005 (Presentation, courtesy of Paul White, ILZSG Director of Market Research and Statistics) & phone call.

INERIS (2015). Donnees technico-economiques sur les substances chimiques en France : Plomb, INERIS –DRC-15-136881-10941A. [online] Available at: http://rsde.ineris.fr/

International Lead Association (2016). [online] Available at: http://www.ila-lead.org/

Mineralinfo (2016). [online] Available at: http://www.mineralinfo.fr/

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

13.8 Acknowledgments

This factsheet was prepared by the French Geological Survey (BRGM). The authors would like to thank the Irish Department of Communications, Climate Action and Environment (Natural Resources and Waste Policy Divisions), the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this factsheet.

14. LIMESTONE

Key facts and figures

Material name and Formula	Calcium carbonate $CaCO_3$ Lime CaO	World/EU production (million tonnes)[1]	Calcium carbonate: 80.5 / 13.65; Lime:337 / 30
Parent group	N/A	EU import reliance[1]	3%
Life cycle stage / material assessed	Processing/ ground calcium carbonate & lime	Substitution index for supply risk [SI(SR)][1]	0.89
Economic importance (EI) (2017)	2.5	Substitution Index for economic importance [SI(EI)][1]	0.87
Supply risk (SR) (2017)	0.1	End of life recycling input rate[2]	58%
Abiotic or biotic	Abiotic	Major end uses in EU	Calcium carbonate: paper (40%), glass (15%), coatings (15%), plastics (15%); Lime: steel (40%), environmental applications (14%), mortars (12%)
Main product, co-product or by-product	Main product	Major world producers[1]	Calcium carbonate: China (25%), USA (18%), Spain (5%); Lime: China (64%), USA (6%)
Criticality results	2011	2014	2017
	Not critical	Not critical	Not critical

[1] 2012 data only; [2] This is not the recycling input rate, but the EOL Recycling rate of all major applications that limestone finds use

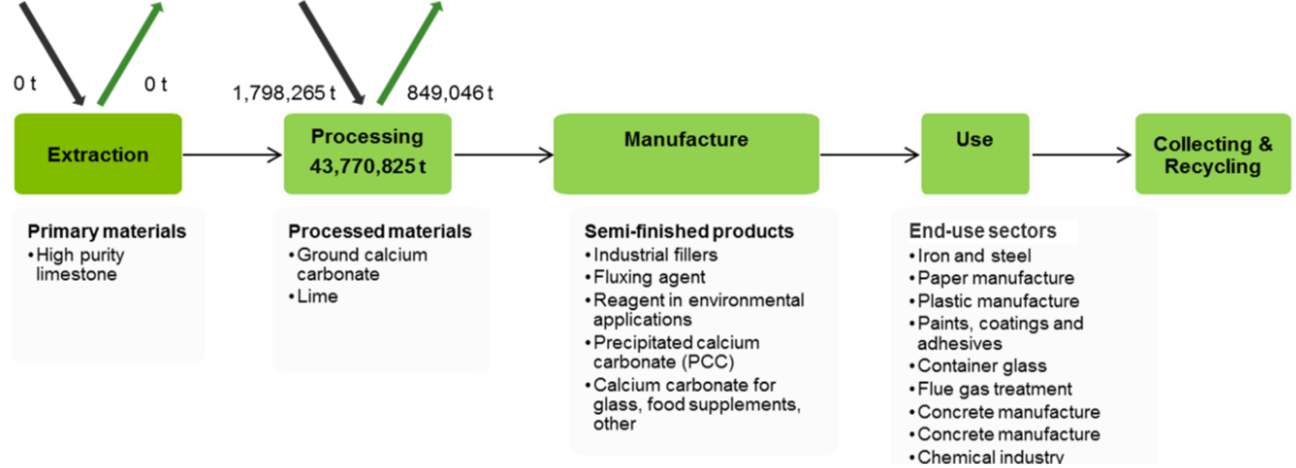


Figure 111: Simplified value chain for limestone (high purity)

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU. A quantitative figure on recycling is not included as the EOL-RIR is below 70%. EU reserves are displayed in the exploration box.

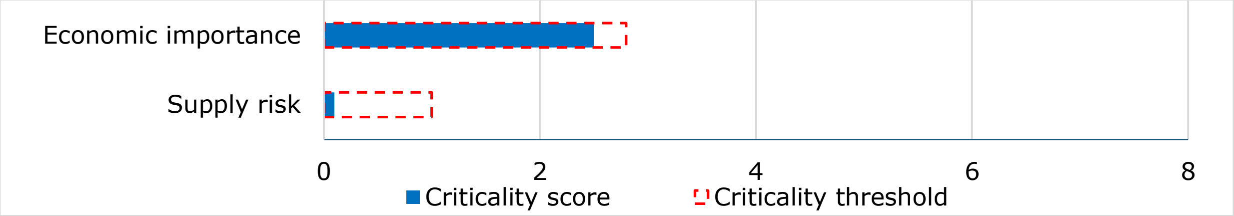


Figure 112: Economic importance and supply risk scores for limestone

14.1 Introduction

Limestones belong to the carbonate rock type and they mainly consist of calcite ($CaCO_3$). Industrial limestone is a commercial term for limestone used for purposes other than construction, where its chemical properties and whiteness are important. Industrial limestones are high grade limestones containing small amounts of impurities and generally valued for their high chemical purity (generally greater than 97% $CaCO_3$). High grade limestone, in calcined, ground and crushed forms, has many industrial applications. It is used in iron and steel making, glass manufacture, sugar refining and numerous other chemical processes, where the amounts of specific impurities present (such as iron, sulphur, silica and lead) and overall consistency of composition are important rather than the absolute values for $CaCO_3$ content. High purity limestone accounts only for a small proportion of total limestone output, most of which is used for construction aggregates (Harrison et al., 2006).

This factsheet is concerned with high grade limestone only and does not include any information related to the use of limestone in construction applications. High grade limestone for the purposes of this factsheet refers to calcium carbonate ($CaCO_3$; crushed and grinded) and lime (CaO, calcined).

In Europe, almost all countries produce high grade limestone, but Spain is reported to be the leading producer with a share of 5% of the total global production in 2012. Other producing European countries include Italy, Austria, Germany, France, Sweden, Finland, Portugal, Austria, Poland, Czech Republic and Croatia.

14.2 Supply

14.2.1 Supply from primary materials

14.2.1.1 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. Reef limestones are often quite pure, as clastic silicates are often absent (Harrison et al., 2006). Bedded limestones tend to have higher clay and quartz content. The most commonly exploited limestone is compact and lithified, but other varieties, such as chalk may also find use. Other naturally occurring forms of calcium carbonate include aragonite, shell sands, marble, carbonatite, vein calcite and others (Evans, 1993; Pohl, 2011).

14.2.1.2 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 (Harrison et al., 2006; Mitchel, 2009).

Lime is produced by the calcination of limestone in rotary or shaft kilns. In this process, calcium carbonate is converted into calcium oxide or 'quicklime'. This is then sold in different forms depending on the end us, for example lump lime, pulverized lime or hydrated lime (Harrison et al., 2006; Mitchel, 2009).

14.2.1.3 Limestone resources and reserves

There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of limestone 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[15], 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.

For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for limestone. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for limestone, 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 limestone at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU, 2015).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 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.

14.2.1.4 World production

World mine production of ground calcium carbonate (GCC) in 2012 was reported at 80.5 million tonnes (Figure 113). China was the largest producer of GCC with a share of 25% of the global production and a 20 million tonnes output in the same year. The United States was the second largest world producer with a share of 18% and 14.7 million tonnes

---

[15] www.crirsco.com

production. Spain's share was 5% with an output of 3.7 million tonnes and Norway's was 4% with 3.2 million tonnes. According to the Industrial Minerals Association, current GCC production in Europe is estimated at 20 million tonnes (IMA-Europe, 2016a). Apart from Spain (3.7 million tonnes) who is the leading producer, Austria (2.75 million tonnes), Germany (2.65 million tonnes), France (2.58 million tonnes) and Italy (1.88 million tonnes) are also important producing countries in the EU-28.

World lime production is estimated at 337 million tonnes per year on average in 2010 – 2014 (Figure 114). China was the largest producer in the world with a share of 64% of the global production and an output of 214 million tonnes. The United States was the second largest producer with a share of 6% and a production of 19 million tonnes. India reported a share of 5% and 15.2 million tonnes production. Russia's share was 3% and produced on average 10.5 million tonnes. Japan and Brazil (2% share each) produced on average about 8 million tonnes. In the EU-28, Germany (2% of the global share) was the leading producer with a 6.9 million tonnes output, followed by Italy (5 million tonnes production) and France (4 million tonnes production). European production on average in 2010 to 2014 was estimated at 30 million tonnes.

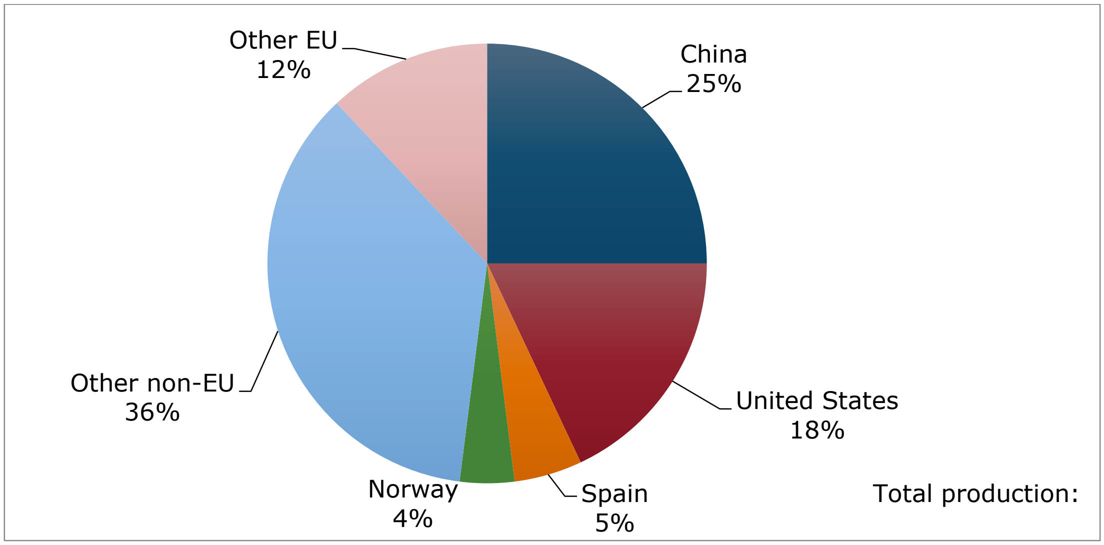


Figure 113: Global mine production of ground calcium carbonate, 2012 (European Commission, 2014)

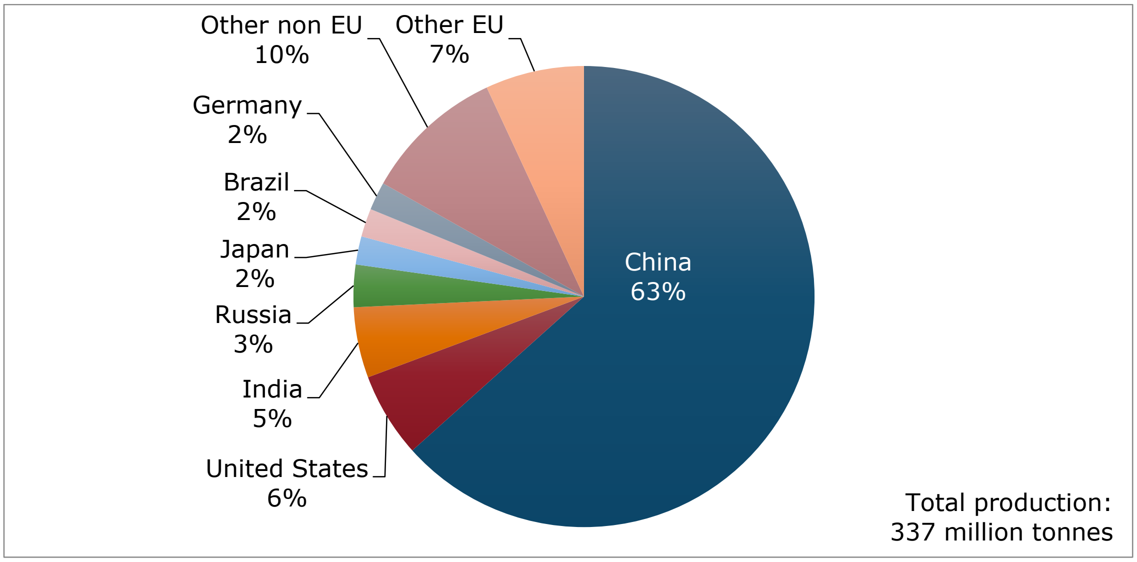


Figure 114: World production of quicklime and hydrated lime, including dead-burnt dolomite, average 2010–2014 (USGS, 2014)

14.2.2 Supply from secondary materials

Calcium carbonate and lime are not commonly recovered from waste and therefore there are not availability as such from secondary sources. However, many of the end-of-life products in which they are used are recycled and the recycling of these applications it is discussed in this section.

Calcium carbonate is used in paper making. Paper is widely recycled across Europe with 40% of waste paper collected being recycled into new paper grades. An additional 30% is incinerated in which limestone ends up in the fly ash stream. Fly ash often finds use in construction products. Calcium carbonate also finds use in plastics. Waste plastics are recycled or used for energy recovery, hence calcium carbonate from these materials is either directed into new products or combustion waste, which is often used in construction applications. Interior and exterior paints rich in calcium carbonate 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. Calcium carbonate in container glass is recycled through the glass recycling process (IMA-Europe, 2013).

Lime is commonly used as a flux in the steel making process, where it removes impurities from the molten steel. Lime and impurities form a slag which is removed from the furnace. Slag is widely recycled and finds use in construction applications. Concrete and bricks products containing lime are often reused as recycled aggregates at the end of their life. Soil stabilization products and mortar containing lime at their end of life find use as recycled aggregates. Precipitated calcium carbonate (PCC) is produced using lime and its main use is in paper manufacture. Similarly to ground calcium carbonate, paper recycling or incineration of paper and use of the fly ash in construction products is common across Europe (IMA-Europe, 2013).

Finally, calcium carbonate and lime are both used in in flue gas treatment, where they reach end of life as gypsum widely used in the production of plasterboard (IMA-Europe, 2013).

14.2.3 EU trade

Figure 115 presents the EU trade flows for GCC in the period 2010 to 2014. According to Eurostat data the EU-28 appeared to be a net importer of GCC, with an average annual figure of net imports of 1 million tonnes. However, the net import flow was not significant considering that the EU GCC production was approximately 20 million tonnes. GCC was imported primarily from Norway (90% of total imports), as shown in Figure 116.

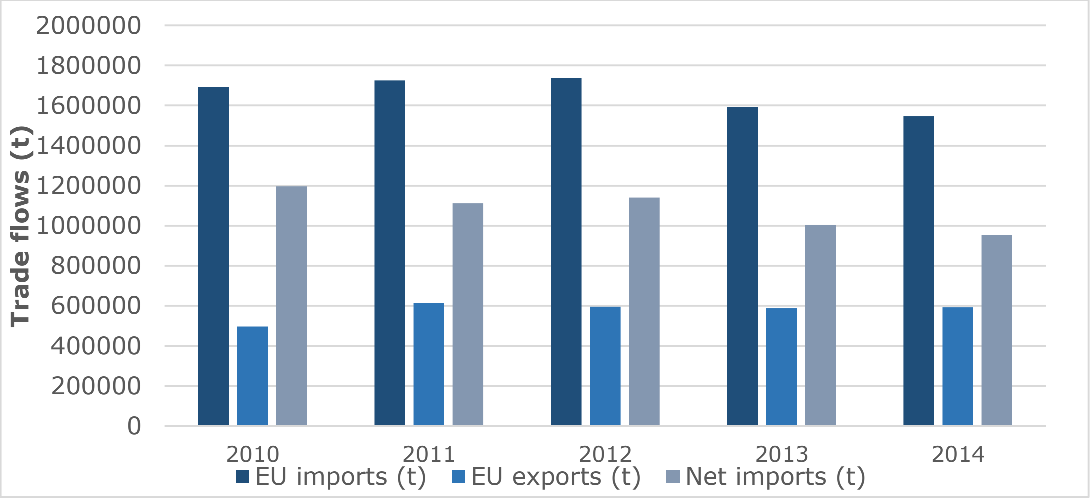


Figure 115: EU trade flows for ground calcium carbonate (Data from (Eurostat, 2016a))

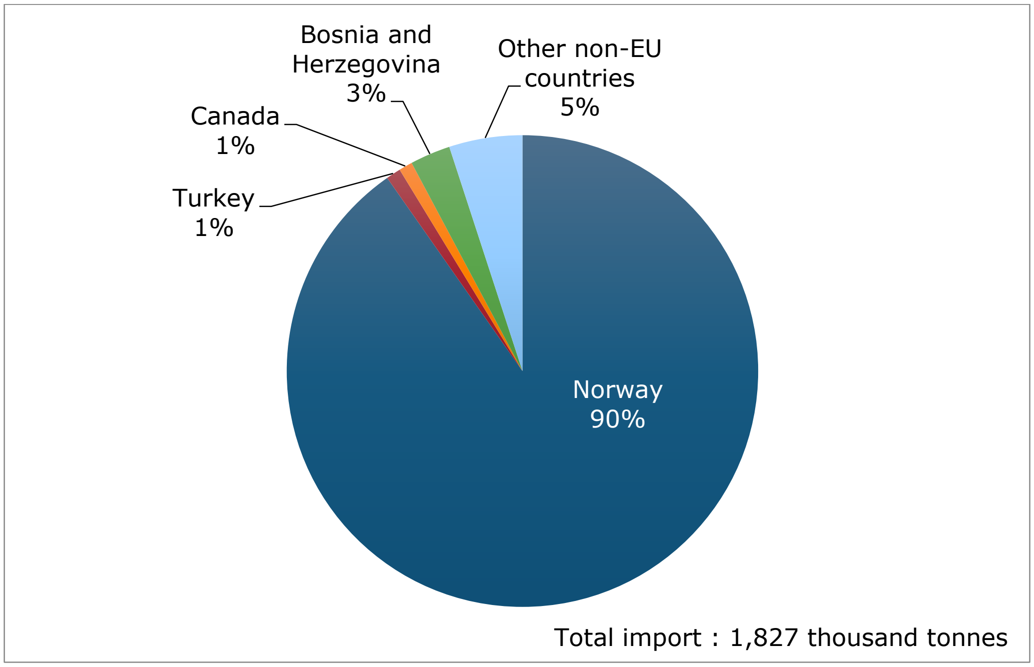


Figure 116: EU imports of limestone, average 2010-2014 (Data from Eurostat, 2016a)

The trade flows of limestone flux, which is the primary material used in lime manufacture are presented in Figure 117. Europe appears to be a net exporter of limestone flux with an average annual net export figure over the examined period (2010-2014) of 132 thousand tonnes. The main export destination for limestone flux from EU-28 is Belarus.

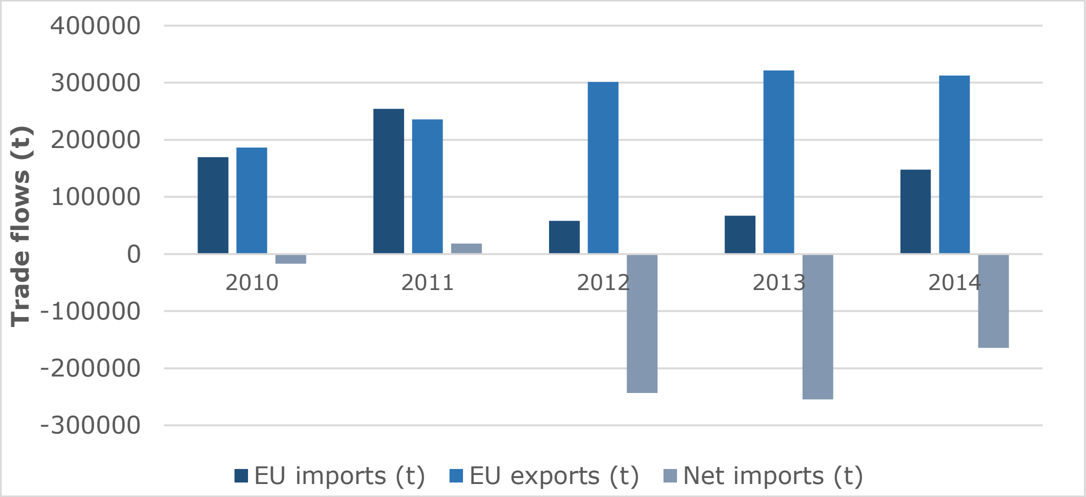


Figure 117: EU trade flows of limestone flux used in the manufacture of lime (Data from Eurostat, 2016a)

Overall neither ground calcium carbonate, nor lime are commodities traded over long distances and they are consumed by domestic markets. Most countries have limestone deposits that can use to produce lime and ground calcium carbonate, if they are of high purity.

No trade restrictions have been reported over the 2010-2014 period (OECD, 2016). The EU has free trade agreements in place with Norway and Turkey (European Commission, 2016).

14.2.4 EU supply chain

The European production of GCC was approximately 20 million tonnes (IMA-Europe, 2016a). This accounts for 17% of the global GCC production. Major producing countries in Europe include Spain, Austria, Germany, France and Italy (European Commission, 2014). The 5 years average European production of lime between 2010 and 2014 was 30 million tonnes per year, which accounts for 9% of the global production. Main producing countries include Germany, Italy and France.

GCC was not traded in significant quantities between the EU-28 and other external countries. Europe was a net importer of GCC supplied almost solely from Norway. Limestone flux was traded only in small quantities in the same five year period (2010-2014). Europe is a net exporter of 132 thousand tonnes per annum. Limestone flux was exported primarily to Belarus. The import reliance for GCC and lime overall is calculated at 3%. The EU sourcing (domestic production + imports) for limestone is presented in the Figure 118.

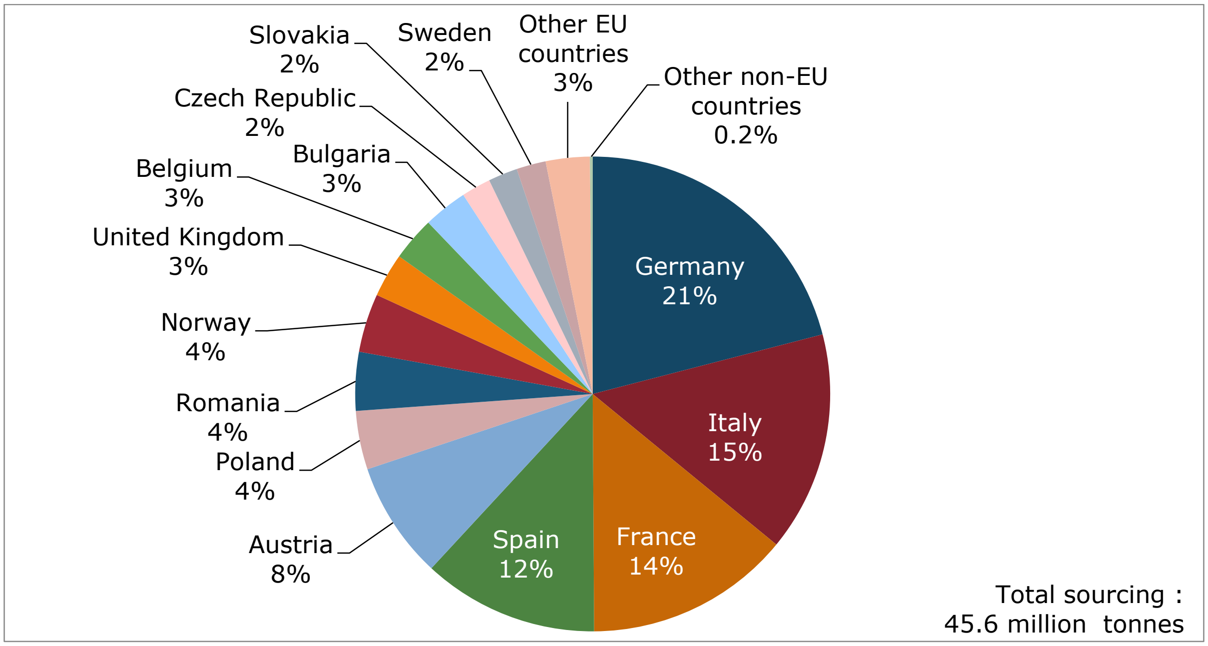


Figure 118: EU sourcing (domestic production + imports) of limestone, average 2010-2014.= (Data from Eurostat, 2016a)

GCC and lime are not recovered during waste management and therefore they are not available from secondary sources. However, the recycling rates of many of the products they find use are significant. In some cases recycling produces the same products they initially participated in, for example, paper or container glass and therefore the demand for additional GCC and lime is reduced.

There are no trade restrictions to Europe on these commodities.

14.3 Demand

14.3.1 EU consumption

The European apparent consumption of ground calcium carbonate and lime in total in the period 2010 and 2014 (5 year average figure) is estimated at 45 million tonnes per year, of which 43.8 million tonnes per annum is the domestic production, 1.8 million tonnes per annum is the imports to the EU from extra EU-28 countries and 535 thousand tonnes per annum is the exports from the EU to extra EU-28 countries in the same period (5 year average figures). The above figures suggest that the majority of the domestic production is consumed within Europe and it can sufficiently satisfy the EU industry demand for high purity limestone, without major import reliance issues.

14.3.2 Applications / end uses

Calcium carbonate 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. The EU market shares are presented in Figure 119 and Figure 120. Relevant industry sectors are described using the NACE sector codes in the following table.

Table 67: Calcium carbonate and lime applications, 2-digit and associated 4-digit NACE sectors

Applications	**2-digit NACE sector**	**4-digit NACE sectors**	**Value added of sector (M €)**
Paper	C17 - Manufacture of paper and paper products	C1712 - Manufacture of paper and paperboard, C1721 Manufacture of corrugated paper and paperboard and of containers of paper and paperboard, C1722 Manufacture of household and sanitary goods and of toilet requisites, C1723 Manufacture of paper stationery, C1724 Manufacture of wallpaper, C1729 Manufacture of other articles of paper and paperboard	41,281.5
Iron and steel	C24 - Manufacture of basic metals	C2410 - Manufacture of basic iron and steel and of ferro-alloys	6,930.8
Concrete and bricks	C23 - Manufacture of other non-metallic mineral products	C2361 Manufacture of concrete products for construction purposes, C2362 Manufacture of plaster products for construction purposes, C2363 Manufacture of ready-mixed concrete, C2364 Manufacture of mortars, C2369 Manufacture of other articles of concrete, plaster and cement	41,281.5
Paint, coating, adhesives	C20 - Manufacture of chemicals and chemical products	C2030 - Manufacture of paints, varnishes and similar coatings, printing ink and mastics	110,000.0
Plastics and rubber	C20 - Manufacture of chemicals and chemical products	C2016 Manufacture of plastics in primary forms, C2017 Manufacture of synthetic rubber in primary forms	110,000.0
Environmental protection (e.g. flue gas)	E36 - Water collection, treatment and supply	E3600 Water collection, treatment and supply, E3511 Production of electricity	34,000.0
Agriculture	C20 - Manufacture of chemicals and chemical products	C2015 Manufacture of fertilisers and nitrogen compounds	110,000.0
Chemical	C23 - Manufacture of other non-metallic mineral products	C2352 Manufacture of lime and plaster	59,166.0
Soil stabilisation and mortars	C23 - Manufacture of other non-metallic mineral products	C2352 Manufacture of lime and plaster	59,166.0
Container glass	C23 - Manufacture of other non-metallic mineral products	C2311 Manufacture of flat glass, C2319 Manufacture and processing of other glass, including technical glassware, C2314 Manufacture of glass fibres, C2313 Manufacture of hollow glass	59,166.0

In paper making, GCC is the most widely used mineral and it is used both as filler and a coating pigment. GCC improves the whiteness, gloss and printing properties of paper. In plastics GCC is used as a filler in plasticized and rigid PVC, unsaturated polyester, polypropylene and polyethylene. It is also used in rubber, sealants and adhesives. In paints and coatings, calcium carbonate is used as the main extender. Calcium carbonate is used in the production of container glass. In flue gas desulphurization calcium carbonate is used as a reagent in coal-fired power plants and other industrial plants to remove gaseous pollutants from the flue gas. Other uses include in ceramics, agriculture, pharmaceuticals, food supplements, animal feed and many more (IMA-Europe, 2016b).

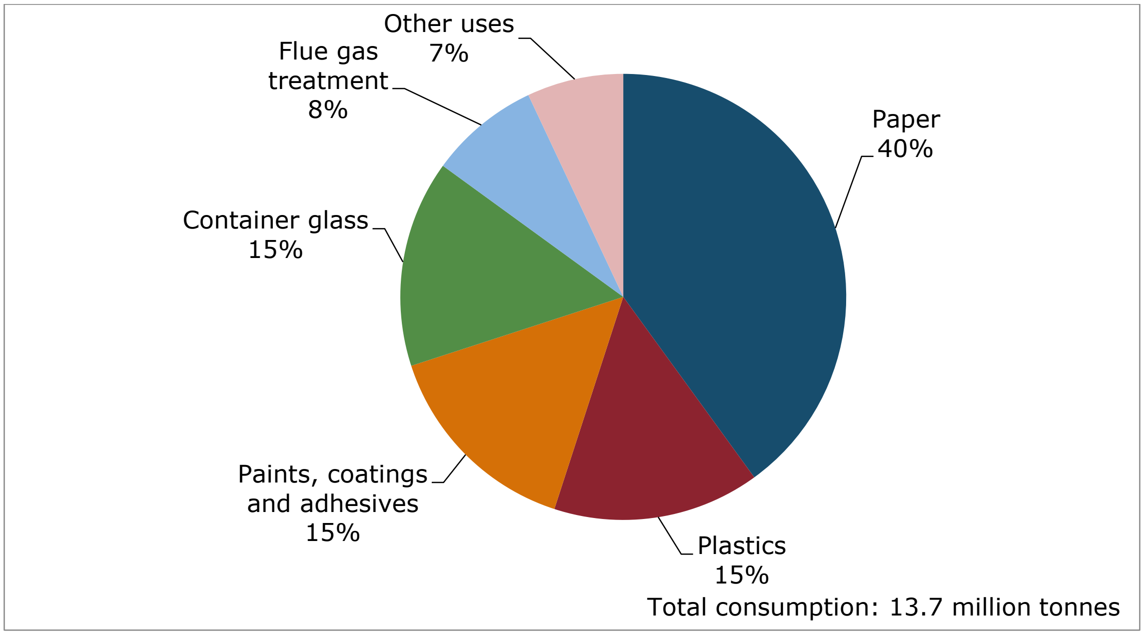


Figure 119: EU end uses of calcium carbonate. Data from Industrial Minerals Association (IMA-Europe) (2013)

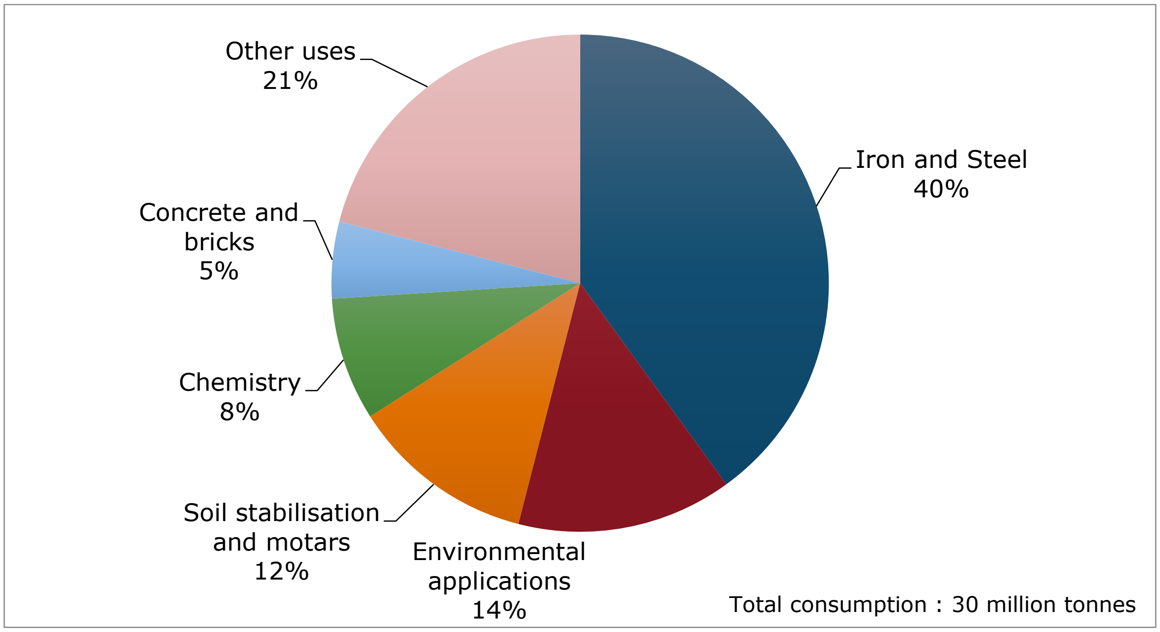


Figure 120: EU end uses of lime. Data from Industrial Minerals Association (IMA-Europe) (2013)

Lime is used as a flux in steel making in the electric arc furnace, basic oxygen furnace and in the manufacture of steel products. Lime assists the removal of phosphorus, silica, sulphur and to a smaller degree manganese. Lime similarly to calcium carbonate is used in flue gas treatment as a reagent. In concrete manufacture, lime is used in substantial volumes for the production of aerated concrete blocks. It also finds application in soil stabilization and in mortars. Finally lime finds use in the production of precipitated calcium carbonate (PCC) (IMA-Europe, 2016b).

14.3.3 Prices and markets

The price of GCC depends on its end use and grade and can range from as low as approximately \$30 per tonne for a 50 to 22μm grade to \$300 per tonne for a sub-micron grade. (Industrial Minerals, 2016). Lime price data are difficult to identify. According to USGS, the price of quicklime in the United States in 2014 was \$119.1 per tonne (USGS, 2014).

14.4 Substitution

Substitutes are identified for the applications and end uses of the commodity of interest. In the case of limestone, substitutes have been identified for the applications of paper manufacture, iron and steel, concrete manufacture, paint, coating and adhesives, plastics and rubber and agriculture.

Substitutes of calcium carbonate 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. Talc and titanium dioxide are much more expensive materials than GCC.

Limestone and lime are the most important fluxing agents used in iron and steel making and in pelletising and sintering processes. Other fluxes that may be used instead of limestone include alumina, fluorspar and silica, but they only represent a minor market share at the moment.

In concrete manufacture, a variety of alternative materials could be used to substitute for limestone including alumina trihydrate (ATH), talc, silica, feldspar, kaolin, ball clay and dolomite.

In paints, adhesives and coatings, multiple materials could substitute for calcium carbonate 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.

In plastics and rubber, calcium carbonate substitutes include talc, kaolin, wollastonite, mica, silica and alumina hydrate.

In environmental applications, limestone is used in water treatment and in flue gas 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, but at the moment they participate in small proportions only.

In agriculture, limestone could be replaced by specific industrial by-products including certain types of slag, paper mill sludge and flue dust.

There are only limited quantified ‘market sub-shares’ for the identified substitutes of limestone based on global figures one. In most cases the ones uses are based on hypotheses made through expert consultation and literature findings. The literature used to identify substitutes for limestone is listed in section 14.7.

14.5 Discussion of the criticality assessment

14.5.1 Data sources

Market shares were based on the statistical data provided by the Industrial Minerals Association and they represent the European market (IMA-Europe, 2016a). Production data for limestone is not publicly available from any of the major data producers. In this assessment production data on GCC was from the criticality assessment published in 2014 (European Commission, 2014) and lime production data was from USGS (USGS, 2014). Trade data was extracted from the Eurostat Easy Comext database (Eurostat, 2016a). 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, 2016). Information on export restrictions were accessed by the OECD Export restrictions on Industrial Raw Materials database (OECD, 2016).

For trade data 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 were used.

Production data on GCC was for a single year (2012) and on lime was an average of five years (2010 – 2014). Trade data was also averaged over the five-year period 2010 to 2014.

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.

Other data sources used in the criticality assessment are listed in section 14.7.

14.5.2 Economic importance and supply risk calculation

The calculation of economic importance was 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 corresponded to 2013 figures.

The supply risk was assessed on limestone using both the global HHI and the EU-28 HHI as prescribed in the revised methodology.

14.5.3 Comparison with previous EU criticality assessments

A revised methodology was introduced in 2017 assessment of critical raw materials in Europe. Both the calculations of economic importance and supply risk are now different therefore the results with previous assessments are not directly comparable. The results of this review and earlier assessments are shown in Table 68.

Table 68: Economic importance and supply risk results for limestone in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Sulphur	5.95	0.73		5.76	0.38		2.5	0.1

Although it appears that the economic importance of limestone has reduced between 2010 and 2017 this is a false impression created by the change in methodology. 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 lower than in the previous years, which is primarily due to the methodological modification and the inclusion of the EU supply flow in the assessment. Also in this assessment market shares and production data on GCC and lime were refined further. It is not possible to quantify what proportion of this change is due to the methodology alone, as new data have been used in the assessment. The poor availability of up to date data on production of limestone may have also impacted on this score.

14.6 Other considerations

Data on global and EU production of high purity limestone are not published by any of the major data providers. Most statistical data available is for its use as aggregate or building stone, which is not part of this assessment.

Limestone and dolomite are used interchangeably by different manufacturing sectors in their end products and in many cases it is difficult to differentiate one over the other. For this assessment and factsheet, we tried to use data and information as much as possible on GCC and lime from limestone only.

14.6.1 Forward look

GCC demand continues to grow, even though the pace of growth is slower in recent years due to the global economic recession and the slowdown in China, who has been a major consumer. Most of the growth in the future is expected in Asia in all industrial filler applications, in which GCC is used. Growth in the European market is expected to be low. In the global paper industry, overcapacity meant that paper mills have shut down, particularly in Europe (Roskill, 2017).

Table 69: Qualitative forecast of supply and demand of limestone

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
Limestone		X	+	+	?	+	+	?

The future of the lime sector will be influenced by any subsequent changes in the iron and steel and environmental protection markets. Both are expected to grow in the future and therefore the demand for lime is expected to increase too.

Lime production is energy intensive and the production process results in CO_2 emissions. Stringent environmental policy and pressure on CO_2 reduction from the industry and Europe are of concern to the sector, as they may affect the demand for lime in Europe. However, the EU lime sector have been proactive and engage in carbon emission reduction initiatives, for example the incorporation of carbon capture and storage processes or investigating options for carbon utilization, which are expected to mitigate such effects (EuLA, 2014).

14.7 Data sources

14.7.1 Data sources used in the factsheet

EuLA (2014). A Competitive and Efficient Lime Industry. [online] Available at: www.eula.eu/file/477/download?token=G4HAme1u

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 (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

Evans, A. M. (1993). Ore Geology and Industrial Minerals. An Introduction. . Third Edition Oxford and Northampton Blackwell Science

Harrison, D. H., D.; Bloodworth, A.; Bate, R. (2006). Limestone [online] Available at: http://www.bgs.ac.uk/mineralsuk/planning/mineralPlanningFactsheets.html

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

Industrial Minerals Association (IMA-Europe) (2016)a. Data and information on limestone 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 Association (IMA-Europe) (2016)b. Calcium Carbonate factsheet [online] Available at: http://www.ima-europe.eu/about-industrial-minerals/industrial-minerals-ima-europe/calcium-carbonate

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%2024.10.2013_0.pdf

Minerals4EU (2014). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

Mitchell C. (2009). High-purity limestone assessment: from mine to market [online] Keyworth, Nottingham Available at: http://nora.nerc.ac.uk/7210/1/High-purityLimestoneAssessment.pdf

OECD (2016). 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.

Roskill (2017). Ground & Precipitated Calcium Carbonate: Global Industry Markets & Outlook. [online] Available at: https://roskill.com/product/ground-precipitated-calcium-carbonate-global-industry-markets-outlook/

USGS (2014). Lime. 2014 Minerals Yearbook. [online] Available at: https://minerals.usgs.gov/minerals/pubs/commodity/lime/

14.7.2 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 Calcium Carbonate Association (2016). Mineral applications [online] Available at: http://www.cca-europe.eu/mineral-applications.html

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 (2016). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

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

Gronfors, J. (2010). Use of fillers in paper and paperboard grades. Tampere University of Applied Sciences. International Pulp and Paper Technology.

Highley, D., A. Bloodworth and R. Bate (2006). Dolomite. [online] Available at: http://www.bgs.ac.uk/mineralsuk/planning/mineralPlanningFactsheets.html

Highley, D., A. Bloodworth, R. Bate and C. E. Wrighton (2009). Kaolin. [online] Available at: http://www.bgs.ac.uk/mineralsuk/planning/mineralPlanningFactsheets.html

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

Industrial Minerals Association (IMA-Europe) (2016). Data and information on limestone 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 Association (IMA-Europe) (2016). Calcium Carbonate factsheet [online] Available at: http://www.ima-europe.eu/about-industrial-minerals/industrial-minerals-ima-europe/calcium-carbonate

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%2024.10.2013_0.pdf

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

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

Peters, J. B., Kelling, K.A., Schulte, E.E., (1996). Choosing between liming materials. [online] Available at: https://learningstore.uwex.edu/

Shaw, R. A. and A. Bloodworth (2011). Ball Clay [online] Available at: http://www.bgs.ac.uk/mineralsuk/planning/mineralPlanningFactsheets.html

USGS (2013). Silica. 2013 Minerals Yearbook. [online] Available at: http://minerals.usgs.gov/minerals/pubs/commodity/silica/

USGS (2014). Lime. 2014 Minerals Yearbook. [online] Available at: https://minerals.usgs.gov/minerals/pubs/commodity/lime/

14.8 Acknowledgments

This Factsheet was prepared by the British Geological Survey (BGS). The authors would like to thank the Industrial Minerals Association and the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this Factsheet.

15. LITHIUM

Key facts and figures

Material name and Element symbol	Lithium, Li	World/EU production (tonnes)[1]	Extraction: 25,500 / 350 Refining: 27,350 / 600
Parent group	-	EU import reliance[1]	86%
Life cycle stage/ material assessed	Processing, Li refined materials	Substitution index for supply risk [SI(SR)][1]	0.91
Economic importance (EI)(2017)	2.4	Substitution Index for economic importance [SI(EI)][1]	0.90
Supply risk (SR) (2017)	1.0	End of life recycling input rate (EOL-RIR)	0%
Abiotic or biotic	Abiotic	Major end uses in EU[1]	Glass and ceramics (57%), Batteries (25%), Cement (6%), Lubricating greases (6%)
Main product, co-product or by-product	Main product	Major world producers[1]	*Extraction*: Chile (44%), Australia (32%), China (16%), Argentina (11%) *Refining*: Chile (36%), Australia (31%), China (16%), Argentina (11%)
Criticality results	2011	2014	2017
	Not critical	Not critical	Not critical

[1] average for 2010-2014, unless otherwise stated;

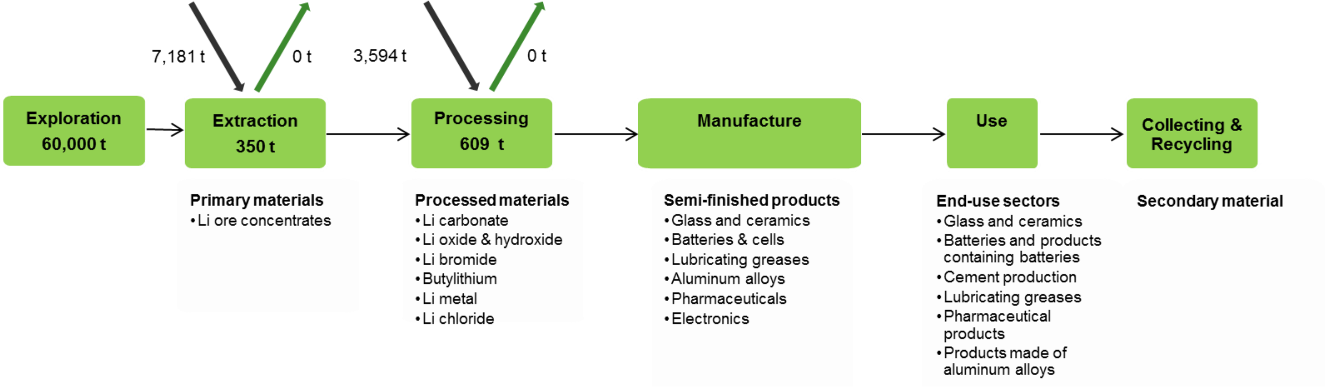


Figure 121: Simplified value chain for lithium

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU. A quantitative figure on recycling is not included as the EOL-RIR is below 70%. EU reserves are displayed in the exploration box.

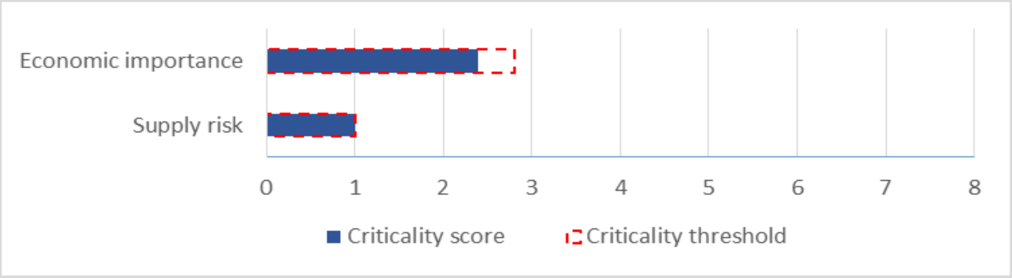


Figure 122: Economic importance and supply risk scores for lithium

15.1 Introduction

Lithium (Li) is a soft, silver-white alkali metal. Under standard conditions it is the lightest metal and the least dense solid element (the density of lithium is half that of water's) and therefore can float on water (BGS, 2016). Lithium is very soft, and is potentially explosive because it reacts easily with water and oxygen. However, it is not found in elemental form in nature and its compounds are non-flammable. To prevent it reacting chemically it is stored in petroleum ether. Because of its high reactivity, lithium never occurs freely in nature and appears only in ionic compounds in a number of pegmatitic minerals. It can also form strong alloys with other metals. Due to its solubility, it is commonly obtained from brines and clays or electrolytically isolated from a mixture of lithium chloride and potassium chloride. Lithium and its compounds have several industrial applications, including heat-resistant glass and ceramics, grease lubricants, flux additives for iron, steel and aluminium production and batteries.

15.2 Supply

15.2.1 Supply from primary materials

15.2.1.1 Geological occurrence

Estimates for the Earth's crustal content range from 20 to 70 ppm but is likely to be approximately 17-20 ppm (BGS, 2016). In igneous rocks the abundance is typically 28-30 ppm but in sedimentary rock is can yield 53-60ppm (BGS, 2016). The abundance of lithium in the uppercrust is 24 ppm (Rudnick, 2003). Although lithium is widely distributed on Earth, it does not naturally occur in elemental form due to its high reactivity. There are more than 100 known minerals that may contain lithium, but few with enough lithium content to be economic to extract. The most common and economic lithium-bearing minerals are spodumene, lepidolite and petalite, hosted in most cases by granitic pegmatites (BGS, 2016).

Lithium is also contained in various types of brines (mainly continental brines) and in seawater, at a relatively constant concentration of 0.14 to 0.25 ppm (BGS, 2016).

15.2.1.2 Mining, processing and extractive metallurgy

Lithium is produced from two sources: hard rocks (pegmatites) and brines. In the past, hard rocks account for 100% of lithium primary sources but nowadays the lower production costs of brine extraction make the latter increasing its share for lithium production (BGS, 2016).

Extraction methods for lithium vary accordingly to the type of deposit. Hard rock deposits are mined using similar techniques to many other metals using surface (open-pit) or sub-surface (underground) methods. Brines are extracted by pumping from wells (BGS, 2016).

The first phase of processing the lithium ores involves physical beneficiation to increase the Li content (crushing and separation by gravity, magnetic or electrostatic method, and froth flotation or dense media separation), and then chemical beneficiation to recover the lithium (mainly through the acid leaching process) (BGS, 2016).

A wide variety of lithium compounds exists although lithium carbonate is the most widely used. Other compounds are lithium hydroxide, butyl-lithium, lithium chloride and lithium metal. Except metal, the Li compounds are obtained by processing the lithium carbonate (BGS, 2016).

15.2.1.3 Lithium resources and reserves

There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of lithium 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.

For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for lithium. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for lithium, 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 lithium at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU, 2015).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.

Global known resources of lithium are about 41 million tonnes (USGS, 2016b). Identified lithium resources in Bolivia and Chile are 9 million tonnes and more than 7.5 million tonnes, respectively. Identified lithium resources in other major producing countries are: US, 6.7 million tonnes; Argentina, 6.5 million tonnes; Australia, 1.7 million tonnes; and China, 5.1 million tonnes. In addition, Canada, Democratic Republic of Congo, Russia, and Serbia have resources of approximately 1 million tonnes each. In Serbia, those resources includes a jadarite (Li borate) deposit of over 100 million tonnes. Identified lithium resources in Brazil and Mexico are 180,000 tonnes each, and Austria has 130,000 tonnes (USGS, 2016b). Resources of lithium in the EU reach 600,000 tonnes (Bio Intelligence Service, 2015). Resource data for some member state are available in the Minerals4EU website (see Table 70) (Minerals4EU, 2014) but cannot be summed as they are partial and they do not use the same reporting code.

---

[16] www.crirsco.com

Global known reserves of lithium are estimated at about 14 million tonnes of Li content, with the most significant reserves held by Chile, China, Argentina and Australia (see Table 71) (USGS, 2016b). The lithium known reserves in EU are about 60,000 tonnes, located in Portugal. Reserve data for the EU are available in the Minerals4EU website, but only for Finland, with 0.5 million tonnes of Li_2O at 1% of proved reserves (JORC) and 0.8 million tonnes of Li_2O at 1% of probable reserves (JORC) (Minerals4EU, 2014).

Table 70: Resource data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Quantity	Unit	Grade	Code Resource Type
Portugal	None	9.3	Mt	0.24%	Historic resource estimate
Spain	None	1	Mt	0.5%	Inferred
France	None	346	kt (Li2O content)	0.7-0.8 % LiO2	Historic resource estimate
UK	None	3.3	Mt	-	Historic resource estimate
Ireland	None	0.57	Mt	1.5% (LiO2 content)	Historic resource estimate
Serbia	JORC	118	Mt	1.8%	Inferred
Czech Republic	Nat.rep.code	113	kt	0.21%	Potentially economic
Finland	JORC	0.4	Mt	1.1%	Measured
Sweden	Nat.rep.code	1	Mt	0.32%	Historic resource estimate

Table 71: Global reserves of lithium in year 2015 (Data from (USGS, 2016b))

Country	Lithium Reserves (tonnes)
Chile	7,500,000
China	3,200,000
Argentina	2,000,000
Australia	1,500,000
Portugal	60,000
Brazil	48,000
United States	38,000
Zimbabwe	23,000

15.2.1.4 World mine production

The global production of lithium ores is about 25,500 tonnes (Li content) in annual average over the period 2010-2014 (BGS, 2016). Other sources provide a higher picture with about 32,000 tonnes (USGS, 2016b). There are 8 countries known to be producing lithium. Australia, China, Zimbabwe, Portugal and Brazil extract from hard rocks, whereas Chile, Argentina, China and USA extract from brines (BGS, 2016). Chile is the most important producer of lithium ores (44%), followed by Australia (32%) and Argentina (11%) (see Figure 123). In the EU, about 350 tonnes of lithium ores are extracted annually in Portugal. Spain production ended in 2011 (Bio Intelligence Service, 2015).

The global production of refined lithium compounds (Li carbonates Li_2CO_3, Li hydroxides LiOH, Li oxides Li_2O, Li metal, Li bromide LiBr, Li chloride LiCl and butyllithium) is estimated to be about 27,350 tonnes in 2011, with Chile and Australia as the main producers (see Figure 124) (Bio Intelligence Service, 2015). In the EU, about 600 tonnes of lithium compounds are produced (Bio Intelligence Service, 2015).

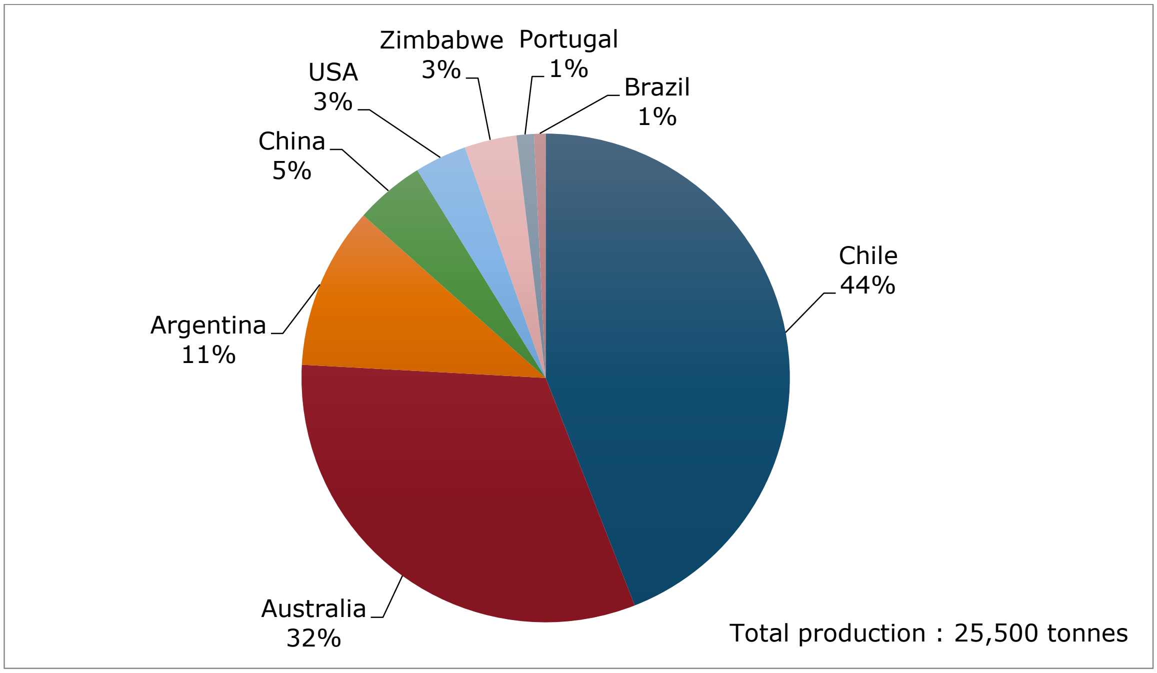


Figure 123: Global mine production of lithium, average 2010–2014 (Data from BGS, 2016)

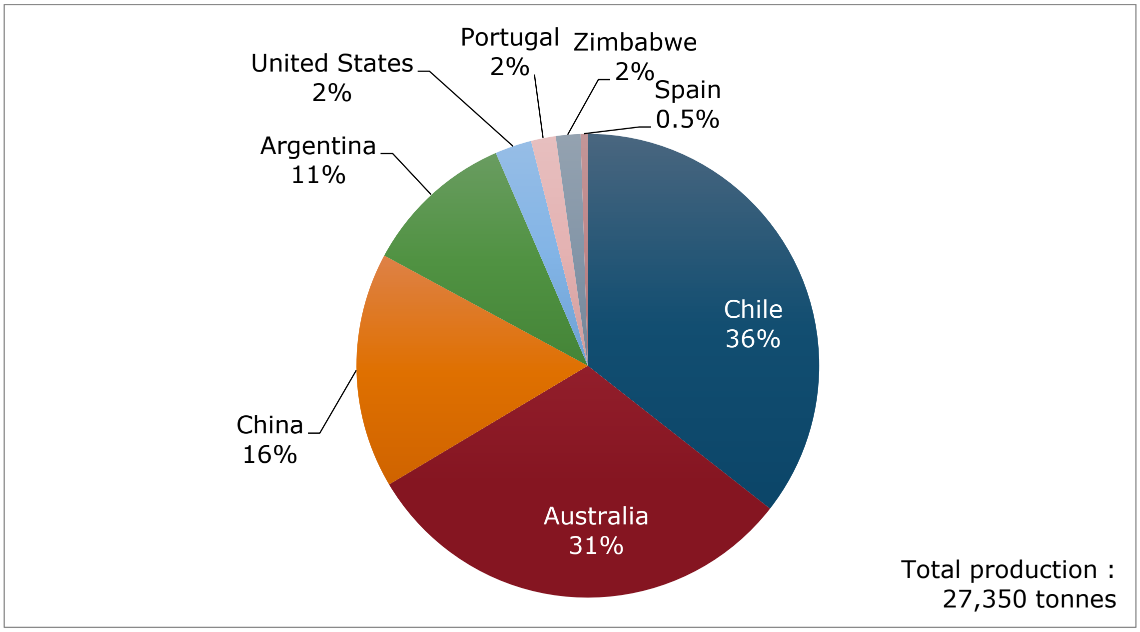


Figure 124: Global production of lithium compounds, data of year 2011 (Data from Bio Intelligence Service, 2015)

15.2.2 Supply from secondary materials

Historically, lithium recycling has been insignificant but interest in such recycling has increased steadily owing to the growth in consumption of lithium batteries. For many of end-uses of lithium, functional recycling is not carried out because of dissipative end-uses (such as in ceramics and glass) or reusable end-uses (such as catalysts) (BGS, 2016). The majority of attention in recent years has been devoted to the recycling of lithium-ion batteries, but the economic interest is limited by the expensive recycling process and the low lithium content, making the primary source more cost-effective (BGS, 2016). The EU has set a mandatory target that 45% of batteries in portable electronics in EU Member States shall be recycled by 2016 (European Commission, 2014). Nevertheless, in such batteries, cobalt and nickel are more valuable and are distinctively recovered whereas lithium remains in the slag, used as construction material (non-functional recycling) (BGS, 2016). Recycling plants for lithium batteries were under development in Belgium and Germany (amongst others) in 2012 (European Commission, 2014).

The end-of-life input recycling rate of lithium is 0%.

15.2.3 EU trade

The EU imports lithium ore concentrates (about 1,3 tonne) (Bio Intelligence Service, 2015) to be directly used for the glass and ceramic production, and other lithium compounds such as Li carbonates, Li hydroxides, Li oxides, Li metal, Li bromide, Li chloride and butyllithium.

On average between 2010 and 2014, the EU imports about 3,600 tonnes of Li contained in such processed materials. Chile is by far the main supplier of the EU (77%) (Eurostat, 2016a) (see Figure 125).

Only Argentina has put export taxes on lithium products (OECD, 2016). The main supplier of lithium to the EU is Chile, with which a free trade agreement is in place (European Commission, 2016).

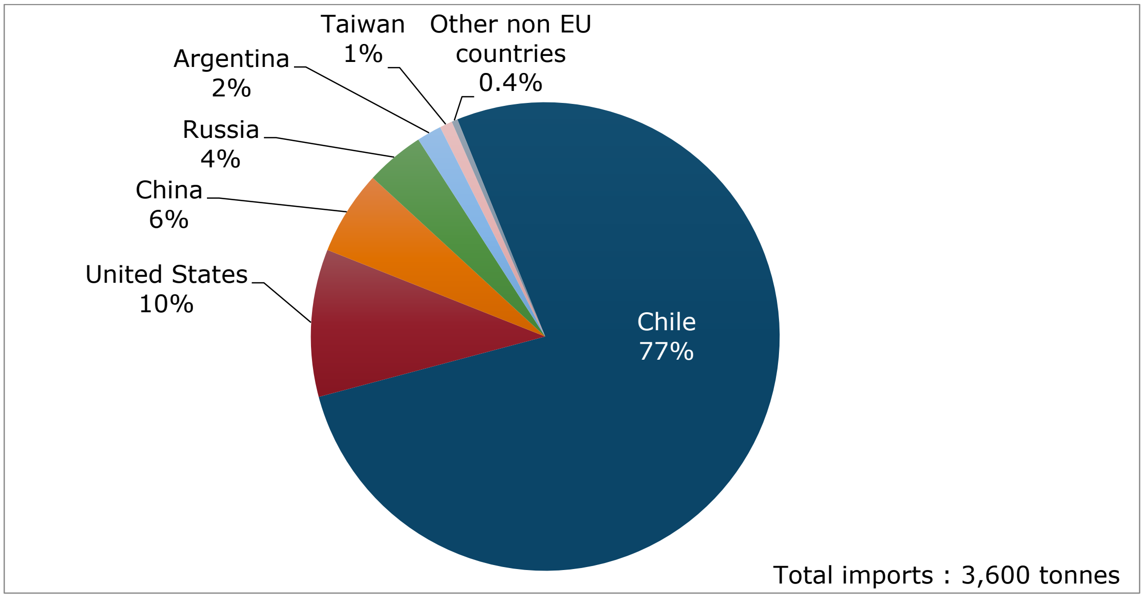


Figure 125: EU imports of lithium compounds, average 2010-2014 (Data from Eurostat, 2016a; Bio Intelligence Service, 2015)

15.2.4 EU supply chain

In the EU, about 350 tonnes of lithium ores are extracted annually only in Portugal from the mineral lepidolite. Spain production ended in 2011 (Bio Intelligence Service, 2015).
On average between 2010 and 2014, the EU imports about 3,600 tonnes of Li contained in Li compounds. Some Li compounds are also produced in Portugal and Spain (about 600 tonnes) but they are not exported. Austria, Belgium, the Czech Republic, Denmark, France, Germany, Italy, the Netherlands, Poland, Slovenia, Spain, Sweden and the United Kingdom are importers and exporters of lithium carbonate and lithium oxide. The EU import reliance is 86%. The Figure 126 presents the EU sourcing (domestic production + imports) of lithium.

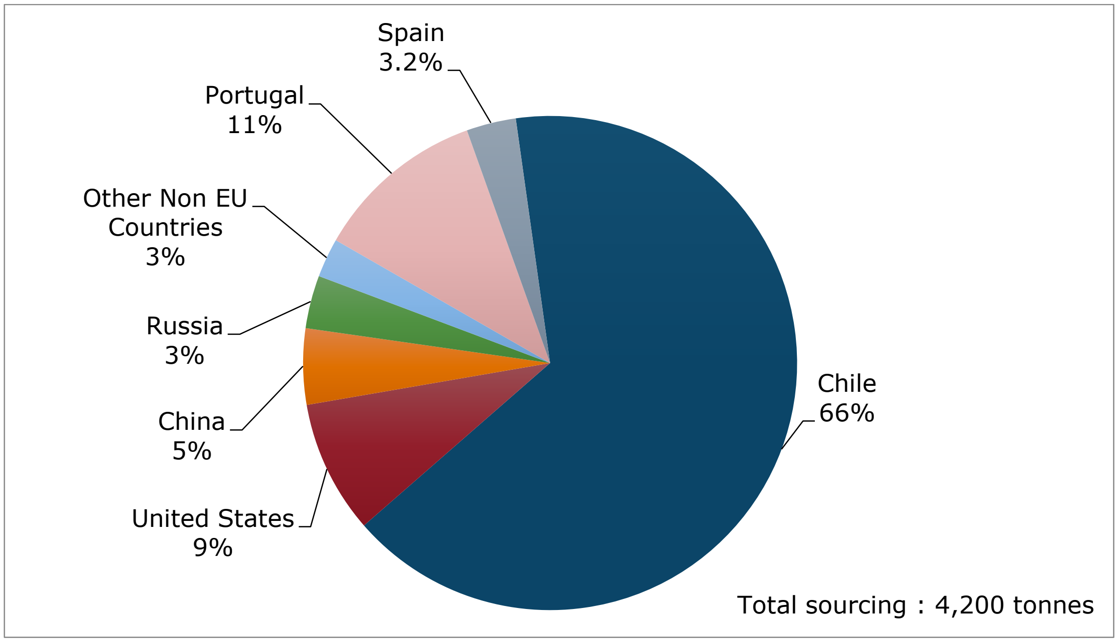


Figure 126: EU sourcing (domestic production + imports) of lithium compounds, average 2010-2014 (Data from Eurostat, 2016a; Bio Intelligence Service, 2015)

Only Argentina has export taxes on lithium products (OECD, 2016). The main supplier of lithium to the EU is Chile, with which a free trade agreement is in place (European Commission, 2016).

Several European industries use various applications of lithium e.g. automotive industry uses lithium in rechargeable batteries for electric or hybrid vehicle. Recycling plants for lithium batteries were under development in Belgium and Germany (amongst others) in 2012 (European Commission, 2014).

15.3 Demand

15.3.1 EU DEMAND AND CONSUMPTION

The EU consumes annually about 4,200 tonnes of lithium in various end-uses (Bio Intelligence Service, 2015).

15.3.2 Uses and end-uses of lithium in the EU

Currently the main use of lithium compounds in the EU is as fluxes in the ceramics and glass industries. Contrary to the global context where lithium is increasingly used to manufacture rechargeable batteries, in the EU there is a very low production of Li-ion batteries so this use is still negligible (Bio Intelligence Service, 2015). The shares of end-uses of lithium in the EU are provided in Figure 127 (Bio Intelligence Service, 2015) and relevant industry sectors are described using the NACE sector codes (Eurostat, 2016c) provided in Table 72.

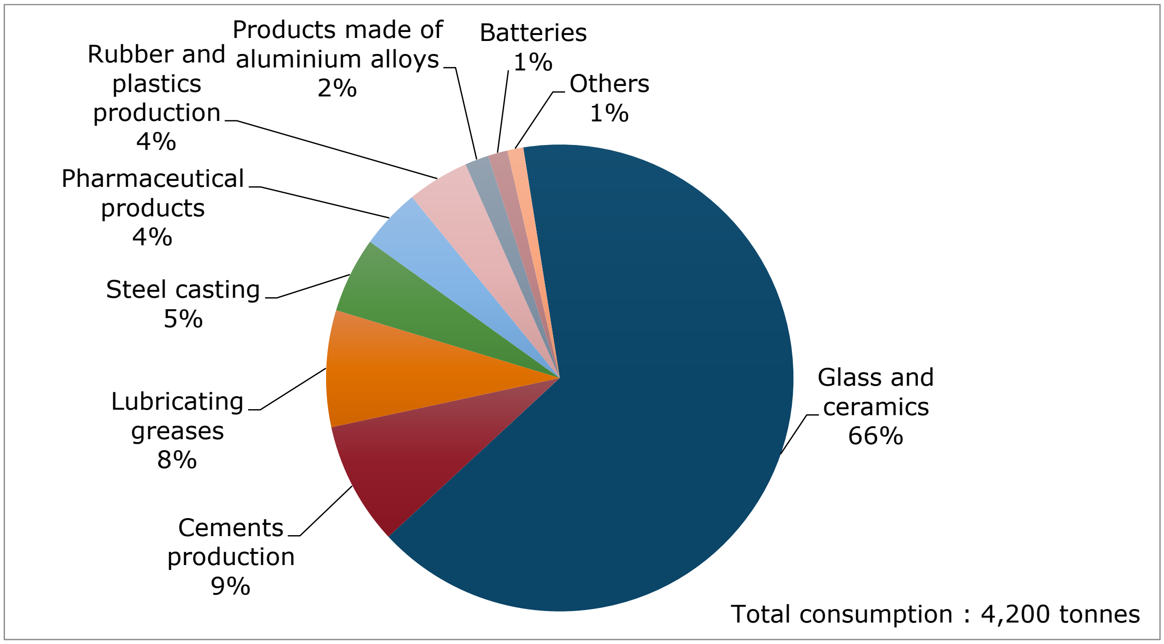


Figure 127: EU end uses of lithium. Average figures for 2010-2014. (Data from Bio Intelligence Service, 2015)

- Ceramics and glass: Lithium oxide is used as a flux in the ceramic and glass industry to reduce the melting point and viscosity of silica-based compounds. As lithium has a low coefficient of thermal expansion, lithium-containing glass or glazes on ceramics are more resistant to higher temperatures. Glass containing lithium can also be more resistance to chemical attack and can have improved hardness and shine (BGS, 2016).
- Glass-ceramics: these rely on crystallisation of a glass to get a very low thermal expansion glass-ceramic material used in heat-resistant applications, typically cooker tops. Lithium is used to obtain the correct crystalline phase.
- Lubricating grease: lithium hydroxide produces a lithium soap grease when heated with a fatty substance, which is one of the most commonly used of all lubricating grease due to its good performance and cost-effectiveness (BGS, 2016).
- Cement production: lithium compounds can be used to control expansion due to the Alkali-silica reaction (ASR), that deteriorate concrete. Lithium is used to both control ASR in new concrete as an admixture, and to retard the reaction in existing ASR-affected structures (US Department of Transportation, 2007).
- Metallurgical: Li metal is used as a flux in welding or soldering because it promotes the fusing of other metals and absorbs impurities at the same time (BGS, 2016). It is used for steel casting and aluminium smelting (where lithium carbonate is added to the cryolite bath to reduce the melting point of alumina). Lithium is also alloyed with aluminium, cadmium, copper or manganese for the manufacture of products made of aluminium or specialized aircraft parts (BGS, 2016).
- Rubber and plastic production: Organolithium compounds, including butyllithium, are used in the production of polymers and other similar chemical uses, such as reagents, catalysts or initiators. These chemicals processes are used in the production of synthetic rubber and plastics (BGS, 2016).
- Pharmaceuticals: a number of lithium compounds, including lithium carbonates, are used in medicine as mood-stabilizing drugs or for psychiatric disorders (BGS, 2016).
- Batteries: Lithium is used in several types of batteries, both rechargeable and non-rechargeable. In non-rechargeable forms, lithium metal is used for the anode. These batteries have a longer lifetime than most of other types of disposable batteries, and are more expensive (BGS, 2016). Lithium is also present in the electrolyte and the

cathode of lithium-ion rechargeable batteries. Although on a global scale almost 35% of lithium consumed is in the battery application, this situation is totally different in the EU where very few batteries are produced (all imported) (Bio Intelligence Service, 2015).

Table 72: Lithium applications, 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2016c)

Applications	**2-digit NACE sector**	**Value added of NACE 2 sector (millions €)**	**4-digit NACE sectors**
Glass and ceramics	C23 - Manufacture of other non-metallic mineral products	59,166	C2311-Manufacture of flat glass; C2312-Shaping and processing of flat glass; C2313-Manufacture of hollow glass; C2319-Manufacture and processing of other glass, including technical glassware; C234-Manufacture of other porcelain and ceramic products
Lubricating greases	C19 - Manufacture of coke and refined petroleum products	13,547	C1920- Manufacture of refined petroleum products
Cement production	C23 - Manufacture of other non-metallic mineral products	59,166	C2351- Manufacture of cement;C2369- Manufacture of other articles of concrete, plaster and cement
Steel casting	C24 - Manufacture of basic metals	57,000	C2452- Casting of steel
Pharmaceutical products	C21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations	79,545	Too broad C211, C212
Rubber and plastics production	C22 - Manufacture of rubber and plastic products	82,000	C221- Manufacture of rubber products; C222- Manufacture of plastic products; C2016-Manufacture of plastics in primary forms; C2017-Manufacture of synthetic rubber in primary forms
Batteries and products containing batteries	C27 - Manufacture of electrical equipment	84,609	C2720- Manufacture of batteries and accumulators
Products made of aluminium alloys	C25 - Manufacture of fabricated metal products, except machinery and equipment	159,513	Too broad C259-Manufacture of other fabricated metal products ; C2420-Aluminium production

15.3.3 Prices

The prices of lithium have dropped in 2001 but increased since 2005 to recover their 2000's value of about 4,500 dollar per tonne (USGS, 2016a). Prices have been multiplied by 3 between 2005 and 2008, but are fairly stable since (see Figure 128). According to the DERA raw materials price monitor and the LMB Bulletin, lithium carbonate prices have again increased since 2015 as it cost 6,222 US$/t in average on the period 2011-2015 but 7,091

US$/t in average on the period December 2015 - November 2016, i.e. a price increase of 14%.

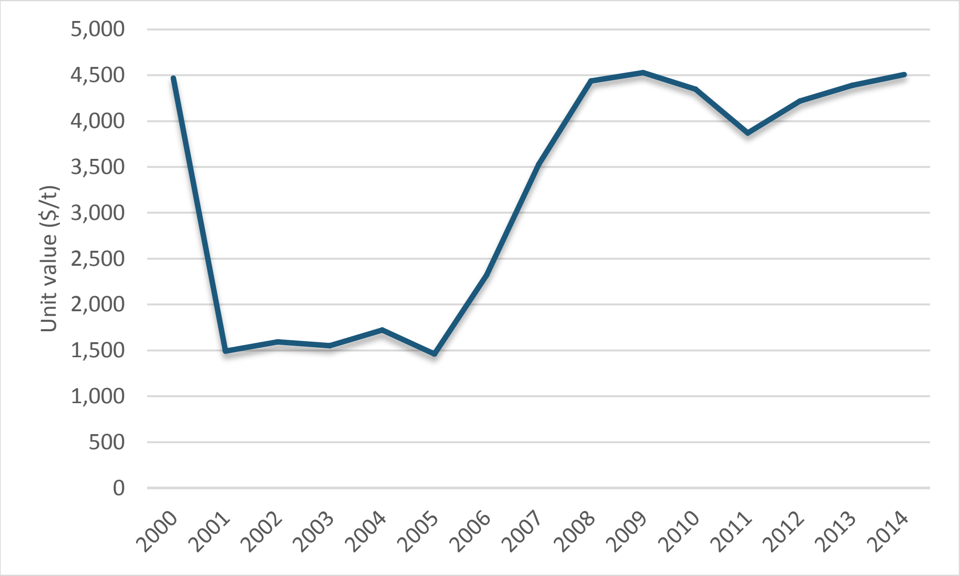


Figure 128: Lithium prices between 2010 and 2014 (USGS, 2016a)

15.4 Substitution

Substitution for lithium compounds is possible in many applications such as batteries, ceramics, greases, and manufactured glass (USGS, 2016b).

Sodic and potassic fluxes can be used instead of lithium in ceramics and glass manufacture, but with a loss of performance (BGS, 2016). For the batteries application, calcium, magnesium, mercury, and zinc can replace lithium as anode material in primary batteries; and NiCd, NiMH batteries or lead-acid batteries compete with Li-ion batteries in the rechargeable batteries market, although the performance of these alternatives can be lower in some applications, notably electric vehicles (USGS, 2016b). Currently Li-ion batteries are the only feasible option for most electric vehicles as Li-ion has the desirable energy and power storage density needed in this application (BGS, 2016). In greases, calcium and aluminium soaps can substitute lithium stearates and composite materials consisting of boron, glass, or polymer fibres in resins can substitute for aluminium-lithium alloys in structural materials (USGS, 2016b).

However, although those various substitutes are available, in reality they are often little incentive to use them instead of lithium because of the relative inexpensive price of lithium and the stability of its supply (BGS, 2016).

15.5 Discussion of the criticality assessment

15.5.1 Data sources

As Eurostat data (Eurostat, 2016a; Eurostat, 2016b) was not usable for all the processed Li materials (only CN8 code for Li carbonate (28369100) and for Li oxide and hydroxide (28252000), but no code for Li metal, bromide, chloride and butyllithium), we used also data from MSA study (Bio Intelligence Service, 2015) for Li metal, bromide, chloride and butyllithium production quantities and imports.

In this way, results are not based on a 2010-2014 average, but on the most recent single-year data (2012).

15.5.2 Economic importance and supply risk calculation

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 72). The value added data correspond to 2013 figures.

The life cycle stage assessed in for the Supply Risk indicator is the processing step. The SR is calculated using both the HHI for world production and the HHI for EU supply as prescribed in the revised methodology. Chile, Australia, China and Argentina account for about 94% of the global supply, but Chile is the main supplier for the EU. The EU production is exclusively performed in Portugal.

15.5.3 Comparison with previous EU assessments

The results of this review and earlier assessments are shown in Table 73.

Table 73: Economic importance and supply risk results for lithium in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017.

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Lithium	5.59	0.73		5.48	0.63		2.4	1.0

Although it appears that the economic importance of lithium has reduced between 2014 and 2017 this is a false impression created by the change in methodology. 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 calculations of the Supply Risk (SR) for 2011 and 2014 lists have been performed for the extraction step (Li ores) whereas the SR in 2017 assessment is calculated for the processing step (Li processed materials), which may explain the slight increase in the SR score as the lithium market did not changed considerably over the 2010-2014 period.

15.6 Other considerations

15.6.1 Forward look for supply and demand

According to USGS (USGS, 2015), numerous lithium producers and lithium market analysts projected world lithium consumption levels through 2015 and 2020 are likely to increase to approximately 190,000 t/yr of LCE (lithium carbonate equivalent) by 2015 and to 280,000 t/yr of LCE by 2020. From 2013 to 2020, average annual growth in world lithium consumption is expected to be 9.5%. The main driver of this increasing demand is the market for lithium batteries between 2011 and 2020, due to the anticipated uptake in hybrid and electric vehicles which contain Li-ion batteries (European Commission, 2014). Annual growth rates for this market could hit nearly 15% per year. More modest growth is expected in most of lithium's other end-markets (European Commission, 2014).

In terms of the supply-side, all of the major lithium-producing companies have already announced significant expansions to their capacity for the coming years. New lithium producers are expected to supply approximately 25% of the lithium required by 2020 (USGS, 2015). Significant excess capacity is forecast for the lithium market, meaning that capacity utilisation rates would be around 50-60% for the coming decade (European Commission, 2014).

Table 74: Qualitative forecast of supply and demand of lithium

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
Lithium		x	+	+	?	+	+	?

15.7 Data sources

15.7.1 Data sources used in the factsheet

BGS (2016). Lithium Profile. [online] Available at: http://www.bgs.ac.uk/mineralsuk/statistics/mineralProfiles.html [Accessed September 2016

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. p41-43

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. Lithium profile. p50-53

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

Eurostat (2016)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

Minerals4EU (2014). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

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

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

US Department of Transportation (2007). The Use of Lithium to Prevent or Mitigate Alkali-Silica Reaction in Concrete Pavements and Structures. [online] Available at: http://www.fhwa.dot.gov/publications/research/infrastructure/pavements/concrete/06133/06133.pdf

USGS (2015). Minerals yearbook—2013: Lithium [advance release]

USGS (2016)a. Historical Statistics for Mineral and Material Commodities in the United States [online] Available at: https://minerals.usgs.gov/minerals/pubs/historical-statistics/ [accessed December 2016].

USGS (2016)b. Mineral Commodity Summaries: Lithium

15.7.2 Data sources used in the criticality assessment

Battery University (2016). BU-103: Global Battery Markets. [online] Available at: http://www.batteryuniversity.com/learn/article/global_battery_markets [Accessed August 2016]

BGS (2016). Lithium Profile. [online] Available at: http://www.bgs.ac.uk/mineralsuk/statistics/mineralProfiles.html [Accessed September 2016]

BGS (2016). World mineral production 2010-2014

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. p 41-43

European Commission (2016). Free trade agreements. [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/[Accessed September 2016]

European Commission (2016). COMEXT Database [Online] CN8 code 28369100 and 28252000). Available at: http://epp.eurostat.ec.europa.eu/newxtweb/setupdimselection.do [Accessed October 2016]

Machinery Lubrication (2014). Choosing a multi-purpose grease: lithium complex or calcium sulfonate?

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

USGS (2013). Review of Selected Global Mineral Industries in 2011 and an Outlook to 2017.

USGS (2016). Mineral Commodity Summaries: Lithium

15.8 Acknowledgments

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

16. MAGNESITE

Key facts and figures

Material name and Element symbol	Magnesite, $MgCO_3$	World/EU production (thousand tonnes MgO contained)[1]	6,324 / 775
Parent group (where applicable)	N/A	EU import reliance[1]	1%
Life cycle stage/ material assessed	Extraction stage/ Ore	Substitution index for supply risk [SI(SR)][1]	0.99
Economic importance (EI) (2017)	3.7	Substitution Index for economic importance [SI(EI)][1]	0.98
Supply risk (SR) (2017)	0.7	End of life recycling input rate (EOL-RIR)	2%
Abiotic or biotic	Abiotic	Major end uses in EU[1]	Steel making (55%), Agriculture (13%), Paper industry (12%), Cement making (9%)
Main product, co-product or by-product	Main product	Major world producers[1]	China (64%), Turkey (10%), Russia (6%)

Criticality results	2011	2014	2017
	Not critical	Critical	Not critical

[1] 2010-2014 average, unless otherwise stated.

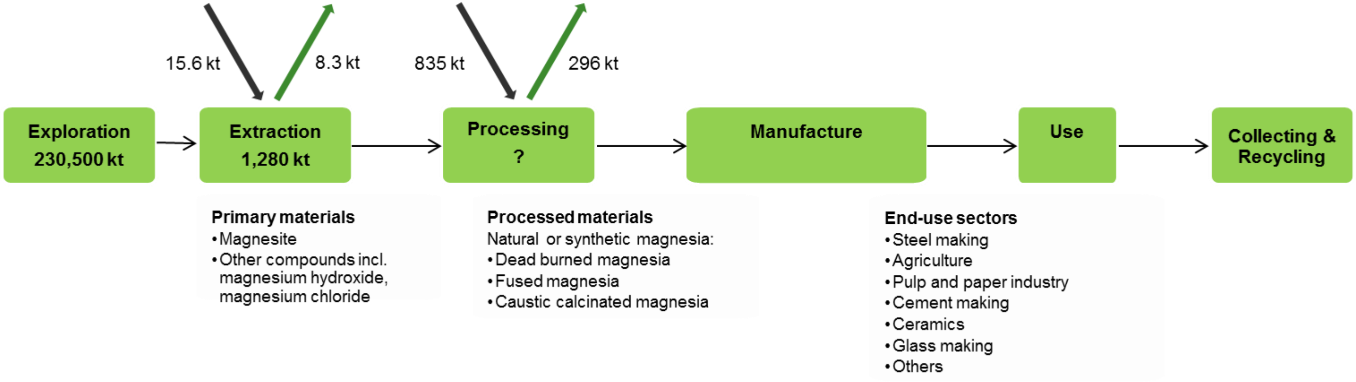


Figure 129: Simplified value chain for magnesite

The green boxes of the Extraction and Processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU. Recycling of magnesite is not significant in the EU. EU reserves are displayed in the exploration box. Volumes are provided in thousand tonnes MgO contained for better comparability between magnesite ($MgCO_3$) and magnesia (MgO). EU reserves are displayed in the exploration box.

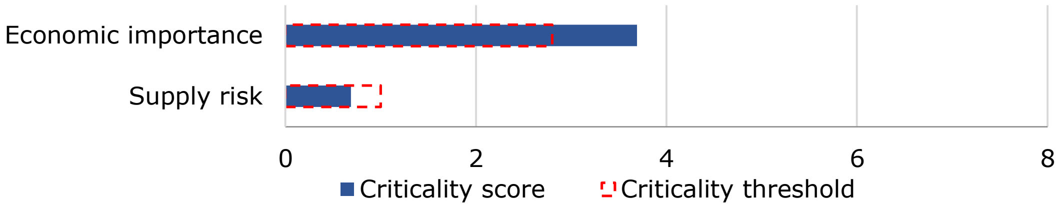


Figure 130: Economic importance and supply risk scores for magnesite

16.1 Introduction

Magnesite is the common name for the mineral magnesium carbonate ($MgCO_3$). Once extracted, magnesite is mainly used magnesia processing (at least in the EU), 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; 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 or dolomite. The obtained material is called synthetic magnesia.

Magnesite extraction in the EU-28 accounts for 12% of the global production (World Mining Congress, 2016). Although there is few trading of magnesite, magnesia imports to the EU represent a quarter of the EU apparent consumption. In addition, the EU magnesia production is sold in the EU, although a wide range of magnesia products is exported outside of the EU; however the production sold in the EU does not meet the demand. The EU apparent consumption of magnesia represents about 15% of the consumption worldwide. The magnesite/magnesia industry in the EU is concentrated in a few Member States.

Note: The present factsheet focuses on the value chain of magnesite/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 (Mg – see relevant factsheet) and the value chain for magnesite/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.

16.2 Supply

16.2.1 Supply from primary materials

16.2.1.1 Geological occurrence of magnesite

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% to 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 to 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 tons. Calcite and dolomite are the main impurities. Cryptocrystalline magnesite is found is many small deposits, although there are exceptions. 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.

Please note that 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).

16.2.1.2 Mining of magnesite and processing of magnesia

16.2.1.2.1 Mining of magnesite

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 worked by underground drifts and stopes. The mines 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).

16.2.1.2.2 Processing of natural magnesia from magnesite

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; Euromines, 2017).

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, 2017).

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.

16.2.1.2.3 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 (Euromines, 2017).

16.2.1.3 Magnesite resources and reserves

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[17], 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.

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).

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 at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU, 2015). 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. Resource data for some countries in Europe are available in the Minerals4EU website (see Table 75) (Minerals4EU, 2014) but cannot be summed as they are partial and they do not use the same reporting code.

---

[17] www.crirsco.com

Table 75: Resource data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

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

According to USGS, world known reserves of magnesite stand at 2.4 billion tonnes Mg contained (i.e. an equivalent of 4.1 billion tonnes MgO contained), with more than 66% of reserves located in Russia, China and North Korea (respectively 27%, 21% and 19% of identified reserves – see Table 76); known reserves in the EU represent less than 10% of the total (USGS, 2016).

Reserve data for some countries in Europe are available in the Minerals4EU website (see Table 76) but cannot be summed as they are partial, they do not use the same reporting code and the grade (e.g. $MgCO_3$ contained) is not always specified.

Table 76: Global reserves of magnesite in year 2015 (USGS, 2016)

Country	Magnesite reserves (thousand tonnes Mg)	Equivalent in thousand tonnes MgO
Russia	650,000	1,075,000
China	500,000	826,923
North Korea	450,000	744,231
Turkey	111,000	183,577
Australia	95,000	157,115
Brazil	86,000	142,231
Greece	80,000	132,308
Slovakia	35,000	57,885
India	26,000	43,000
Austria	15,000	24,808
Spain	10,000	16,538
Unites States	10,000	16,538
Other countries	390,000	645,000
Total	*2,458,000*	*4,065,154*

Table 77: Reserve data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

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

16.2.1.4 World production of magnesite

World extraction of magnesite is summarised in Figure 88, and totals 24,300,000 tonnes annually (gross weight) on average during the 2010-2014 period (estimated 90% $MgCO_3$

purity, i.e. around 10,500,000 tonnes of MgO contained). Global supply of magnesite is dominated by China with about 64% of the total extracted production, equivalent to 15,600,000 tonnes (gross weight, average 2010-2014). Turkey and Russia are the second and third largest producing countries accounting for 10% and 6% (average over 2010-2014) respectively of worldwide magnesite extraction.

Magnesite production doubled within a decade during 1990 and 2000, and followed a progressive increase since then. This growth is attributed to the industrial expansion of China, where magnesite extraction was estimated to grow from 2,000,000 tonnes in 1990 (gross weight – around 20% of global production) to 8,000,000 tonnes before 2000 (gross weight – nearly half of global production). The global magnesite extraction decreased by 6% in 2015.

Although the largest identified reserves are located in Russia, China and North Korea (see Table 76), China represents the majority of magnesite production worldwide.

The EU28 represents about 12% of the global magnesite extraction, with about 1,280,000 tonnes MgO contained during the 2010-2014 period. The production of magnesite in Europe decreased in comparison to the production of magnesite worldwide: in 1981, countries in Europe produced were responsible for 32% of global production (JRC, 2013).

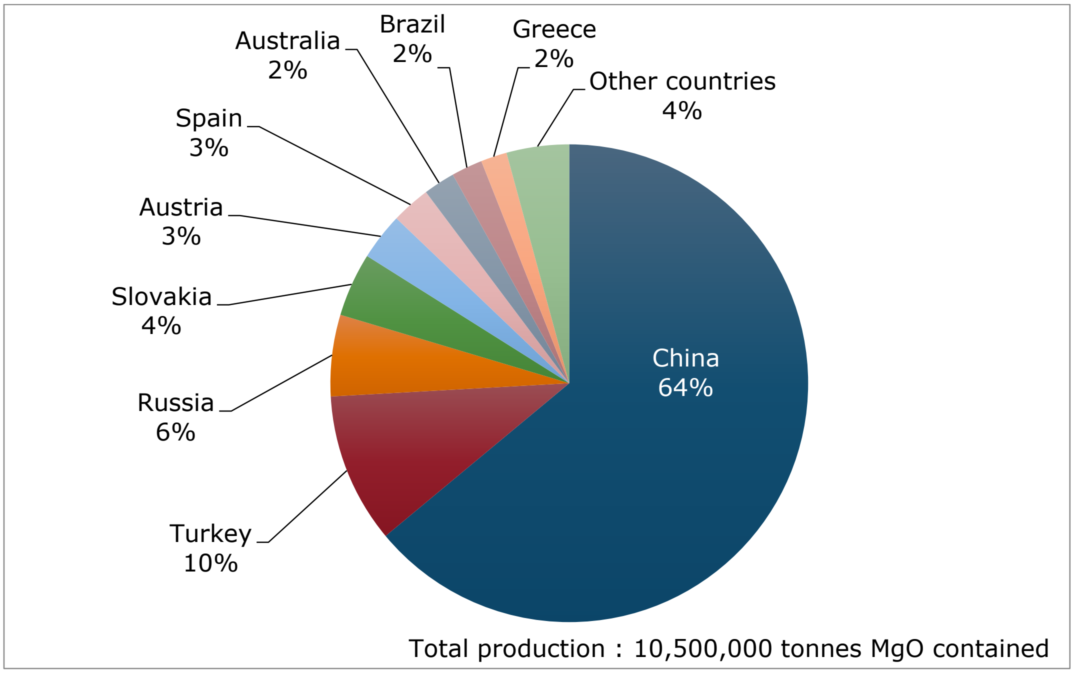


Figure 131: Global magnesite extraction, average 2010–2014 (Data from World Mining Congresses, 2016)

Note: The figures come from the annual World Mining Data publication (World Mining Congresses, 2016) and do not include extraction of magnesite equivalent (used to process synthetic magnesia). Other sources such as BGS publications (BGS, 2016) seem to provide overestimated figures on magnesite production. Potential explanations are the inclusion of magnesite equivalents (e.g. magnesium chloride), or accounting for magnesite production capacity rather than actual production. For instance in 2015, global magnesite extraction reached 26,800,000 tonnes (gross weight) according to the Austrian Federal Ministry (China: 14,800,000 tonnes in gross weight); to be compared to 44,900,000 tonnes (gross weight) declared in BGS database (China: 37,000,000 tonnes in gross weight), and including magnesite equivalents such as: chloride produced from solution mining (e.g. in

Netherlands); magnesitic dolomite and brucite (e.g. in Canada); magnesium chloride (e.g. Israel).

16.2.1.5 World production of magnesia

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 current global magnesia production (Bio Intelligence Service, 2015), a share that significantly decreased in the past decades (BGS, 2004). 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).

Regarding **natural magnesia**, the mines ore is rarely shipped or used in crude form: it is mainly processed near the mine site to yield magnesia products. For that reason, a similar distribution of worldwide production is expected for natural magnesia as for magnesite.

There are more than 20 plants around the world processing **synthetic magnesia** from magnesium hydroxide. The main countries producing synthetic magnesia today are the Netherlands, Ireland, Norway, Israel, Japan, South Korea, Mexico, the US, recently 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, 2017).

The production capacity of magnesite and magnesia is much higher than the actual production. According to Euromines, the Chinese dead-burned magnesia (DBM) capacity is 11 million mt/year, i.e. 2.2 times the actual production in China, while the electro-fused magnesia (EFM) capacity is 3.6 million mt/year, 2.1 times the actual production in China (Euromines, 2016).

16.2.2 Supply from secondary materials

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 (European Commission, 2014).

The end-of-life recycling input rate is calculated at 2% for magnesite/magnesia (Bio Intelligence Service, 2015).

16.2.3 EU trade of magnesite and magnesia

16.2.3.1 Trade of magnesite

Trade of magnesite between the EU28 and the rest of the world is not significant compared to magnesite extraction in Europe, mainly because the mines ore is rarely shipped or used in crude form, but is rather processed near the mine site to yield magnesia products. Imports of magnesite in the EU represent around 1% of the EU magnesite consumption on 2010-2014 average. Most of magnesite imports to the EU come from Turkey and China (see Figure 133), which represent respectively 85% and 11% of the total imports to the EU (Eurostat, 2016a).

Depending on the year, the EU is a net importer or a net exporter of magnesite: the commercial balance can be considered in equilibrium. On the average over the 2010-2014 period, the annual net import figure is of 17,100 tonnes in gross weight, i.e. around 7,300 tonnes in MgO contained (Figure 132) – with 15,600 tonnes MgO contained imported, and 8,300 tonnes MgO contained exported annually.

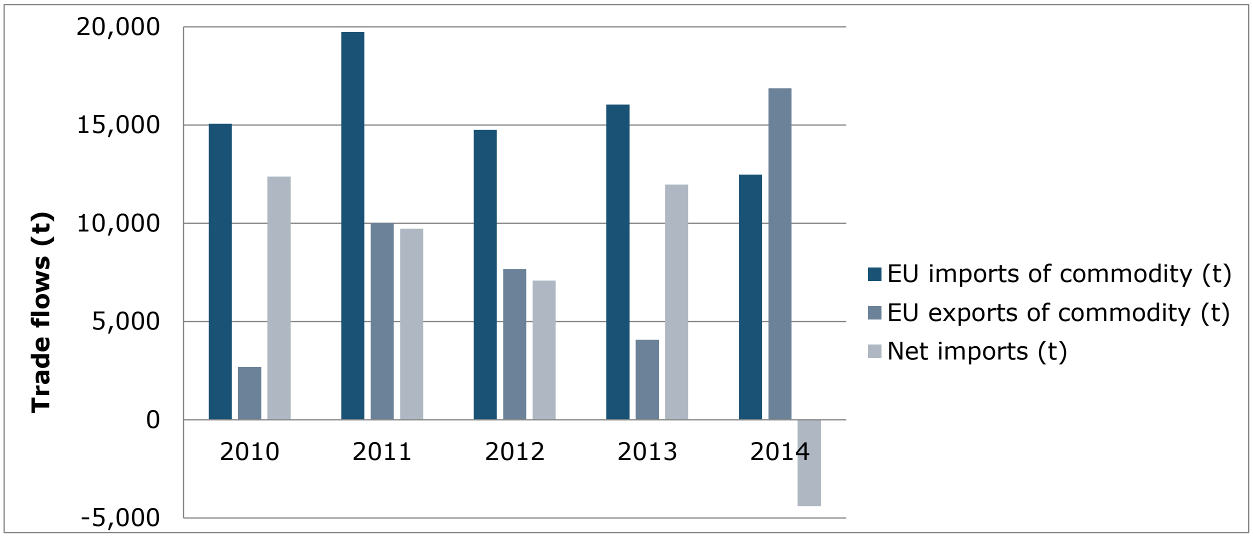


Figure 132: EU trade flows for magnesite, MgO contained. (Data from Eurostat - Eurostat, 2016a)

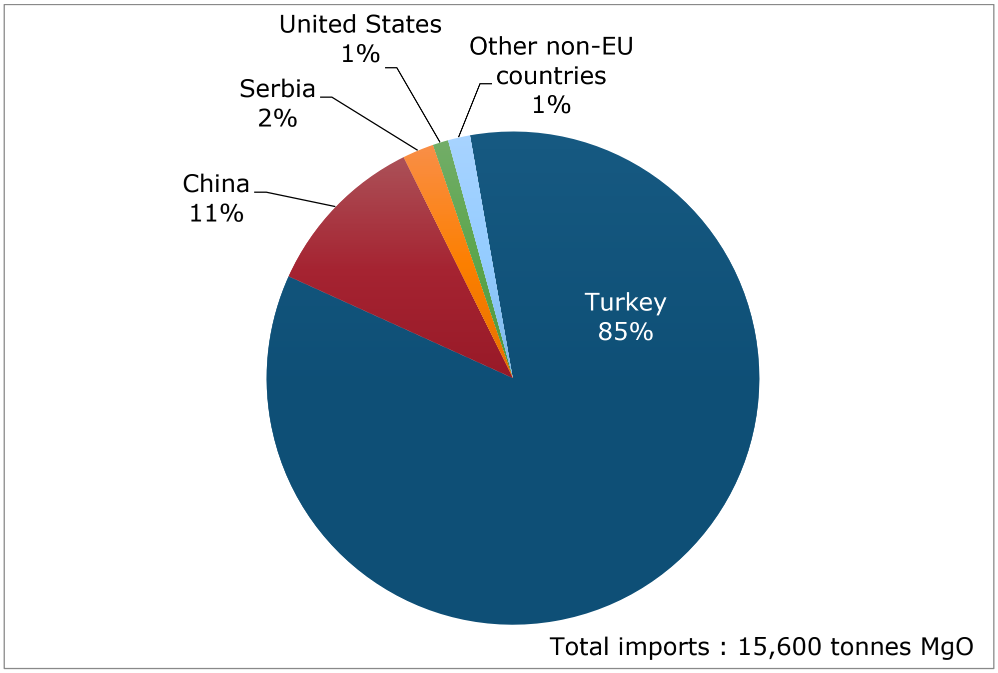


Figure 133: EU imports of magnesite from extra-EU28 countries, average 2010-2014 (Eurostat, 2016a)

For magnesite trade data the Combined Nomenclature (CN) code 25191000 'Natural magnesium carbonate "magnesite"' (estimation of 43% MgO contained) has been used.

16.2.3.2 Trade of magnesia

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 840,000 tonnes MgO contained between 2010 and 2014, and dead burned magnesia (DBM) concerned the majority of imports: 54% of total imports on average between 2010 and 2014. China is the main country supplying magnesia, and accounts for more than 40% than total imports (Eurostat, 2016a) – this share varies from 33% for DBM to more than 61% of fused magnesia (FM) (Figure 134). Imports of magnesia to the EU increased regularly from 2000 to 2007, with a 7% annual rise. However after 2007, imports started declining gradually and were below 2000 value in 2012-2013 (Figure 135).

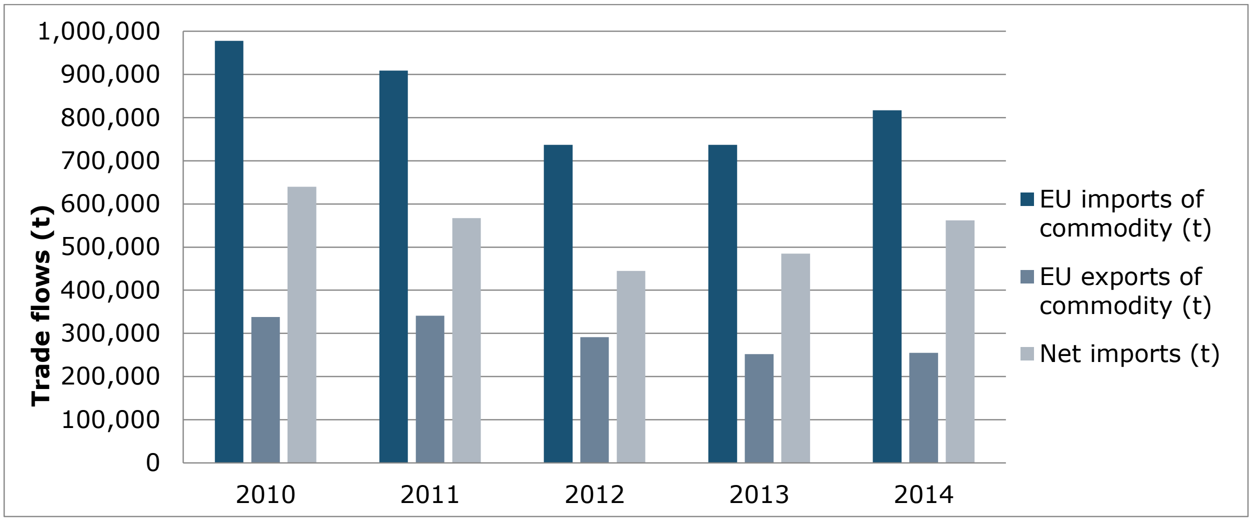


Figure 134: EU trade flows for magnesia, MgO contained. (Data from Eurostat, 2016a)

Exports of magnesia from the EU are estimated at 300,000 tonnes MgO contained on the 2010-2014 period; exports of magnesia decreased in the past decade (16% lower in 2015 than 2000). The majority of exports are fused magnesia (50% of exports in 2015) and dead burned magnesia (47% of exports in 2015), with fused magnesia gradually prevailing over other magnesia forms in the past decade.

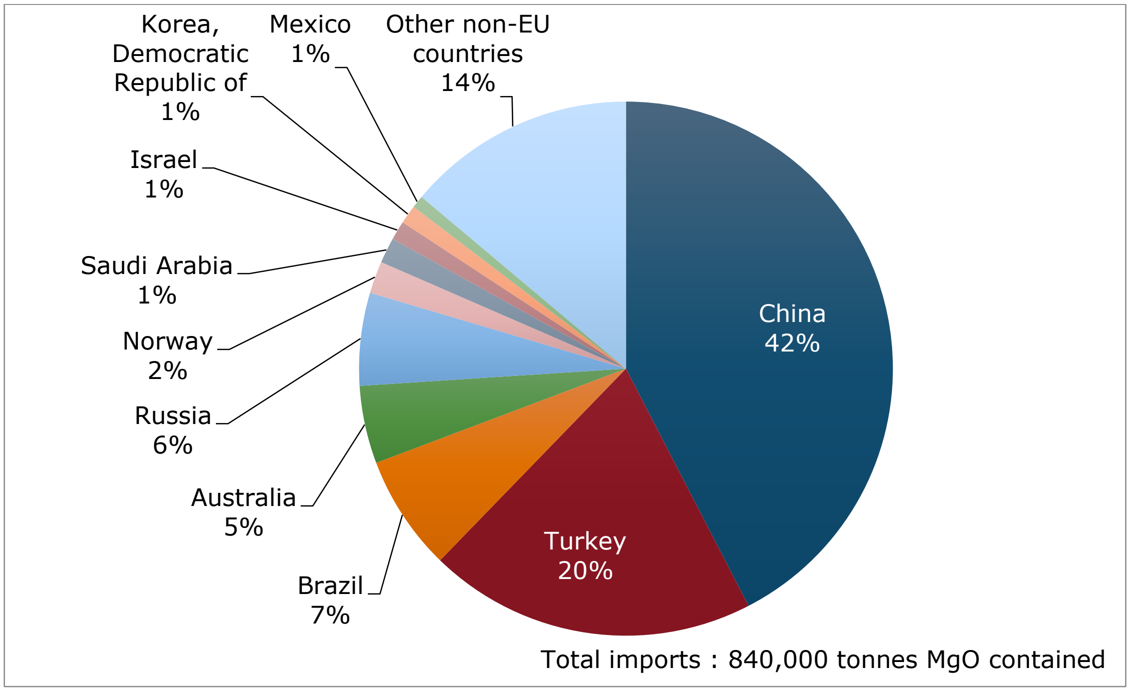


Figure 135: EU imports of magnesia from extra-EU28 countries, average 2010-2014 (Eurostat, 2016a)

For magnesia trade data, the following CN codes were used: 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); and 25199010 'Magnesim oxide, whether or not pure (excl. calcined natural magnesium carbonate)' (estimation of 84% MgO contained).

16.2.4 EU supply chain

The EU supply chain of magnesite/magnesia can be described by the following key points:

- The 5-year average European production of magnesite between 2010 and 2014 was 1,280,000 tonnes MgO contained per year (2,980,000 tonnes gross weight), which accounts for 12% of the global production. Producing countries include Slovakia, Austria and Spain, as well as Greece and Poland.
- The EU magnesite production is processed into natural magnesia in Europe. In addition, synthetic magnesia is produced in European countries such as Netherlands; however no robust information is available on synthetic magnesia production.
- There are 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 EU28 and the rest of the world are not significant compared to magnesite extraction in Europe. On average between 2010 and 2014, 15,600 tonnes MgO contained of magnesite were annually imported; annual magnesite exports were of 8,300 tonnes MgO contained. Depending on the year, the EU is a net importer or a net exporter of magnesite: the commercial 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 is a net importer of magnesia since the domestic production of magnesite and magnesia does not satisfy the European demand. On average between 2010 and 2014, net imports of magnesia were of 540,000 tonnes MgO contained. China is the main country supplying magnesia, and accounts for more than 40% than total imports (Eurostat, 2016a).
- The import reliance for magnesite in Europe is estimated at 1%; 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.
- China implemented restrictions on magnesite and magnesia trade: a 5% export tax was imposed for magnesite during the 2010-2014 period; the export tax for magnesia went from 10% in 2010 to 5% in 2014. India also imposed an export tax for magnesia, at 3.25% in 2014 (compared to 6.5% previously) (OECD, 2016).
- In addition, export quotas are imposed in China for both magnesite and magnesia. Export quotas (covering both forms) were strengthened from 1,330,000 tonnes in 2010 (gross weight – equivalent to 570,000 tonnes MgO contained) to 1,050,000 tonnes in 2014 (gross weight – equivalent to 450,000 tonnes MgO contained) (OECD, 2016).
- 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).

Figure 136 shows the EU sourcing (domestic production + imports) for magnesite.

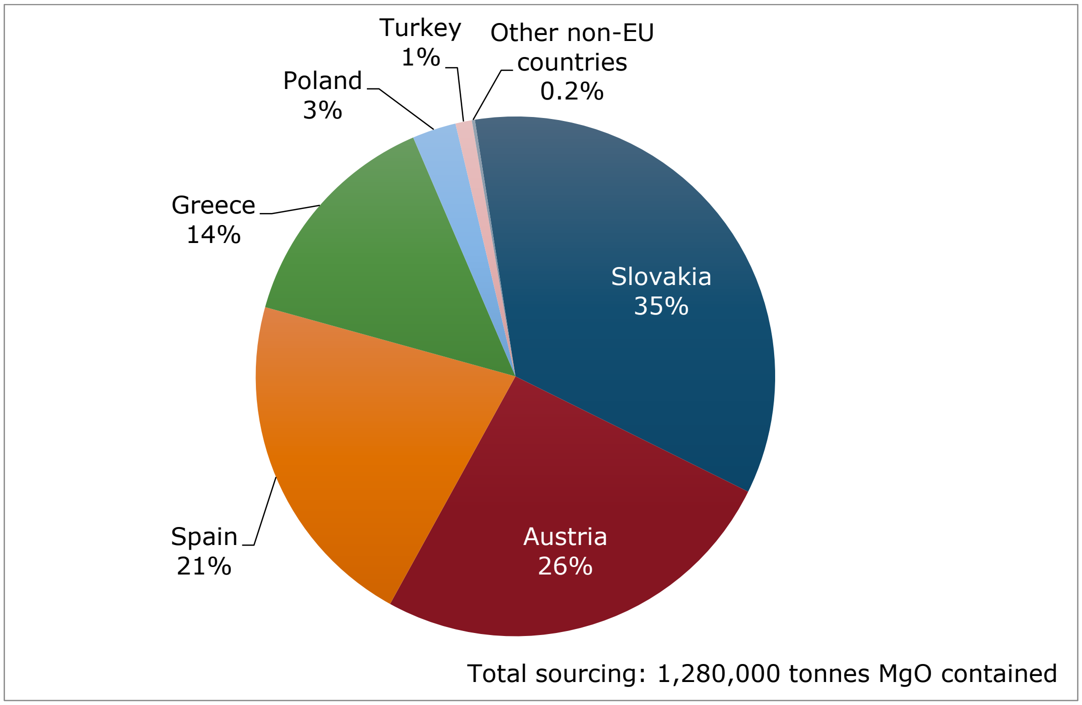


Figure 136: EU sourcing (domestic production + imports) of magnesite, average 2010-2014. (Eurostat, 2016a)

The graph presented in Figure 100 applies to the EU sourcing of magnesite and cannot be applied to the EU sourcing of magnesia since no robust information is available on magnesia production. However the EU magnesia imports by country is available on Figure 135.

16.3 Demand

16.3.1 EU demand and consumption

The EU annual apparent consumption of magnesite totalled 1,280,000 tonnes MgO contained. It was calculated based on reported production of magnesite within the EU, as well as imports and exports of magnesite.

A reliable estimate of magnesia apparent consumption in the EU is 1,830,000 tonnes MgO contained annually used on average between 2010 and 2014. 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).

16.3.2 Uses and end-uses of magnesite in the EU

In Europe, magnesite is used in magnesia processing only. 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/magnesia in the EU vary depending on the type of magnesia. Dead burned magnesia (DBM) accounts for the largest volumes compared with fused magnesia 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 fused magnesia (FM) is in refractories, as for DBM. It is also used for electrical insulation in medium and high-duty heating elements (Euromines, 2017).

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, 2017).

The end-uses of magnesite/magnesia displayed in Figure 137 are as follow:

- Steel industry: DBM and FM is widely used as a refractory brick 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) 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).
- Agriculture: 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: magnesia is a refractory binder based on a magnesium oxychloride formulation. It is fast-hardening and has a number of refractory 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)
- Other applications of magnesite/magnesia include electrical insulation components (DBM), pharmaceuticals and cosmetics (CCM), sugar refining (CCM), fillers in plastics, rubber, paints and adhesives (CCM), etc. (Euromines, 2017).

Relevant industry sectors are described using the NACE sector codes in Table 78.

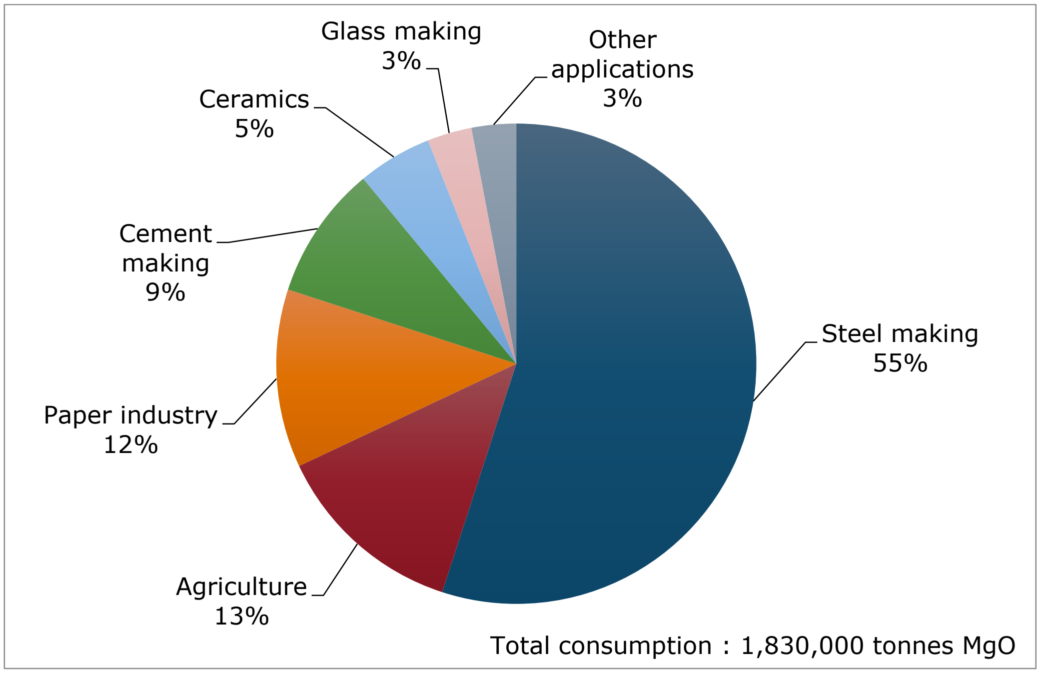


Figure 137: EU end uses of magnesite/magnesia. Average figures for 2010-2014. (Euromines, 2017). Total consumption displayed is apparent consumption of magnesia

Table 78: Magnesite/magnesia applications, 2-digit and associated 4-digit NACE sectors, and value added per sector. [Data from the Eurostat database (Eurostat, 2016b)]

Applications	2-digit NACE sector	Value added of NACE 2 sector (millions €)	4-digit NACE sectors
Steel making	C24 - Manufacture of basic metals	57 000.0	C2410 - Manufacture of basic iron and steel and of ferro-alloys
Agriculture	C20 - Manufacture of chemicals and chemical products C10 - Manufacture of food products	110 000.0 174 000.0	C2015 - Manufacture of fertilisers and nitrogen compound C1091 - Manufacture of prepared feeds for farm animals
Paper industry	C17 - Manufacture of paper and paper products	41 281.5	C1711 - Manufacture of pulp C1712 - Manufacture of paper and paperboard
Cement making	C23 - Manufacture of other non-metallic mineral products	59.166.0	23.51 Manufacture of cement
Ceramics	C23 - Manufacture of other non-metallic mineral products	59.166.0	23.43 Manufacture of ceramic insulators and insulating fittings 23.44 Manufacture of other technical ceramic products 23.49 Manufacture of other ceramic products
Glass making	C23 - Manufacture of other non-metallic mineral products	59.166.0	C2311 - Manufacture of flat glass, C2313 - Manufacture of hollow glass

16.3.3 Prices and markets

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):

- 295 €/tonne of calcined magnesia for agricultural industry in Europe – prices for CCM are expected to remain stable;
- 473 $/tonne of dead burned magnesia on the Chinese market – a price decreasing by 15% compared to 2013;
- 1,050 $/tonne of fused magnesia on the Chinese market, slightly lower than in 2013.

The tendency for fused magnesia seems to continue in 2014 and 2015 (Shillito 2015): although high grade FM is gaining preference in refractories applications due to its superior quality and performance characteristics, prices have fallen due to weaker demand and overcapacity. By March 2015, prices were between 950 $/tonne and 1,000 $/tonne (Shillito 2015).

However the tendency seemed to invert in 2016 and 2017, due to various reasons including the ongoing environmental inspections of local production processes, limited use of dynamite for mining activities, lack of magnesite ores out of Haicheng (China) and government’s requirement on higher stripping ratio, among others. FM export prices out of China rose by 20% in first months of 2017, a percentage that varied depending on grade and destination. European magnesia prices remained unchanged in the same period, although demand reportedly increased (IM, 2017).

Magnesite prices decreased in 2013-2014, with magnesite extracted in Greece sold 70 €/tonne on the Mediterranean market (BGR, 2014); for comparison, magnesite extracted in Greece was sold around 90 €/tonne in 2011-2012 (BGR, 2012). In the past decades, magnesite prices decreased due to increasing magnesia overcapacity, despite higher demand from the industry. The overcapacity of the market is expected to impact the outlook of magnesite industry, which remains uncertain.

16.4 Substitution

Substitutes are identified for the applications and end uses of the commodity of interest. In the case of magnesite/magnesia, there are no materials that can replace any of the main uses of magnesite/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. The literature used to identify substitutes for magnesite/magnesia is listed in section 16.7.

There is no material for replacement of caustic calcinated magnesia in agriculture and industrial applications, which are the major uses of CCM (Euromines, 2017). 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 (Euromines, 2017).

16.5 Discussion of the criticality assessment

16.5.1 Data sources

Market shares between intermediate applications (refractory, agricultural and other applications) are based on the study on Material System Analysis (Bio Intelligence Service, 2015) and were updated by industry experts (Euromines, 2017). Market shares between end-applications are calculated based on data on refractory applications, provided by industry experts (Euromines, 2017). Production data for magnesite are from World Mining Data (World Mining Congress, 2016) and were preferred over BGS World Mineral Statistics database. Trade data were extracted from the Eurostat Easy Comext database (Eurostat, 2016a). 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 derived from the OECD Export restrictions on the Industrial Raw Materials database (OECD, 2016).

For magnesite trade data the Combined Nomenclature (CN) code 25191000 'Natural magnesium carbonate "magnesite"' (estimation of 43% MgO contained) has been used. These data were averaged over the five-year period 2010 to 2014. Other data sources used in the criticality assessment are listed in section 16.7.

16.5.2 Economic importance and supply risk calculation

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 78). The value added data correspond to 2013 figures. The calculation of economic importance for magnesite/magnesia is not straightforward due to its wide ranging and varied end-uses. For the applications in agriculture, two 2-digit NACE sectors have been applied and the calculation formula adjusted to accommodate this.

The supply risk was assessed at the extraction stage of magnesite/magnesia value chain using both the global HHI and the EU-28 HHI as prescribed in the revised methodology. Although the supply risk of magnesia is expected to be higher than for magnesite, the processing stage (magnesia form) could not be assessed due to the lack of reliable data on worldwide as well as European production. In particular, magnesia production in China seemed overestimated in most data sources.

16.5.3 Comparison with previous EU criticality assessments

The results of this review and earlier assessments are shown in Table 79.

Table 79: Economic importance and supply risk results in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Magnesite	8.90	0.86		8.28	2.15		3.7	0.7

The economic importance of magnesite/magnesia decreased between 2014 and 2017, due to the change in methodology as well as a better representativeness of end-use applications covered by refractories. In the 2014 criticality assessment, refractory applications represented 83% of magnesite applications, the rest being split between caustic calcined end-use applications. In the 2017 criticality assessment, the project team was able to distribute refractories between specific end-use applications, thanks to various stakeholders' feedback.

The supply risk indicator is lower than in the previous years, which is due to the methodological modification, i.e. the inclusion of the EU supply and global supply in the calculation of the supply risk, rather than to an evolution in the global supply of magnesite.

16.6 Other considerations

16.6.1 Forward look for supply and demand

On the short term, consumption of caustic calcined magnesia is expected to register relatively faster growth as compared to that of dead burned magnesia and fused magnesia. Steady demand for magnesium oxide from the refractory industry coupled with increasing demand for industrial applications is expected to drive growth of the global magnesite market in coming years. In addition, some of the key companies are expected to undertake capacity expansions, and certain new capacities are expected to become operational by 2017 (Future Markets Insights, 2016).

Revenue from the global magnesium oxide market is anticipated to increase at a CAGR of 4.1% over 2016–2026, reaching US$ 8.2 Bn in revenues by 2026. APEJ will remain the largest market throughout the forecast period and is expected to witness fastest growth in terms of value, registering a CAGR of 4.6% over 2016–2026 (Future Markets Insights, 2016).

The estimations for the outlook for supply and demand of magnesite are shown in Table 80, provided by industry experts. No information was available regarding the outlook for supply and demand of magnesia.

Table 80: Qualitative forecast of supply and demand of magnesite

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
Magnesite		x	+	+	+	+	+	+

16.7 Data sources

16.7.1 Data 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). [online] Available at: http://www.euromines.org/news/newsletters/1-2016/european-magnesite-producers-position-euromines

Euromines (2017). Communication during the review.

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 (2014). 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

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 (2017). 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/

16.7.2 Data 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

16.8 Acknowledgments

This Factsheet was prepared by Deloitte. The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials for their contributions to the preparation of this Factsheet, as well as the industrial experts from Euromines and NedMag.

17. MANGANESE

Key facts and figures

Material name and element symbol	Manganese, Mn	World / EU production (tonnes)[1]	49,775,091 / 143,711
Parent group	n.a.	EU import reliance[1]	89%
Life cycle stage/ material assessed	Mine production/ Ore	Substitution index for supply risk [SI(SR)][1]	1.00
Economic importance (EI) (2017)	6.1	Substitution Index for economic importance [SI(EI)][1]	1.00
Supply risk (SR) (2017)	0.9	End of life recycling input rate (EOL-RIR)	12%
Abiotic or biotic	Abiotic	Major global end uses[1]	2014 sector shares: Steel (all forms) (87%) Non-steel alloys (6%) Chemicals (5%)
Main product, co-product or by-product	Mostly primary production	Major world producers[1]	China (29%) South Africa (20%) Australia (14 %)
Criticality results	2011	2014	2017 (current)
	Not critical	Not critical	Not critical

[1] average for 2010-2014, unless otherwise stated.

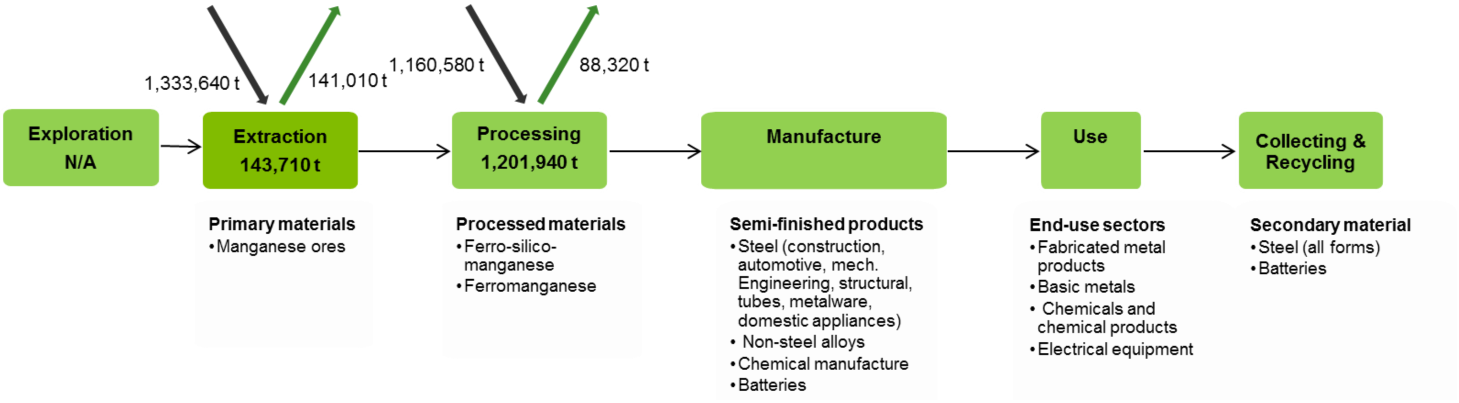


Figure 138: Simplified value chain for manganese.

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the extraction and processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU. A quantitative figure on recycling is not included as the EOL-RIR is below 70%. EU reserves are displayed in the exploration box.

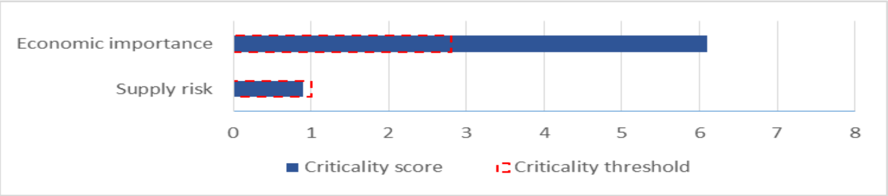


Figure 139: Economic importance and supply risk scores for manganese.

17.1 Introduction

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 and 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 Mn-silicate), psilomelane (a Mn-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.

In the EU, manganese is extracted as a primary product in Bulgaria, Romania and Hungary, although this accounts for less than 1 % of total global mine output. Apparent consumption of manganese in Europe (2010–2014) was almost 1.4 million tonnes, the majority of which (ca. 87 %) was used in the manufacture of steel. The International Manganese Institute (IMnI) estimates that the total economic value of manganese-related activities in the EU is in the order of €11 billion, and that the industry directly employs an estimated 5,000–7,000 people (IMnI, 2015).

17.2 Supply

17.2.1 Supply from primary materials

17.2.1.1 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 deposit 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).

17.2.1.2 Exploration

During the Minerals4EU project it was identified that in 2013 manganese exploration in Europe took place in Portugal and Romania. However, exploration may have taken place in other EU countries where no information was provided during the survey (Minerals4EU, 2015).

17.2.1.3 Mining, processing and extractive metallurgy

Manganese is chiefly extracted as a primary product. The mining methods employed to extract manganese will 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 will be crushed and milled, before the 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 ore being mined.

Generally manganese concentrates are further refined by 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 the ferromanganese can be altered by adding differing amounts of carbon, iron and/or silicon (Zhang and Cheng, 2007).

17.2.1.4 Resources and reserves

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[18], 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.

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, 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 manganese at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU, 2015).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 USGS estimates that global land-based manganese resources are large, but concentrated in only a few countries, namely South Africa and the Ukraine; jointly these two countries account for almost 85 % of global manganese resources. In Europe, 10 countries are known to have manganese resources, these are: Germany, Bulgaria, Spain, Portugal, Finland, the Czech Republic, Hungary, Romania, Kosovo, and Greece. However, Romania is the only country to report these resources in accordance with the UNFC system of reporting. Data for Germany is not reported at all because data collection in that country is the responsibility of sub-national level authorities (Minerals4EU, 2015). Resource data for some countries in Europe are available in the Minerals4EU website (see Table 81) (Minerals4EU, 2014) but cannot be summed as they are partial and they do not use the same reporting code.

Table 81: Resource data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Value	Unit	Grade	Code Resource Type
Finland	None	7	Mt	5.9% Mn	Historic resources estimate
Spain	None	74, 000	t	-	Demonstrated
Portugal	None	4,8	Mt	9.38 % Mn	Historic resources estimate
Romania	UNFC	1	Mt	-	333
Hungary	Russian Classification	0.25	Mt	17.8% Mn Carbonatic Manganese ore	A
Ukraine	Russian Classification	300	kt	Manganese ore	P1
Kosovo	Nat. Rep. Code	6.5	Mt	-	Historic resources estimate
Greece	USGS	0.3	Mt	35-40% Mn	Measured
Czech Republic	Nat. rep. code	138.8	Mt	11.3% Mn	Potentially economic

---

[18] www.crirsco.com

Global manganese reserves are also large and unevenly distributed. Currently the USGS estimates global reserves to be somewhere in the region of 620 million tonnes (see Table 82). However, more than half are found in South Africa (32 %) and the Ukraine (23 %) (USGS, 2016). Reserve data for some countries in Europe are available in the Minerals4EU website (see Table 82) but cannot be summed as they are partial and they do not use the same reporting code.

Table 82: Global reserves of manganese in year 2016 (Data from USGS, 2016)

Country	Manganese Reserves (tonnes)	Percentage of total (%)
South Africa	200,000,000	32
Ukraine	140,000,000	23
Australia	91,000,000	15
India	52,000,000	8
Brazil	50,000,000	8
China	44,000,000	7
Gabon	22,000,000	4
Ghana	13,000,000	2
Kazakhstan	5,000,000	<1
Mexico	5,000,000	<1
World total (rounded)	*620,000,000*	*100*

Table 83: Reserve data for Europe compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Value	Unit	Grade	Code Reserve Type
Ukraine	Russian Classification	283,230	kt	Manganese ore	A
Romania	UNFC	1	Mt	-	111
Kosovo	Nat. Rep. Code	790,836	t	22.21% Mn	A+B

17.2.1.5 World mine production

Global manganese extraction is geographically widespread, currently taking place in 27 countries. Average annual production of manganese is almost 50 million tonnes (BGS, 2016). However, production is concentrated with more than 60 % of global supply coming from just three countries, namely China (29 %), South Africa (20 %) and Australia (14 %). Notable mine production also occurs in Gabon (7 %), Brazil (6 %), Kazakhstan (6 %) and India (5 %) (Figure 140). Primary manganese supply in Europe comes from Bulgaria, Hungary and Romania, although jointly this accounts for less than 1 % of total global supply (BGS, 2016).

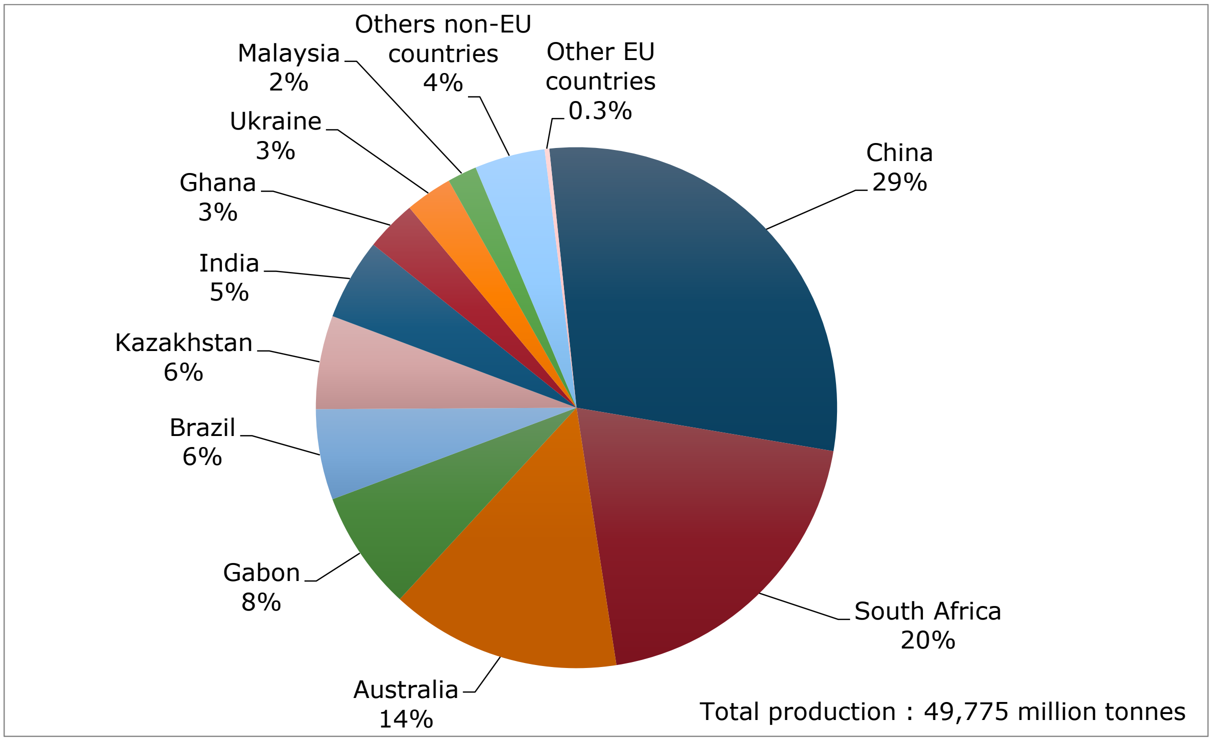


Figure 140: Global mine production of manganese, average 2010–2014 (Data from BGS World Mineral Statistics database (BGS, 2016))

17.2.2 Supply from secondary materials

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 negligible, with estimates by the Ad hoc Working Group on defining Critical Raw Materials placed at about 12 % (EC, 2014). Manganese can also be recovered from slag generated during the production of steel (USGS, 2016).

17.2.3 EU trade

Mine production of manganese in the EU is relatively small (about 1 % of the global total) and thus the EU is heavily reliant on imports for its supply, with an average net import figure of almost 1.4 million tonnes during the period 2010–2014 (see Figure 141). Manganese is traded in a number of forms (e.g. ores and concentrates, ferromanganese, ferro-silico-manganese and manganese oxide); of these forms ores and concentrates, and ferromanganese are volumetrically the most significant for the EU.

Almost 90 % of all EU imports of manganese ores and concentrates come from just three countries, namely South Africa (32 %), Brazil (31 %) and Gabon (26 %) (Figure 142).

Imports to the EU have fluctuated slightly during the period 2010–2014, with notable decreases between 2010 and 2012, and 2013 and 2014 (Figure 141). These fluctuations appear to be related to a significant reduction in export volumes from Brazil during these periods. In 2011, Brazilian exports were almost 1.2 million tonnes lower than in 2010, and in 2014 they were almost 2.3 million tonnes lower than in 2013. However, during the same period imports from South Africa and Gabon have risen slightly. During the period 2010–2014 the EU exported, on average, about 93,000 tonnes of manganese ores and concentrates per annum, the majority of which came from Bulgaria (93 %). Romania was the only other exporting country during this period, accounting for the remaining 7 % (ca. 7,000 tonnes).

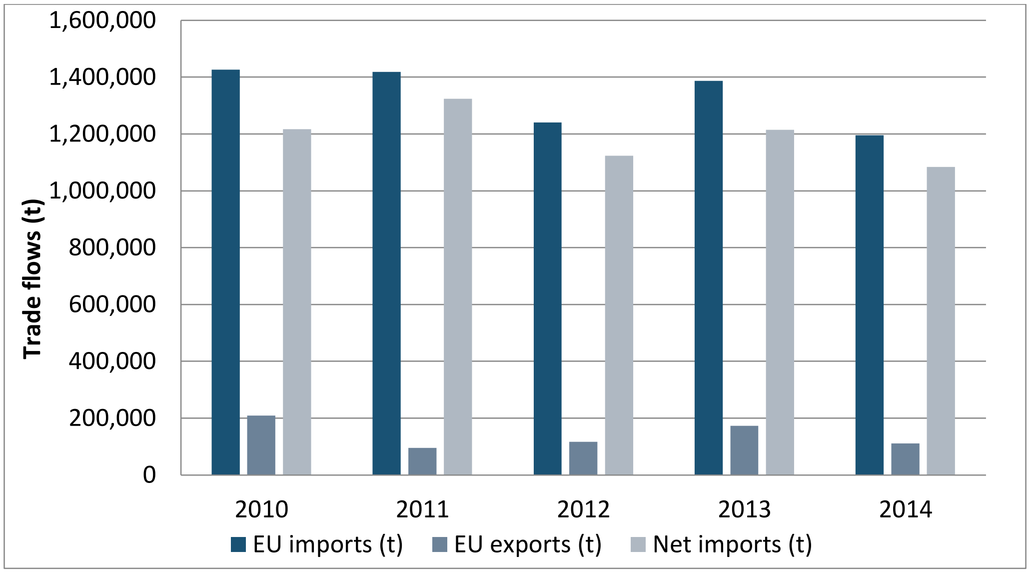


Figure 141: EU trade flows for manganese ores and concentrates. Data for years 2010 to 2014. (Data from Eurostat COMEXT database (Eurostat, 2016a))

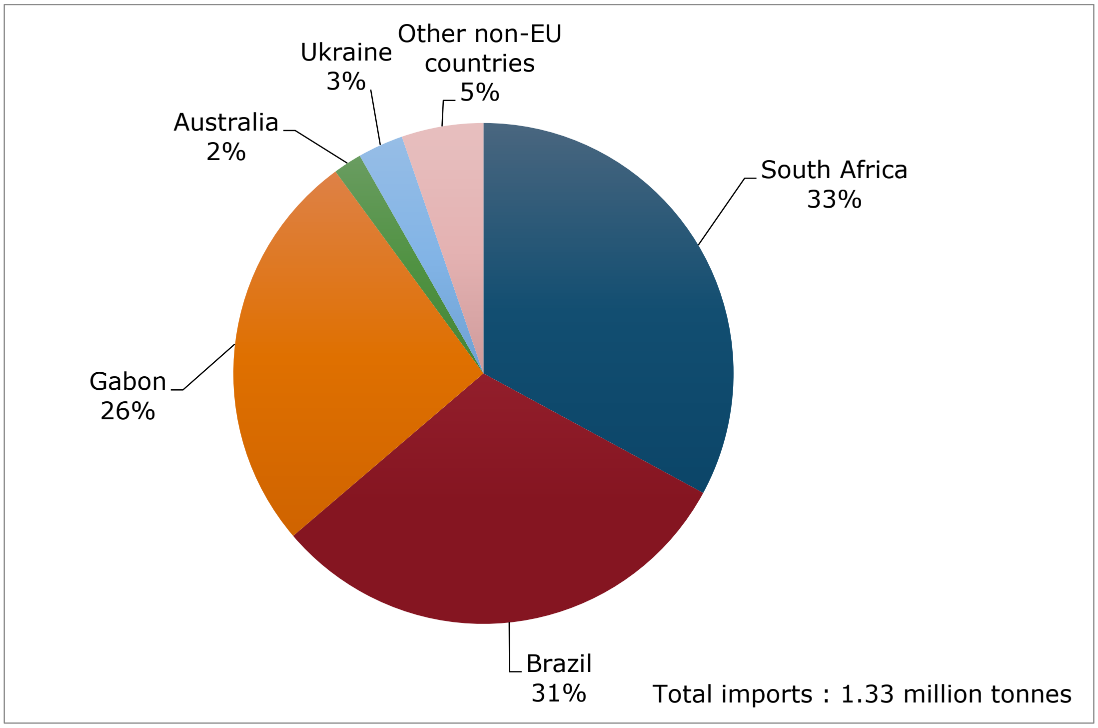


Figure 142: EU imports of manganese ores and concentrates, average 2010-2014. (Data from Eurostat COMEXT database)

Ferromanganese imports into the EU were similar in volume to primary ores and concentrates, with an average 1.2 million tonnes per year being imported during the period 2010–2014. A significant amount (ca. 51 %) of EU imports of ferromanganese and ferro-silico-manganese also come from just three countries, South Africa (21 %), India (19 %), and Ukraine (11 %).

17.2.4 EU supply chain

Manganese ores and concentrates are mined in only three EU countries, namely Bulgaria, Romania and Hungary, although on a global scale primary EU production is small at just under 145,000 tonnes. Imports of manganese ores and concentrates into the EU are an order of magnitude higher than EU domestic production. Based on averages during the period 2010–2014 over 1.3 million tonnes per year of manganese ores and concentrates were imported into the EU, the majority of which goes to France and Spain, with small amounts also going to Italy, Greece, Netherlands and Slovakia. The Figure 143 presents the EU sourcing (domestic production + imports) for manganese ores and concentrates.

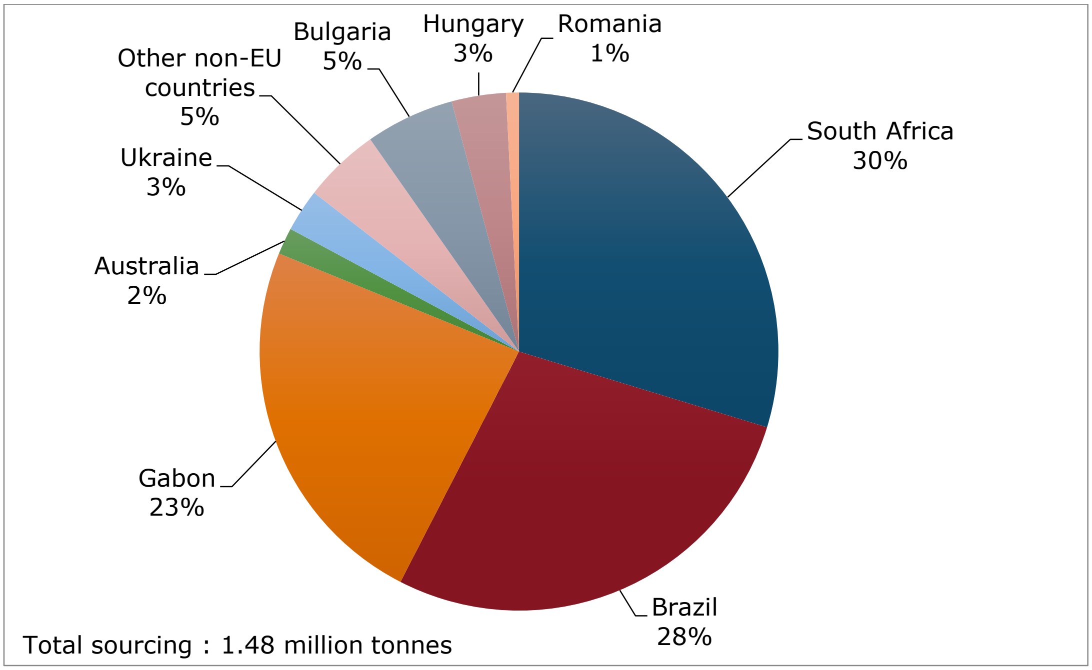


Figure 143: EU sourcing (domestic production + imports) of manganese ores and concentrates, average 2010-2014. (Data from COMEXT database Eurostat, 2016a: BGS, 2016)

There are currently no export quotas placed on manganese ores and concentrates exported to the EU from other countries; however, for the period 2010-2014 manganese exports from China, Gabon and India entering the EU are subject to an export tax of up to 25 % (OECD, 2016).

Ferromanganese imports amounted about 1.2 million tonnes per year during the period 2010–2014. The EU produces ferromanganese at plants in France, Spain and Slovakia, the production from which is consumed in the manufacture of steel in Europe (IMnI, 2015).

17.3 Demand

17.3.1 EU consumption

Consumption of manganese ores and concentrates in the EU was almost 1.4 million tonnes per year during the period 2010–2014. Less than 4 % of this (on average almost 53,000 tonnes per year) came from within the EU. The remainder was imported from outside the EU. Therefore it is hardly surprising that the estimated import reliance is as high as 89 %.

17.3.2 Applications/end-uses

Global end-uses of manganese in 2014 are shown in Figure 144.

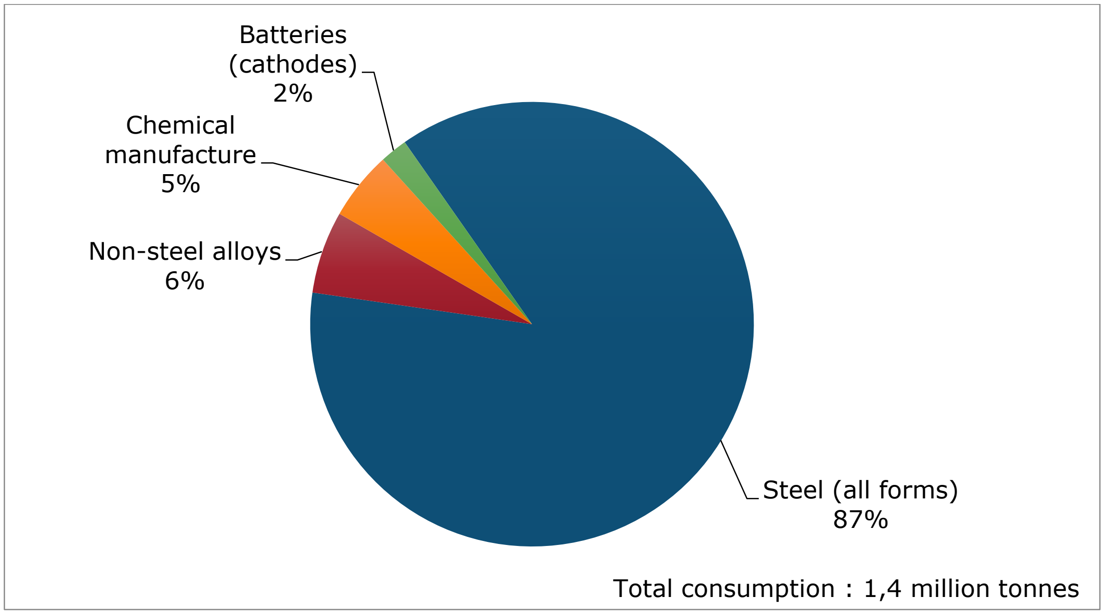


Figure 144: Global end uses of manganese. Figures for 2014. (Data from EC, 2014)

About 87 % of manganese is used in the production of steel. 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). 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). 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). 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 on a small-scale for the aerospace industry; however, they are too expensive to produce in large quantities. Adding 01.–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).

Relevant industry sectors are described using the NACE sector codes in Table 84.

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. During discharge of a battery hydrogen is generated at the electrodes, if this hydrogen is allowed to accumulate in the battery cell it can seriously impede energy generation. The role of manganese dioxide in this instance is to oxidise the hydrogen to form water, which improves battery function. 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 used as an agricultural fungicide. Manganese oxides and salts are also used as catalysts, pigments and in the purification of uranium ores to produce U_3O_8 (or 'yellow cake' as it is known) (IMnI, 2016).

Table 84: Manganese applications, 2-digit and associated 4-digit NACE sectors, and the value added of those sectors (Eurostat, 2016c)

Application	2-digit NACE sector	Value added of NACE 2 sector (€ millions)	4-digit NACE sector
Steel (construction)	C25 - Manufacture of fabricated metal products, except machinery and equipment	159,513	C2511 Manufacture of metal structures and parts of structures.
Steel (automotive)	C29 - Manufacture of motor vehicles, trailers and semi-trailers	158,081	C2910 - Manufacture of motor vehicles.
Steel (mechanical engineering)	C24 - Manufacture of basic metals	159,513	C2452 - Casting of steel.
Steel (structural steelworks)	C25 - Manufacture of fabricated metal products, except machinery and equipment	159,513	C2511 Manufacture of metal structures and parts of structures.
Steel (tubes)	C25 - Manufacture of fabricated metal products, except machinery and equipment	159,513	C2599 - Manufacture of other fabricated metal products n.e.c.
Steel (metalware)	C25 - Manufacture of fabricated metal products, except machinery and equipment	159,513	C2599 - Manufacture of other fabricated metal products n.e.c.
Non-steel alloys	C25 - Manufacture of fabricated metal products, except machinery and equipment	159,513	C2592 - Manufacture of light metal packaging.
Chemical manufacture	C20 - Manufacture of chemicals and chemical products	110,000	C2059 - Manufacture of other chemical products n.e.c.
Steel (domestic appliances)	C27 - Manufacture of electrical equipment	84,609	C2751 - Manufacture of electric domestic appliances.
Batteries (cathodes)	C27 - Manufacture of electrical equipment	84,609	C2720 - Manufacture of batteries and accumulators.

17.3.3 Prices

According to data on the InfoMine website (2016) global manganese prices have been declining over the last five years from a high of almost US$3,500 per tonne in 2012 to just under US$2,000 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 part 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; as it cost 2,493 US$/t in average on the period 2011-2015 but only 1,779US$/t in average on the period December 2015 - November 2016, i.e. a price drop of 28.6%.

The same trend can be observed for ferro-manganese (78% Mn), with a price drop of 17.3% since 2015 from 828.6 €/t in average on the period 2011-2015 but only 685 €/t in average on the period December 2015 - November 2016.

17.4 Substitution

There are currently no suitable substitutes for manganese in its major applications (i.e. iron and steel) (USGS, 2016).

17.4.1 Discussion of the criticality assessment

17.5 Data sources

Production data for manganese ores and concentrates was taken from the British Geological Survey's World Mineral Statistics dataset (BGS, 2016). Trade data were taken from the Eurostat COMEXT online database (Eurostat, 2016) using the Combined Nomenclature (CN) code 2602 0000 (manganese ores and concentrates, including. ferruginous manganese ores and concentrates with a manganese content of >=20% calculated on dry weight). Data were averaged over the five-year period 2010–2014 inclusive. Other data sources have been used in the assessment and are listed in section 17.7.

17.5.1 Calculation of economic importance and supply risk indicators

The calculation of Economic Importance (EI) was based on the 2-digit NACE sectors shown in Table 84. For information about the application share of each sector see section on applications and end-uses. Figures for value added were the most recently available at the time of the assessment (i.e. 2013) and are expressed in thousands of Euros.

The Supply Risk (SR) was calculated at the ores and concentrates stage of the life cycle using both the global HHI and EU-28 HHI calculation as outlined in the methodology.

17.5.2 Comparison with previous EU criticality 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 85.

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. 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.

Table 85: Economic importance and supply risk results for manganese in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017.

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Manganese	9.80	0.45		7.78	0.43		6.1	0.9

17.6 Other considerations

Due to the close association of manganese with steel production 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 86).

Table 86: Qualitative forecast of supply and demand of manganese

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
Manganese		x	+	+	+	+	+	+

17.7 Data sources

17.7.1 Data sources used in the factsheet

BGS (2016). World Mineral Production 2010-2014 [online]. Keyworth, Nottingham British Geological Survey, Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.html

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/

Eurostat (2016)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

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/

Minerals4EU (2014). European Minerals Yearbook [online]. Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

OECD Export Restriction database [online]. Available at: http://www.oecd.org/tad/benefitlib/export-restrictions-raw-materials.htm

Pohl, W.L. (2011). Economic Geology, Principals and Practice. Oxford: Wiley-Blackwell, 678.

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.

Stansbie, J.H. (1908). Iron and Steel. New York: Van Nostrand, 408.

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

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

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.

17.7.2 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

Eurostat COMEXT database [online]. Available at: http://ec.europa.eu/eurostat/data/database

OECD Export Restriction database [online]. Available at: http://www.oecd.org/tad/benefitlib/export-restrictions-raw-materials.htm

17.8 Acknowledgments

This Factsheet was prepared by the British Geological Survey (BGS). The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this Factsheet.

18. MOLYBDENUM

Key facts and figures

Material name and Element symbol	Molybdenum, Mo	World/EU production (tonnes)[1]	271,489/ 0
Parent group	n/a	EU import reliance[1]	100%
Life cycle stage assessed	Extraction	Substitution index for supply risk [SI (SR)][1]	0.98
Economic importance (EI) (2017)	5.2	Substitution Index for economic importance [SI(EI)][1]	0.96
Supply risk (SR) (2017)	0.9	End of life recycling input rate (EOL-RIR)	30%
Abiotic or biotic	Abiotic	Major end uses in the EU[1]	Metal products (28%), Base metal and alloys (15%), Automotive (14%), High strength parts (12%)
Main product, co-product or by-product	Main product, by-product of Cu	Major world producers[1]	China: 42%, United States: 23%, Chile: 15%
Criticality results	2011	2014	2017
	Not critical	Not critical	Not critical

[1] average for 2010-2014, unless otherwise stated;

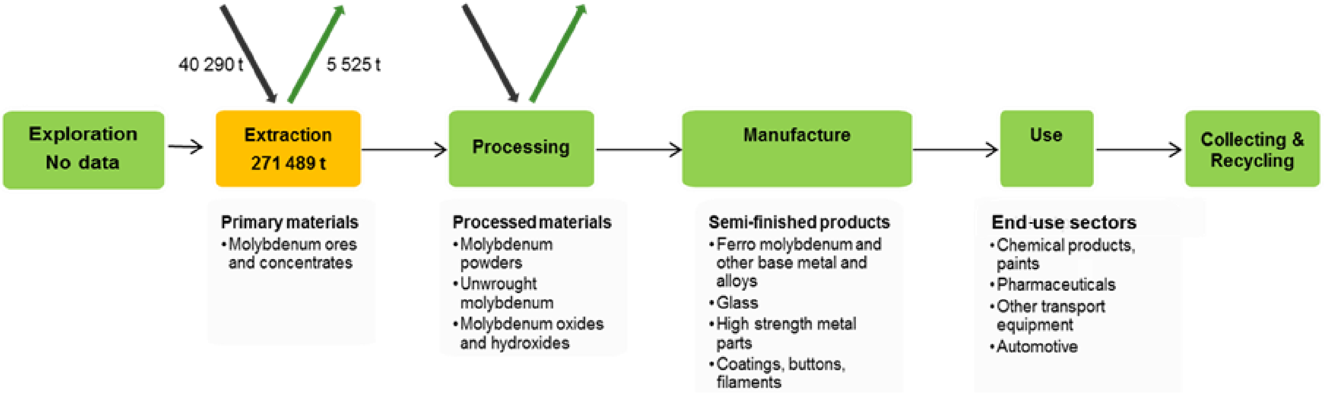


Figure 145: Simplified value chain for molybdenum

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU.

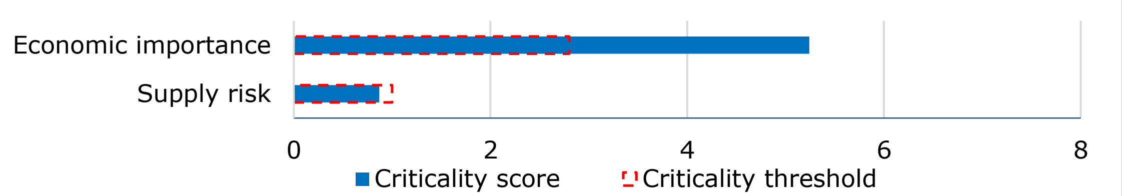


Figure 146: Economic importance and supply risk scores for molybdenum

18.1 Introduction

Molybdenum is a chemical element with symbol Mo and atomic number 42. It readily forms hard, stable carbides in alloys, and for this reason most of world production of the element (about 80%) is used in steel alloys, including high-strength alloys and superalloys. Molybdenum is an essential trace element in agriculture. Some lands are barren for lack of this element in the soil.

Molybdenum occurs in the earth's crust most commonly as the mineral molybdenite (MoS_2). Small quantities are also found in other metals such as wulfenite ($PbMoO_4$), powellite ($CaMoO_4$) and ferrimolybdite ($Fe_2Mo_3O_{12}$). Molybdenite is the primary source of molybdenum. A significant rise in demand for molybdenum would make additional sources necessary, which is unlikely given present technical constraints (IMOA, 2016b).

The metal is silvery white, very hard transition metal, but is softer and more ductile than tungsten. It appears dull grey when produced as a powder. Swedish Chemist Carl Wilhelm Scheele discovered it in 1778. It was often confused with graphite and lead ore. It has a high elastic modulus, and only tungsten and tantalum, of the more readily available metals, have higher melting points. Molybdenum has one of the highest melting points of all pure elements (Lenntech, 2016). The typically metallic properties of molybdenum depend to a large degree on the production method used and on its subsequent treatment (Sebenik et al., 2000).

18.2 Supply

18.2.1 Supply from primary materials

18.2.1.1 Geological occurrence

The presence of molybdenum in the earth's crust is rare, with 1.1 parts per million upper crustal abundance (Rudnick & Gao, 2003). Compared to metals such as vanadium or nickel, the abundance is estimated to be 160 and 80 times lower respectively (Roskill, 2012). At present there are basically three generic types of molybdenum deposits with economic importance. Firstly, porphyry deposits in which metallic sulphides are disseminated throughout large volumes of altered and fractured rock. Secondly, contact-metamorphic zones and bodies in which silicated limestone is adjacent to intrusive granites (skarn deposits); and thirdly, quartz veins. However, average molybdenum concentration is very low. In primary porphyry deposits, it ranges from 0.05% to 0.25% (Sebenik et al., 2000).

According to the Minerals4EU website (Minerals4EU, 2014), exploration activities take place in Greenland, Portugal, Ireland, Sweden, Poland, Slovakia and Ukraine, but with no specific information for molybdenum, aggregated with other raw materials.

18.2.1.2 Processing

Molybdenite is the chief mineral ore. Roughly half of all molybdenite is obtained as a by-product of copper production, and to a much lesser extent, tungsten production. Depending upon the minerals contained in the ore body, mines can be grouped into primary mines, where the recovery of MoS_2 is the sole objective, or by-product mines where the recovery of copper-bearing ores is the primary objective and MoS_2 provides additional economic value (USGS, 2015). The resulting concentration of molybdenum in concentrates after processing is between 45 and 55%; in the criticality assessment a concentration of 60% is assumed for traded (roasted) ores and concentrates, following estimates in (Nassar et al., 2015).

18.2.1.3 Resources and reserves

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[19], 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.

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 molybdenum, 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 at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU, 2015).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.

World resources are adequate to satisfy projected demands in the foreseeable future (USGS, 2015). The large-scale mining, milling, and processing facilities now required for economic production of molybdenum compounds are only justified where large resources exist. The largest European deposit of molybdenum is located in Norway (fields named Knaben and Nordli in particular) (NGU, 2014), though there is no documented production so far. Resource data for some countries in Europe are available in the Minerals4EU website (see Table 87) (Minerals4EU, 2014) but cannot be summed as they are partial and they do not use the same reporting code.

Table 87: Resource data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

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	168	Mt	0.006%	Indicated
	JORC	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

Molybdenum occurs widely in all continents but usually in small quantities, and global reserves of molybdenum are estimated at 11 million tonnes (see Table 88). Reserve data

---

[19] www.crirsco.com

for some countries in Europe are available in the Minerals4EU website (see Table 89) but cannot be summed as they are partial and they do not use the same reporting code.

Table 88: Global reserves of molybdenum in 2015 (Data from USGS, 2015)

Country	Molybdenum Reserves (tonnes)	Percentage of total (%)
China	4,300,000	40
USA	2,700,000	25
Chile	1,800,000	17
Peru	450,000	4
Canada	260,000	2
Russia	250,000	2
Australia	190,000	2
Mongolia	160,000	1
Armenia	150,000	1
Kazakhstan	130,000	1
Mexico	130,000	1
Kyrgyzstan	100,000	1
Turkey	100,000	1
Uzbekistan	60,000	1
Iran	43,000	0
World total (rounded)	*11,000,000*	*100*

Table 89: Reserve data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Quantity	Unit	Grade	Code Reserve Type
Sweden	FRB-standard	499	Mt	27 g/t	Proven
Turkey	None	0.1	Mt	-	Historic Reserve Estimate

18.2.1.4 World mine production

The global production of molybdenum between 2010 and 2014 was annually 271,489 tonnes on average. China, the United States and Chile are the main producers of molybdenum (see Figure 147).

The share of production as main or by-product varies between each way source country, where particularly Chile and China extract molybdenum from copper.

According to BGS (2016), there is no molybdenum production in the EU. As a consequence the EU molybdenum consumption is entirely covered by imports.

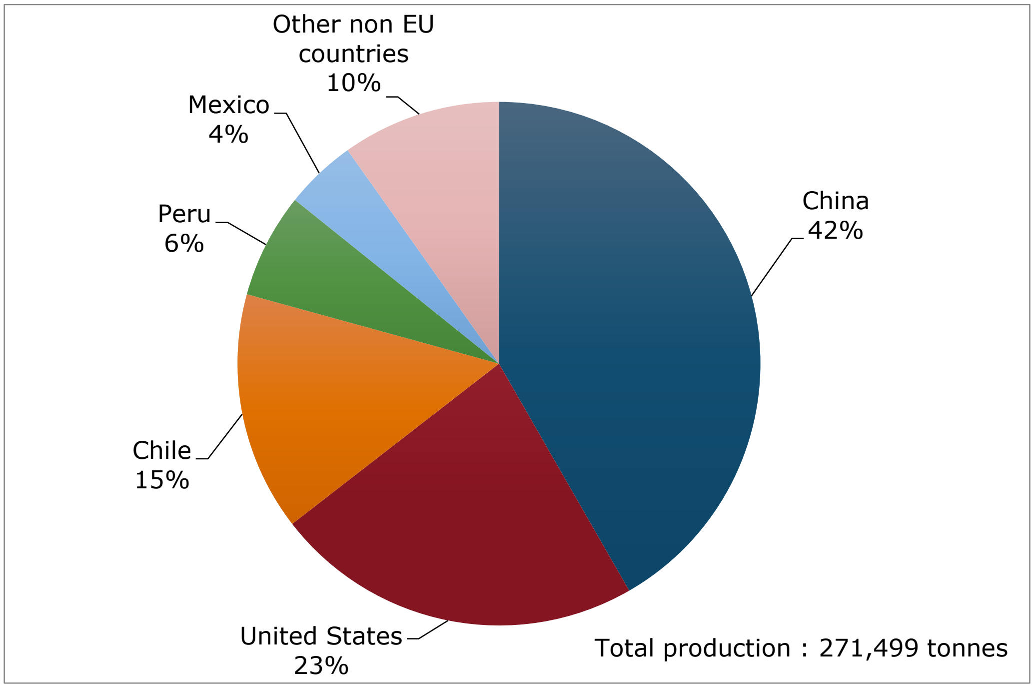


Figure 147: Global mine production of molybdenum, average 2010–2014 (BGS World Mineral Statistics database, 2016)

18.2.2 Supply from secondary materials

Molybdenum is not recovered from scrap steel, but because of the significant recycling of steel alloys, a substantial percentage of molybdenum content is reutilized. Molybdenum-containing stainless steel scrap, e.g. type 316, tool steel scrap and nickel-based alloy scrap, etc. is economically segregated to reuse molybdenum. Molybdenum is still only to a limited extend recovered from scrap steel, but because of the significant recycling of steel alloys, some molybdenum content is reutilized. The amount of molybdenum recycled as part of new and old steel and other scrap is estimated up to 30% of the apparent supply of molybdenum (USGS, 2015).

Segregation of molybdenum containing scrap (end of life and process scrap) increased around 2004 and 2005, and the recycling input rate has remained higher since. Due to the growth of molybdenum use, scrap availability and therefore the secondary molybdenum share has not increased even though segregation may have improved. The improved collection of molybdenum containing scrap may not affect only equipment (i.e. old scrap) but also scrap directly collected from production processes (even though this is still limited). Without the improved collection of "new" scrap, the amount of total scrap would probably have decreased in recent years (IMOA, 2016b).

18.2.3 EU trade

Around 95% of the EU supply comes from four countries: United States, Chile, Peru and Canada (Figure 148). The trend of imports of molybdenum seems to be downward between 2010 and 2014, but there was no major shift in the supply (in terms of origins or volume) of molybdenum to the EU economy (see Figure 149).

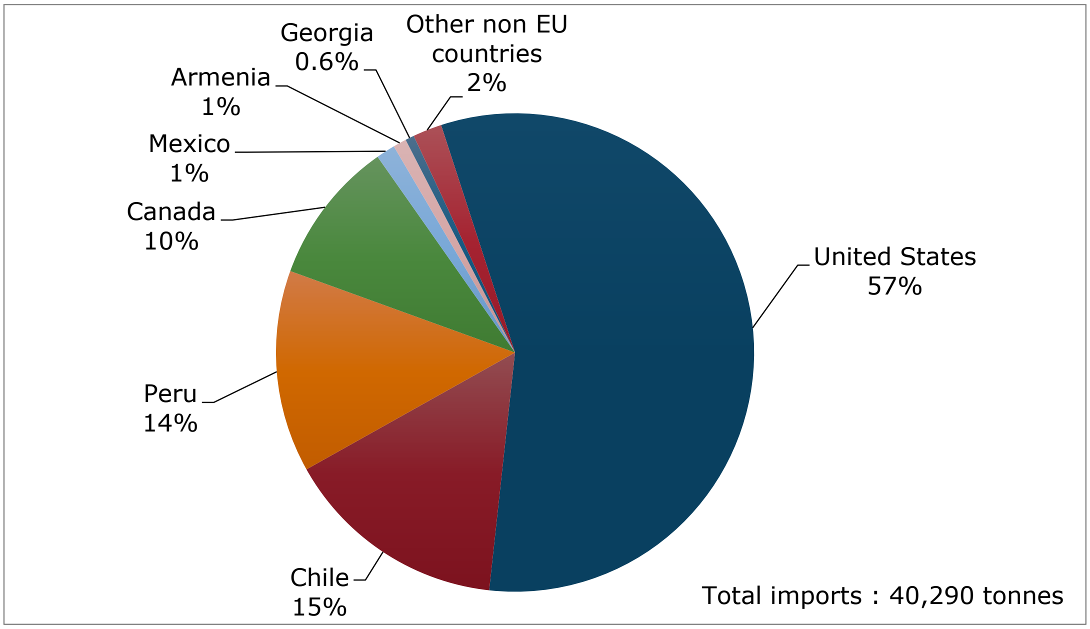


Figure 148: EU imports of molybdenum, average 2010-2014. (Data from Eurostat Comext 2016)

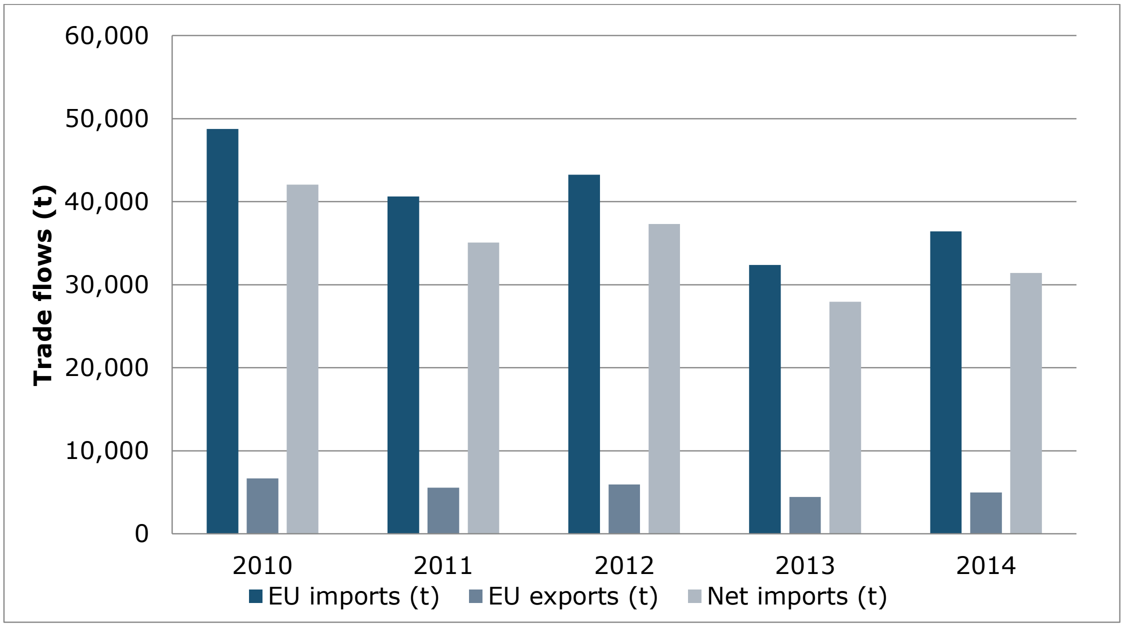


Figure 149: EU trade flows for molybdenum. (Data from Eurostat Comext 2016)

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.

18.2.4 EU supply chain

The import reliance of the EU stands at 100% for molybdenum ores and concentrates.

The supply chain in the EU starts right after the stage of ores and concentrates, with a few chemical and base metal companies processing the (quasi) raw material. Furthermore, Europe has a strong global import trading position on molybdenum given the presence of trading companies and a transport hub represented by the port of Rotterdam (Cox, 2016).

The EU steel industry is one of the major users of molybdenum with an estimated annual consumption for the production of stainless steel grades only at more than 20kt. Ferro-molybdenum is produced on a few number of locations in the EU, for instance in the United Kingdom. The location of copper refineries, for instance in Finland and Germany, manufacture metal products with a significant amount of molybdenum content.

As for trade restrictions in place for the 2010-2014 period, Chile, Peru, Argentina, Russia and China have, as supplying countries to the EU, a relatively small export tariff imposed of around 10-15% for ores and concentrates (OECD, 2016). According to this OECD's inventory on export restrictions, molybdenum waste and scrap is also still subject to export taxes in Russia (6.5%), to a system of non-automatic export licensing in Algeria and South Africa.

18.3 Demand

18.3.1 EU consumption

Apparent consumption of molybdenum ores and concentrates in the EU amounts to 53,000 tonnes per year on average during 2010–2014. If ferro-molybdenum are taken into account, the consumption would be around 61,000 tonnes (IMOA, 2016b).

18.3.2 Applications / End uses

The properties of molybdenum result in a wide range of applications for the material (Figure 150).

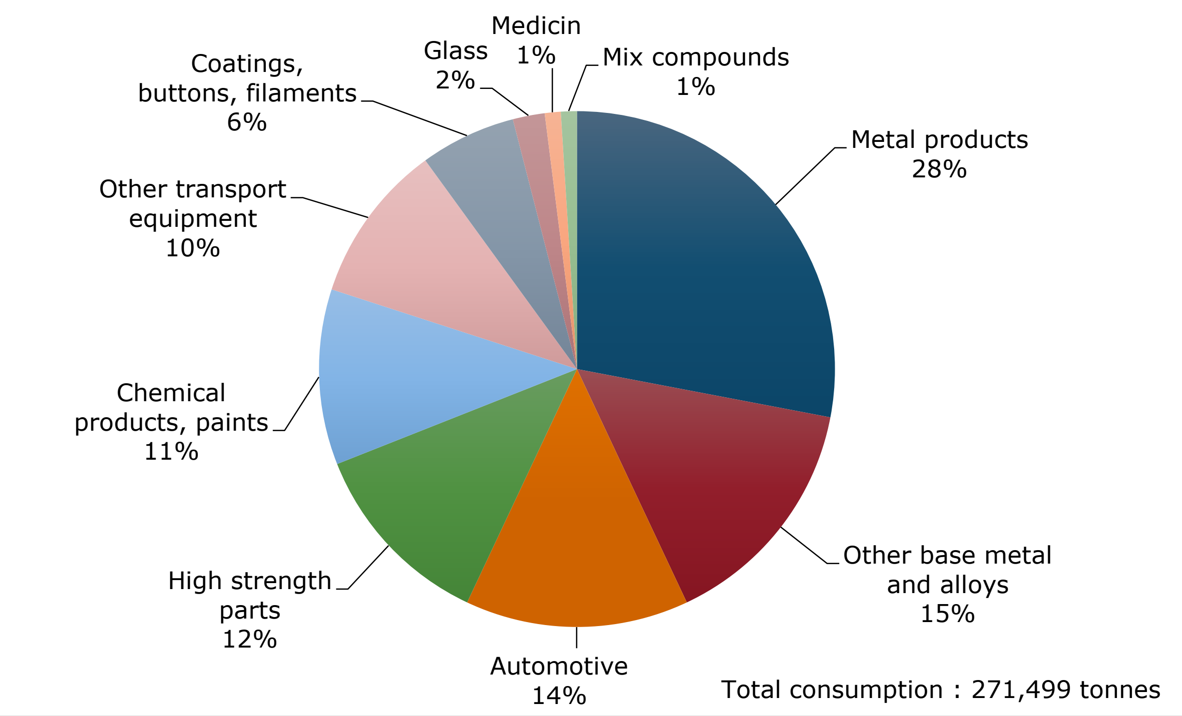


Figure 150: Global end uses of molybdenum. Average figures for 2010-2014. (Data from IMOA 2016a)

18.3.2.1 Molybdenum grade stainless steels

The generic term “Stainless Steel” covers a large group of iron-base alloys that contain chromium. The term “stainless” implies a resistance to staining or rusting in air. Stainless steels contain at least 10.5% chromium, which promotes formation of a thin, chromium-enriched surface oxide. Without this minimum amount of chromium, iron-base alloys or steels corrode in moist air, forming the familiar red rust. While chromium content determines whether or not a steel is "stainless," molybdenum improves the corrosion resistance of all stainless steels. It has a particularly strong positive effect on pitting and crevice corrosion resistance in chloride-containing solutions.

Stainless steels are grouped in several different types defined by the steel's microstructure. Austenitic stainless steels account for almost 75% of all stainless steels used in the world; ferritic, about 25%; duplex (mixed austenite and ferrite), about 1%; and martensitic about 1%. Composition is the primary determinant of stainless steel microstructure.

18.3.2.2 Molybdenum grade Alloy Steels & Irons

Molybdenum is used efficiently and economically in alloy steel & iron to:

- improve hardenability
- reduce temper embrittlement
- resist hydrogen attack & sulphide stress cracking
- increase elevated temperature strength
- improve weldability, especially in high strength low alloy steels (HSLA)
- In the present section the focus is on grades and properties of Mo containing alloy steel and iron. End uses cover the whole world of engineered products for:
- Automotive, shipbuilding, aircraft and aerospace
- Drilling, mining, processing
- Energy generation, including boilers, steam turbines and electricity generators
- Vessels, tanks, heat exchangers
- Chemical & Petrochemical processing
- Offshore; Oil Country Tubular Goods (OCTG)

In most cases molybdenum is needed to meet the high end of the application properties, which is accomplished with comparatively small molybdenum additions. In fact, with the exception of High Speed Steel and Maraging Steel the Mo content often ranges between 0.2 and 0.5% and rarely exceeds 1%.

18.3.2.3 Molybdenum grade superalloys

Molybdenum is a very important alloying element in high performance nickel-based alloys. These alloys fall into two basic classes:

- Corrosion-resistant alloys
- High temperature alloys. The high temperature alloys can be further subdivided into solid-solution strengthened and age-hardenable alloys.

In corrosion resistant nickel-based alloys, molybdenum imparts resistance to non-oxidizing environments such as the halide acids (HCl, HBr and HF) and sulphuric acid, for example. The alloy most resistant to these environments contains 28.5% Mo. Molybdenum also acts in conjunction with chromium to provide resistance to localized corrosion attack such as pitting and crevice corrosion.

The corrosion-resistant nickel-based alloys find extensive use in the chemical processing, pharmaceutical, oil & gas, petrochemical and pollution control industries in which highly corrosive environments are very common.

In the case of high temperature alloys, additions of molybdenum are often used to impart resistance to damage caused by high temperature creep. For the solid-solution strengthened alloys, advantage is taken of the fact that molybdenum diffuses very slowly in nickel. Since high temperature creep is generally diffusion controlled, additions of molybdenum are quite effective in reducing creep rates. In the age-hardenable alloys, molybdenum additions improve the stability of the precipitates.

Alloys which contain large amounts of molybdenum, find use as seal rings in gas turbine engines in order to exploit this effect. The high temperature alloys are extensively used in gas turbine engines for components such as turbine disks, combustors, transition ducts, turbine cases, seal rings, afterburners parts, and thrust reversers. They are also used in applications involving industrial heating, heat treating, mineral processing, heat exchangers, and waste incineration.

18.3.2.4 Molybdenum metal & alloys

Molybdenum metal is usually produced by powder metallurgy techniques in which Mo powder is hydrostratically compacted and sintered at about 2,100°C.

Molybdenum alloys have excellent strength and mechanical stability at high temperatures (up to 1,900°C). Their high ductility and toughness provide a greater tolerance for imperfections and brittle fracture than ceramics.

The unique properties of molybdenum alloys are utilised in many applications:

- High temperature heating elements, radiation shields, extrusions, forging dies, etc.
- Rotating X-ray anodes used in clinical diagnostics;
- Glass melting furnace electrodes and components that are resistant to molten glass;
- Heat sinks with thermal expansivity matching silicon for semiconductor chip mounts;
- Sputtered layers, only ångstroms (10^{-7} mm) thick, for gates and interconnects on integrated circuit chips;
- Sprayed coatings on automotive piston rings and machine components to reduce friction and improve wear.

For specialised applications, Mo is alloyed with many other metals:

- Mo-tungsten alloys are noted for exceptional resistance to molten zinc;
- Mo is clad with copper to provide low expansion and high conductivity electronic circuit boards;
- Mo-25% rhenium alloys are used for rocket engine components and liquid metal heat exchangers which must be ductile at room temperature.

18.3.2.5 Molybdenum uses in chemicals

Molybdenum is a transition metal in Group 6 of the Periodic Table between chromium and tungsten. Although molybdenum is sometimes described as a ‘heavy metal’ its properties are very different from those of the typical heavy metals, mercury, thallium and lead. It is much less toxic than these and other heavy metals. Its low toxicity makes molybdenum an attractive substitute for more toxic materials.

Molybdenum-based technical chemicals exploit the versatility of molybdenum chemistry in its various oxidation states. Uses include catalysts, pigments, corrosion inhibitors, smoke suppressants, lubricants and micronutrients for agriculture.

Molybdenum is also an essential trace nutrient element for plant, animal and human life.

Relevant industry sectors are described using the NACE sector codes in Table 90.

Table 90: Molybdenum applications, 2-digit NACE sectors, 4-digit NACE sectors and value added per sector (Data from the Eurostat database - Eurostat, 2016c)

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (millions €)
Chemical products, paints	C20 - Manufacture of chemicals and chemical products	20.12 Manufacture of dyes and pigments	110,000.0
Pharmaceuticals	C21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations	21.20 Manufacture of pharmaceutical preparations	79,545.0
Mix compounds	C22 - Manufacture of rubber and plastic products	22.29 Manufacture of other plastic products	82,000.0
Glass	C23 - Manufacture of other non-metallic mineral products	23.19 Manufacture and processing of other glass, including technical glassware	59,166.0
Other base metal and alloys	C24 - Manufacture of basic metals	24.45 Other non-ferrous metal production	57,000.0
Metal products	C25 - Manufacture of fabricated metal products, except machinery and equipment	25.11 Manufacture of metal structures and parts of structures	159,513.4
Coatings, buttons, filaments	C27 - Manufacture of electrical equipment	27.32 Manufacture of other electronic and electric wires and cables	84,608.9
High strength parts	C28 - Manufacture of machinery and equipment n.e.c.	28.15 Manufacture of bearings, gears, gearing and driving elements	191,000.0
Automotive	C29 - Manufacture of motor vehicles, trailers and semi-trailers	29.20 Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers	158,081.4
Other transport equipment	C30 - Manufacture of other transport equipment	30.11 Building of ships and floating structures	53,644.5

18.3.3 Prices

The price trend of molybdenum metal (not the ores and concentrates) follows the general trend of lower prices throughout the recent decades. This trend is fuelled by the productivity gains in mining operations. It is clear that molybdenum reacted on the general commodity price inflation observed in the first decade of the 21st century, following a spike in Chinese demand. The price has remained constant in recent years (after 2009), see Figure 151.

Molybdenum concentrate in the London Metal Exchange warehouse was on average 24.758,34 US$/t between 2011 and 2015 – see Figure 152 (DERA, 2016).

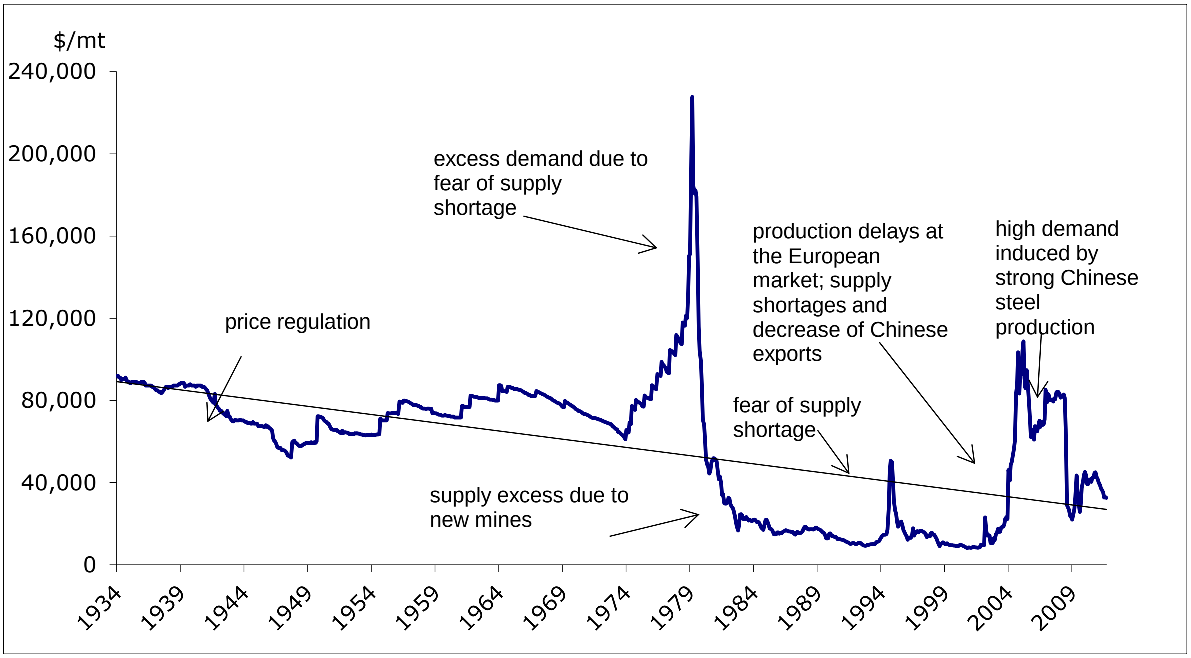


Figure 151: Development of real molybdenum prices (constant prices 2011 = 100) (DERA 2013)

Figure 152: Monthly average cash price for molybdenum in US$ per tonne (data from LME, 2017)

18.4 Substitution

'First uses' of molybdenum include stainless steels, low alloy steels, tool and high-speed steels, cast iron, nickel-based alloys and super alloys, chemicals and molybdenum metal and molybdenum-based alloys. Each first use has some potential for substitution of molybdenum with different elements, including tungsten, nickel, titanium, cobalt, niobium and chromium. Although these metals can have a similar performance, substitution usually results in some cost increase given the need to adapt the production process (EC, 2014).

Although these metals have a similar performance, substitution usually results in some cost increase given the need to adapt the production process (Tercero et al., 2015). In the domain of industrial resistance to corrosion and high-temperature environment, there is some suggestion that molybdenum can also be replaced by PGM or even glass products, but this evidence was insufficient to be used in the criticality assessment.

In high-temperature applications, molybdenum can be substituted by iron-, nickel- and cobalt-based super-alloys, ceramics, and other high-melting point metals (tungsten, tantalum, and niobium). But, while alternative super-alloys can be used up to 1,200°C, some molybdenum materials show adequate heat resistance and creep properties up to 1,800°C. In addition molybdenum materials have a higher failure tolerance and ductility than ceramics and are less expensive than tantalum and niobium.

18.5 Discussion of the criticality assessment

18.5.1 Data sources

Public data sources for molybdenum provide the coverage and quality required for this assessment. There is also relevant literature available to sketch the field of substitution and recycling to a satisfying level.

18.5.2 Calculation of Economic Importance and Supply Risk indicators

Molybdenum is now assessed at the mining stage. The variety and geological spread of manufacturing of processed molybdenum makes the refining stage less suitable for criticality assessment.

For the trade analysis, CN codes 2613 10 00 and 2613 90 00 were used for the 2017 assessment, named molybdenum ores and concentrates (both roasted and unroasted). The content of Mo in "ores and concentrates" is reported to be around 60%, noting that ore content is usually lower than 0.25%.

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 90). The value added data correspond to 2013 figures.

The supply risk was assessed on molybdenum ore using both the global HHI and the EU-28 HHI as prescribed in the revised criticality assessment methodology.

18.5.3 Comparison with previous EU assessments

The numerical values of molybdenum have been remarkably insensitive between the 1st criticality assessment in 2011 and the 2017 assessment. Given the absence of developments in trade, recycling or economic application (e.g. related to fast growing demand of certain electronics) this stable result can be explained. See Table 91.

Table 91: Economic importance and supply risk results for molybdenum in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Molybdenum	8.9	0.5		5.9	0.9		5.2	0.9

18.6 Other considerations

18.6.1 Forward look for supply and demand

A steady increase in both demand and supply is expected (Roskill, 2012) for the coming years, see Table 92. Historically molybdenum supply has kept pace with demand. There is currently significant shuttered capacity and there are abundant reserves for future supply (Outteridge, 2016). The demand increase will come from an expected increased use of super alloys. The demand will likely come from an increase in production of molybdenum metal from copper ores and concentrates, as this molybdenum material content is not yet fully extracted (Blossom, 2006).

Table 92: Qualitative forecast of supply and demand of molybdenum

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
Molybdenum		x	+	+	?	+	+	?

Molybdenum-based catalysts have a number of important applications in the petroleum and plastics industries. A major use is in the hydrodesulphurization of petroleum, petrochemicals, and coal-derived liquids. Production of ultra-low-sulphur diesel fuels is expected to more than double the amount of molybdenum used in oil refineries (Roskill Information Services Ltd., 2012). Falling importance of Diesel engines could have a very strong negative effect on Mo use for catalysts in the long term (IMOA, 2016b).

18.6.2 Environmental and regulatory issues

Molybdenum plays a vital role in the energy industry as part of high strength super alloys, a sector that now is poised to incest in capital stock especially north-western parts of Europe. Molybdenum may also become an increasingly important factor in environmental protection technology, where it is used in high-strength steels for automobiles to reduce weight and improve fuel economy and safety.

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, not molybdate.

18.6.3 Supply market organization

The market for molybdenum metal supply to Europe and the world is relatively stable is supplied by a significant number of individual businesses (NMC Resource Corp. 2014). The number of suppliers prevents oligarchical powers to influence the market. Supply to the EU is mostly from Western sources. China, whilst the largest producer and consumer of molybdenum, is relatively self-contained, with only a small net east-west trade (IMOA, 2016b).

18.7 Data sources

18.7.1 Data sources used in the factsheet

Blossom J. W.(2006) U.S. Geological Survey. Flow Studies for Recycling Metal Commodities in the United States. Available at: https://pubs.usgs.gov/circ/2004/1196am/c1196a-m_v2.pdf

DERA (2013) Rohstoff informationen. Ursachen von Preispeaks, -einbrüchen und -trends bei mineralischen Rohstoffen. Available at : http://www.deutsche-rohstoffagentur.de/DE/Gemeinsames/Produkte/Downloads/DERA_Rohstoffinformationen/rohstoffinformationen-17.pdf?__blob=publicationFile&v=2

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

Eurostat (2016)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

IMOA (2016b). Tim Outteridge, expert consultation.

Lenntech (2016) Molybdenum. Available at:
http://www.lenntech.com/periodic/elements/mo.htm

London Metal Exchange (2017). Molybdenum pricing. https://www.lme.com/metals/minor-metals/molybdenum/#tab2

Minerals4EU (2014). European Minerals Yearbook. [online] Available at:
http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

Nassar, N. T.,Graedel, T. E.,Harper, E. M. (2015). By-product metals are technologically essential but have problematic supply. Sci. Adv. 1, e1400180. Available at:
http://advances.sciencemag.org/content/1/3/e1400180

NGU (2014). Mineral resources in Norway 2013 Available at:
http://www.ngu.no/upload/publikasjoner/rapporter/2014/Mineral%20Resources2013_screen.pdf?fileId=560

NMC Resource Corp., (2014). Condensed consolidated interim financial statements: Vancouver, British Columbia, Canada, NMC Resource Corp., 23 p.

Roskill Information Services Ltd., (2012). Market outlook to 2016: London, United Kingdom, Roskill Information Services Ltd., 323 p.

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.

Sebenik, R. F., Burkin, A. R., Dorfler, R. R., Laferty, J. M., Leichtfried, G., Meyer-Grünow, H., Mitchell, P. C. H., Vukasovich, M. S., Church, D. A., Van Riper, G. G., Gilliland, J. C. and

Thielke, S. A. (2000). Molybdenum and Molybdenum Compounds. Ullmann's Encyclopedia of Industrial Chemistry.

18.7.2 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

Cox, M. (2016) representing MMTA, interview.

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

IMOA (2016a) Uses of Molybdenum. Available at: http://www.imoa.info/molybdenum-uses/molybdenum-uses.php

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

Polyak, D. E. (2015). USGS 2015 Minerals Yearbook. Available at: http://minerals.usgs.gov/minerals/pubs/commodity/molybdenum/myb1-2015-molyb.pdf

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. Available at: http://www.criticalrawmaterials.eu/wp-content/uploads/D3.3-Raw-Materials-Profiles-final-submitted-document.pdf

18.8 Acknowledgments

This Factsheet was prepared by the Netherlands Organisation for Applied Scientific Research (TNO). The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this Factsheet.

19. NATURAL CORK

Key facts and figures

Material name	Natural cork	World/EU production (tonnes)[1]	201,428/ 172,865
Parent group (where applicable)	-	EU import reliance[1]	0%
Life cycle stage assessed	Extraction	Substitution index for supply risk [SI (SR)][1]	0.89
Economic importance (EI)(2017)	1.5	Substitution Index for economic importance [SI(EI)][1]	0.89
Supply risk (SR) (2017)	1.1	End of life recycling input rate	8%
Abiotic or biotic	Biotic	Major end uses in the EU[1]	Beverages (72%), Construction material (20%), Furniture (5%)
Main product, co-product or by-product	Main product	Major world producers[1]	Portugal (50%), Spain (30%), Morocco (6%)
Criticality results	2011	2014	2017 (current)
	Not assessed	Not assessed	Not critical

[1] average for 2010-2014, unless otherwise stated;

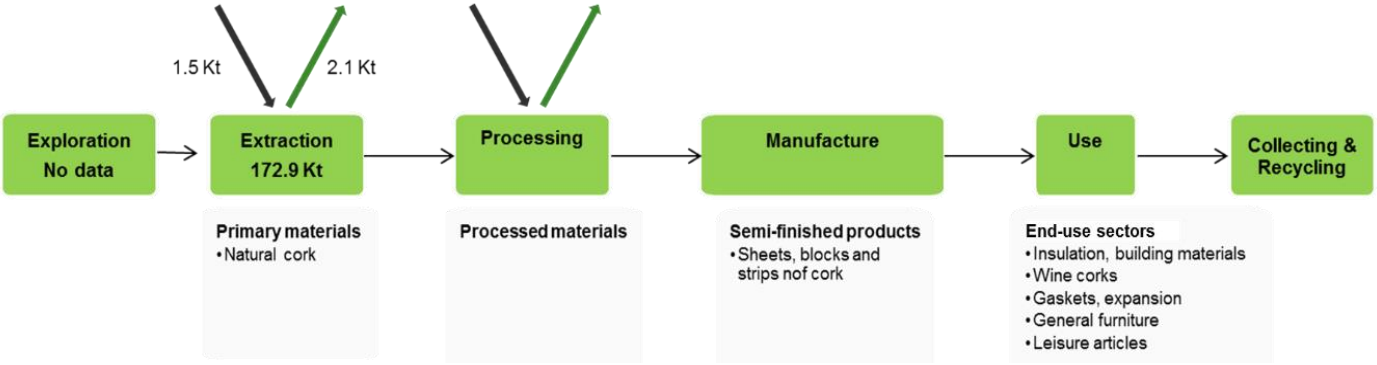


Figure 153: Simplified value chain for natural cork

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The arrows pointing towards or away the Extraction stages represent imports to or exports from of material to the EU. EU reserves are displayed in the exploration box.

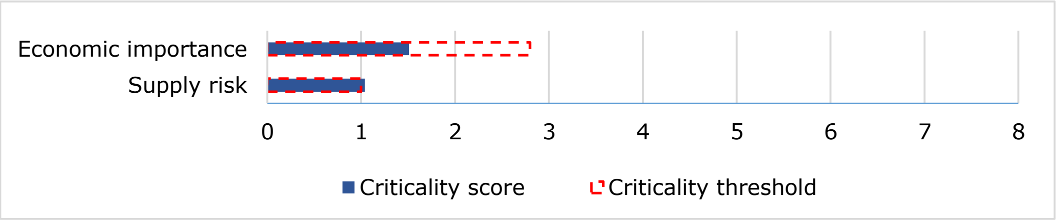


Figure 154: Economic importance and supply risk scores for natural cork

19.1 Introduction

Cork is the bark of the cork oak (*Quercus suber*). It is a 100% natural plant tissue consisting of a hive of microscopic cells containing a gas identical to air and coated primarily with suberin and lignin. It has a range of applications associated with its attributes that no technology has yet managed to emulate, match or exceed (APCOR, 2016).

19.2 Supply

19.2.1 Supply from primary materials

19.2.1.1 Geographical occurrence

The tree grows typically in summer months of the Northern hemisphere, depending on the geophysical circumstances. The coldest months should remain above -5C^{O} (Pereira, 2011). It takes each cork oak 25 years before it can be stripped for the first time and it is only from the third harvest that the cork will have reached the high standard of quality. The first two tours usually provide raw material for insulation, floors or other purposes. The trees can produce cork for over 200 years.

19.2.1.2 Processing

The cork is removed in large bulging planks, which are very light and still damp from the tree's sap. An average of 40 to 60 kg of cork is harvested from each cork oak. Before further processing, the cork material has to dry for a couple of months, after which it is boiled to kill all insects and bacteria and to make the bark more flexible.

19.2.1.3 Resources and reserves

The current land use of natural cork is shown in Table 93.

Table 93: Global reserves of natural cork in year 2016 (Data from APCOR, 2016).

Country	Natural cork Reserves (ha)	Percentage of total (%)
Portugal	736,000	29
Spain	415,000	16
Morocco	250,000	10
Other Countries	1,154,000	45
World total (rounded)	*2,550,000*	*100*

19.2.1.4 World production

The global production of natural cork between 2010 and 2014 was annually 201Kt on average. The global producers of natural cork are concentrated in the western Mediterranean area, with a dominant role for the Iberian Peninsula, see Figure 155.

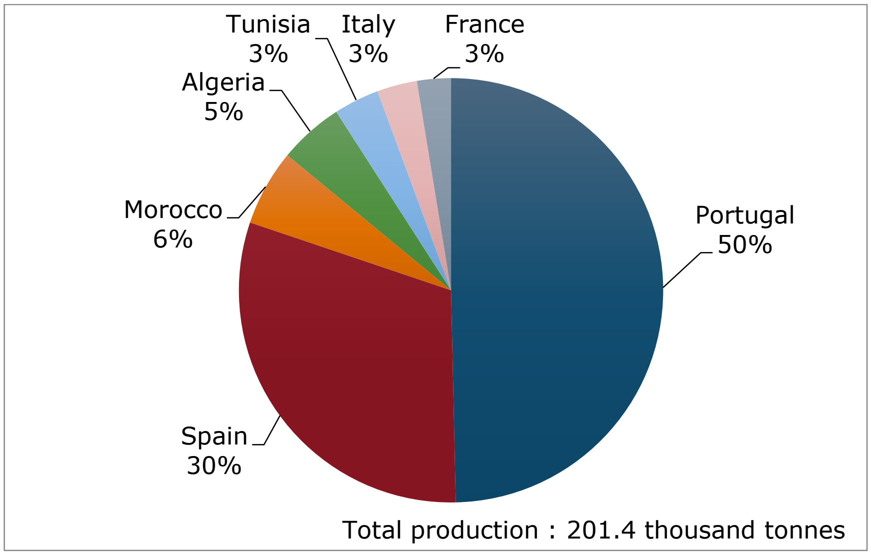


Figure 155: Global production of natural cork, average 2010–2014 (Data from APCOR 2016b)

19.2.2 Supply from secondary materials

End of life recycling input rate for natural cork is estimated to be 8%, based on (APCOR, 2015; PWC, 2008).

Especially for construction purposes can processed secondary cork replace primary cork. The limited need to replace primary cork is influencing the recycling input rate; helping to raise awareness of the importance of ecological issues in the protection of the environment seems the most important aim of collection efforts. Potential for more extensive recycling is not yet reported.

19.2.3 EU trade

The traded volumes of natural cork with countries outside the EU are shown in Figure 156. The totals of the traded volumes are very small compared to the EU production. The annual import of natural cork between 2010 and 2014 was for instance 1,060 tonnes, compared to a domestic production of 172,865 tonnes in those years.

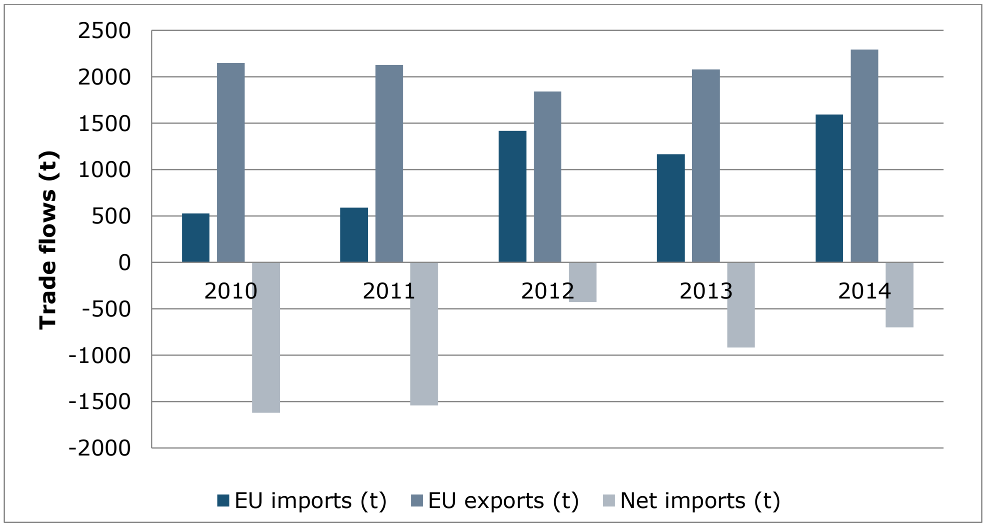


Figure 156: EU trade flows for natural cork (Data from Eurostat Comext, 2016)

The limited imports to the EU of natural cork come mostly from Morocco, see Figure 157. Other originating countries seem insignificant to EU production.

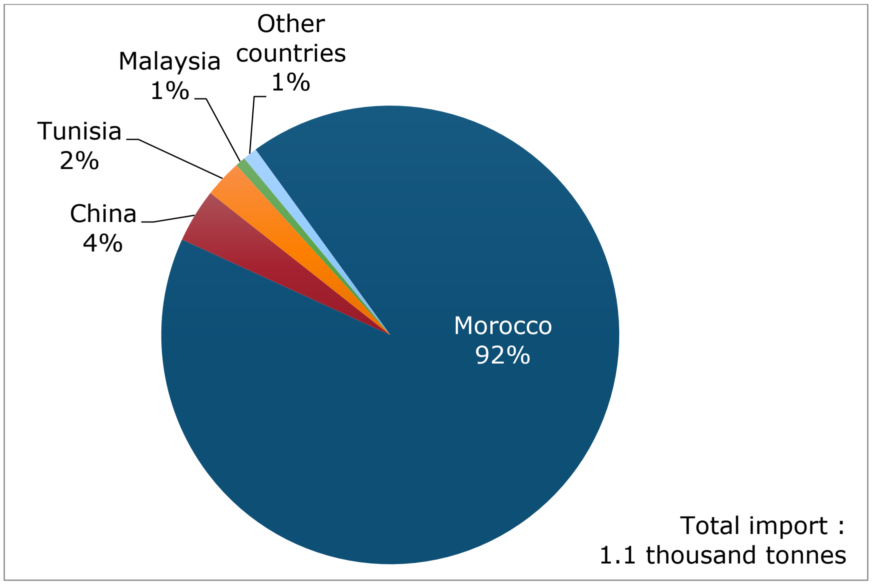


Figure 157: EU imports of natural cork, average 2010-2014 (Data from Eurostat Comext, 2016)

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.

No trade restriction were observed over the 2010-2014 period (OECD, 2014). Some EU free trade agreements exist with suppliers such as Morocco, Tunisia, Switzerland and Israel (European Commission, 2016).

19.2.4 EU supply chain

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. The NACE4-digit code “Manufacture of other products of wood; manufacture of articles of cork, straw and plaiting materials” has around 29.000 registered enterprises in 2014 and a value added of close to 3bio. EUR. (Eurostat, 2016). It is as expected strongly represented in Portugal, but also in France and Germany.

The EU relies for the supply of natural cork for 0% on its imports. No reported trade restriction for the relevant product groups (OECD, 2016).

Figure 158 shows the EU sourcing (domestic production + imports) for natural cork.

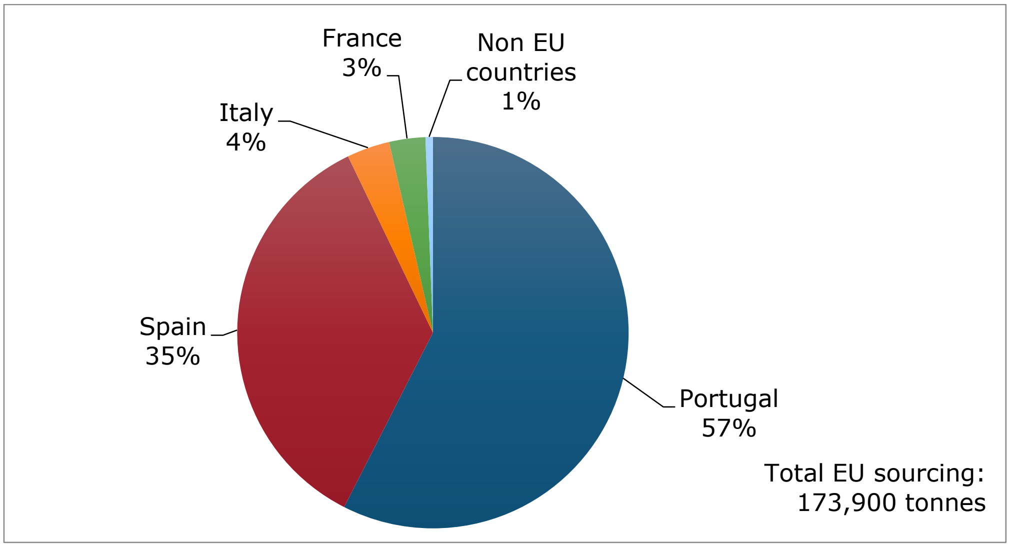


Figure 158: EU sourcing (domestic production + imports) of natural cork, average 2010-2014. (FAO, 2016)

19.3 Demand

19.3.1 EU consumption

The EU consumption of natural cork between 2010 and 201 was on average 174 kt.

19.3.2 Applications / End uses

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 temperature and sound making it suitable for insulation) and slow burning.

Currently, due to their intrinsic properties, Insulation Cork Board (ICB) is used in the construction industry as insulation, though in a limited way (Sierra-Pérez et al., 2014).

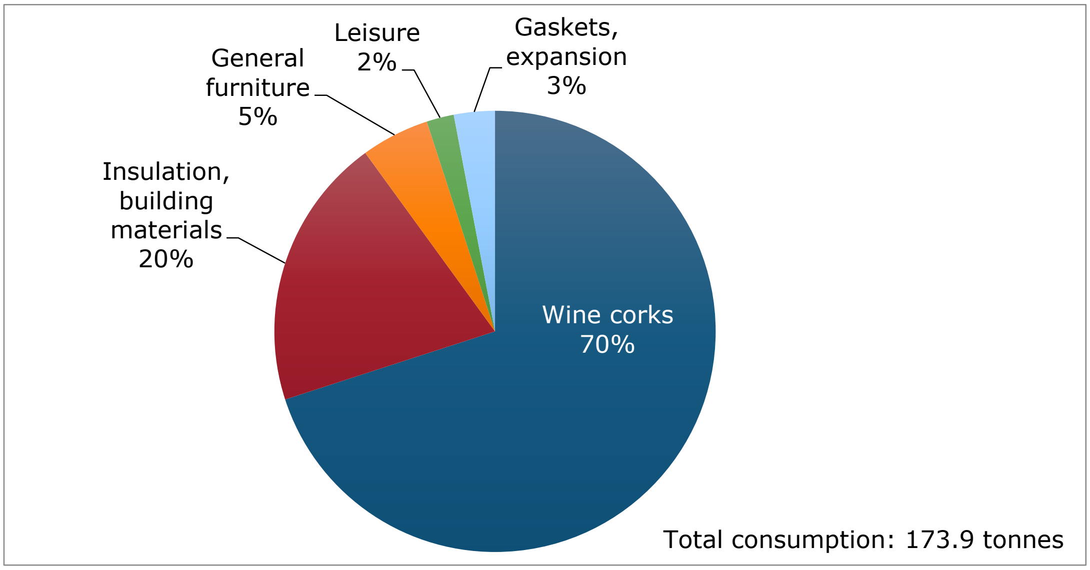


Figure 159: Global/EU end uses of natural cork. Average for 2010-2014 (Data from ACPOR, 2016a; CIF, 2016)

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. Relevant sectors are shown in Table 94.

Table 94: natural cork applications, 2-digit NACE sectors, 4-digit NACE sectors and value added per sector (Data from the Eurostat database, Eurostat, 2016).

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (millions €)
Wine corks	C11 - Manufacture of beverages	C11.01 - Manufacture of wine from grape	37,636.4
Insulation, building materials	C16 - Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	C16.29 - Manufacture of other products of wood; manufacture of articles of cork	29,584.8
Gaskets, expansion	C28 - Manufacture of machinery and equipment n.e.c.	C28.99 - Manufacture of other special-purpose machinery n.e.c.	191,000.0
Gaskets, expansion	C29 - Manufacture of motor vehicles, trailers and semi-trailers	C29.32 - Manufacture of other parts and accessories for motor vehicles	158,081.4
Gaskets, expansion	C30 - Manufacture of other transport equipment	C30.12 - Building of pleasure and sporting boats	53,644.5
General furniture	C31 - Manufacture of furniture	C31.09 - Manufacture of other furniture	28,281.7
Leisure articles	C32 - Other manufacturing	C32.99 - Other manufacturing n.e.c.	41,612.6

19.3.3 Prices

The price of natural cork is expressed per 15kg, a measure called "arroba". Since 2003 the price of cork fell dramatically, from €44.80 per arroba piled cork to €26,34 in 2013, or 1.75EUR/kg. The extraction cost are around €4 per 15kg (Pereira, 2011).

19.4 Substitution

Cork is assumed to be possibly be substituted for 50% for all construction purpose and plastic for beverage purposes (based on APCOR, 2016; Sierra-Pérez et al., 2014; PWC, 2008).

19.5 Discussion of the criticality assessment

19.5.1 Data sources

The CN codes used are 4501 1000 and 4502 0000, which are labelled "Natural cork, raw or simply prepared merely surface-worked or otherwise cleaned" 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 strong coverage. The production data is not from an official, independent source. At the same time, it is updated at regular 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.

19.5.2 Calculation of Economic Importance and Supply Risk indicators

For consistency, it is best to assess cork at the extraction stage. Given the proximity of extraction of natural cork, it was not expected that an assessment in the refining stage would provide different results.

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 94). The value added data correspond to 2013 figures.

The supply risk was assessed on natural cork using both the global HHI and the EU-28 HHI as prescribed in the revised methodology.

19.5.3 Comparison with previous EU assessments

There are no previous assessment results available to compare the current analysis of natural cork (see Table 95).

Table 95: Economic importance and supply risk results for natural cork in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

Assessment year	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Natural cork	N/A	N/A		N/A	N/A		1.5	1.1

19.6 Other considerations

19.6.1 Forward look for supply and demand

There are signs that demand, and therefore supply, of natural cork may continue to rise in the coming decade. The material could function as a remittance to environmental concerns, given the properties that make it a relatively highly recyclable and reusable material with a low environmental impact. This would particularly be true in innovative areas such as Design for Sustainability and Eco-Design (APCOR, 2015). See Table 96.

Table 96: Qualitative forecast of supply and demand of natural cork

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
Natural cork		x	+	+	?	+	+	?

19.6.2 Environmental and regulatory issues

Cork has a significantly lower impact than plastic and aluminium for use in the beverage industry (PWC, 2008).

Effects on agricultural land are less negative compared to other land use types. Natural Cork requires less water, can harbour a greater biodiversity and avoid Aeolian (wind) erosion (PWC, 2008).

Since 1990, there was a massive dieback of cork oaks. The trees first get weakened by drought or insect pests. 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).

19.7 Data sources

19.7.1 Data sources used in the factsheet

Eurostat (2016). Structural Business Statistics by size class. [online] available at: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=sbs_sc_ind_r2&lang=en

Moreira, A.C. (2002) Distribution of Phytophthora cinnamomi in cork oak stands in Portugal. Bulletin OEPP/EPPO Bulletin 25(5):41-48. Available at: https://www.researchgate.net/publication/235437050_Distribution_of_Phytophthora_cinnamomi_in_cork_oak_stands_in_Portugal

Pereira, H. (2011). Cork: Biology, Production and Uses. Available at: https://books.google.nl/books?id=5uiycUoRmFkC&dq=cork+occurrence+iberian+peninsula&source=gbs_navlinks_s

PWC (2008). Evaluation of the environmental impacts of Cork Stoppers versus Aluminium and Plastic Closures. Available at: https://web.archive.org/web/20090913143609/http://www.corkfacts.com/pdffiles/Amorim_LCA_Final_Report.pdf

19.7.2 Data sources used in the criticality assessment

APCOR (2015). Recycling of natural cork. Available at: http://www.apcor.pt/en/cork/recycling/

APCOR (2016a). Associação Portuguesa da Cortiça. Cork in numbers [online] Available at: http://www.apcor.pt/en/media-center/statistics/

APCOR (2016b). Associação Portuguesa da Cortiça. Yearbook p.22 Available at: http://www.apcor.pt/wp-content/uploads/2016/09/Boletim-estatistico-2016.pdf

CIF (2016). Cork Industry Federation. Cork Products [online] Available at: http://www.cork-products.co.uk/products.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

FAO (2016). Statistics database. [online] Available at: http://www.faostat.org/

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

Sierra-Pérez, J., Boschmonart-Rives, J., Gabarrel, X. (2014). Environmental implications in the substitution of non-renewable materials by renewable materials. Available at:

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

19.8 Acknowledgments

This Factsheet was prepared by the Netherlands Organisation for Applied Scientific Research (TNO). The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this Factsheet.

20. NATURAL TEAK WOOD

Key facts and figures

Material name	Teak	World/EU production (tonnes)[1]	657,442/0
Parent group (where applicable)	N/A	EU import reliance[1]	100%
Life cycle stage assessed	Extraction	Substitution index for supply risk [SI(SR)][1]	0.90
Economic importance EI (2017)	2.0	Substitution Index for economic importance [SI(EI)][1]	0.90
Supply risk SR (2017)	0.9	End of life recycling input rate	0%
Abiotic or biotic	Biotic	Major end uses in the EU[1]	Boat making (90%), Furniture (10%)
Main product, co-product or by-product	Main product	Major world producers[1]	India (33%), Indonesia (25%), Myanmar (8%)
Criticality results	2011	2014	2017
	Not assessed	Not assessed	Not critical

[1] Average for 2010-2014, unless otherwise stated.

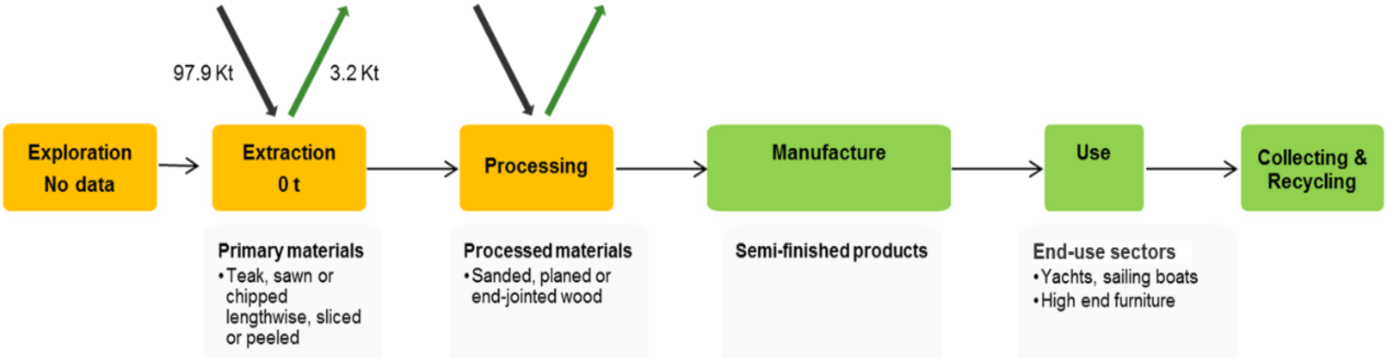


Figure 160: Simplified value chain for teak

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU.

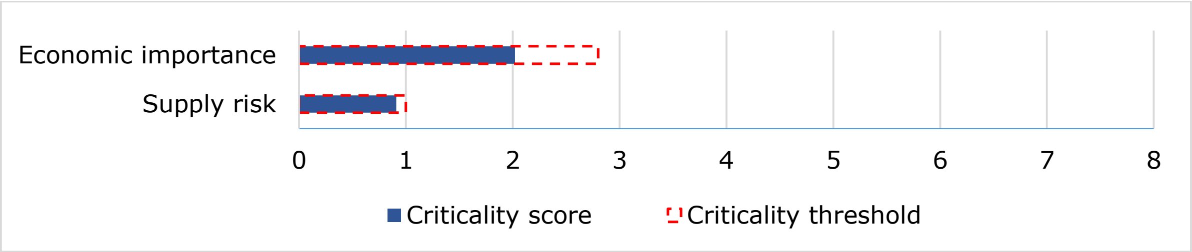


Figure 161: Economic importance and supply risk scores for teak

20.1 Introduction

Teak wood comes 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). It is one of the most expensive types of wood on the planet.

The wood at the heart 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, 2016).

Common uses in the EU of teak wood are in the shape of veneer, for applications such as boatbuilding furniture, exterior construction and carving of small wood objects.

20.2 Supply

20.2.1 Supply from primary materials

20.2.1.1 Geographical occurrence

Teak is a small to medium sized tree with bright purple blooms. The tree is easily distinguishable by its flaky bark (Arkive, 2016). 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 Phillipines, 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, 2016).

There are many wood types called teak that are not actually not tectona grandis teak. Much like the many names and synonyms of mahogany, the moniker "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, 2016).

20.2.1.2 Processing

Teak is deemed easy to process, with the only caveat being that teak contains a high level of silica (up to 1.4%) which has a pronounced blunting effect on cutting edges (Wood-database, 2016).

20.2.1.3 Resources and reserves

There are studies (Kollert & Cherubini, 2012; FAO, 2010) that have mapped the global production of teak wood, resulting in a relatively accurate estimation of production potential.

Table 97: Global reserves of teak in year 2016 (Kollert & Cherubini, 2012; FAO, 2010)

Country	Teak reserves (000 ha)	Percentage of total (%)
India	2,561	37
Indonesia	1,470	21
Thailand	836	12
Other Asia	814	12
Africa	538	8
Myanmar	390	6
Latin America	278	4
World total (rounded)	*6,887*	*100*

20.2.1.4 World production

The global production of teak between 2010 and 2014 was annually 657 kt on average. The major producers of teak are shown in Figure 162. The dominant role of Asia is clearly shown, which was also reflected in the overview of the current acreage of teak.

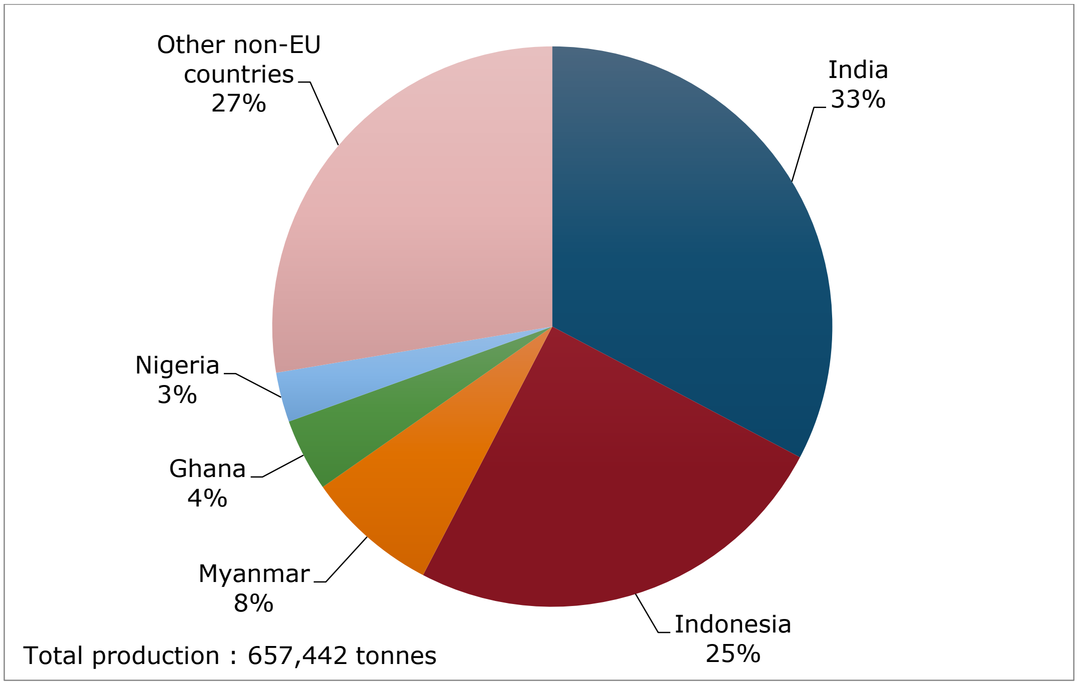


Figure 162: Global production of teak, average 2010–2014 (Data from ACIAR, 2015)

20.2.2 Supply from secondary materials

The end of life recycling input rate for teak is estimated to be 0%. There is no evidence found of activities that can produce secondary teak wood that replaces primary production.

20.2.3 EU trade

Imports to the EU are shown in Figure 163. The rise in 2013 and especially 2014 of teak imports cannot with certainty be attributed to the imports of teak alone. There was a general rise of imports of the products within the teak containing product groups).

The exports from the EU are without exception re-exports, mostly shipped to European destinations outside the EU-28.

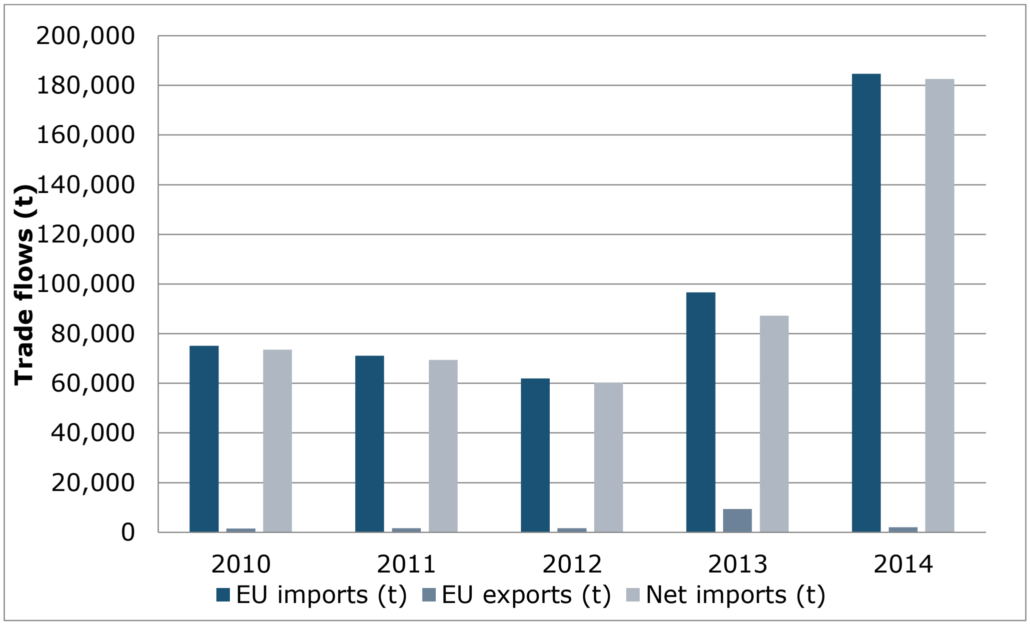


Figure 163: EU trade flows for teak (Data from Eurostat Comext, 2016)

The countries that are the origin of external trade flows of teak wood to the EU-28 are shown in Figure 164. The dominant role of Malaysia (62%) comes from re-exports from other south-east Asian producers. Imports from India, China and the United States are aggregated given the remarkable small share of these trading partners.

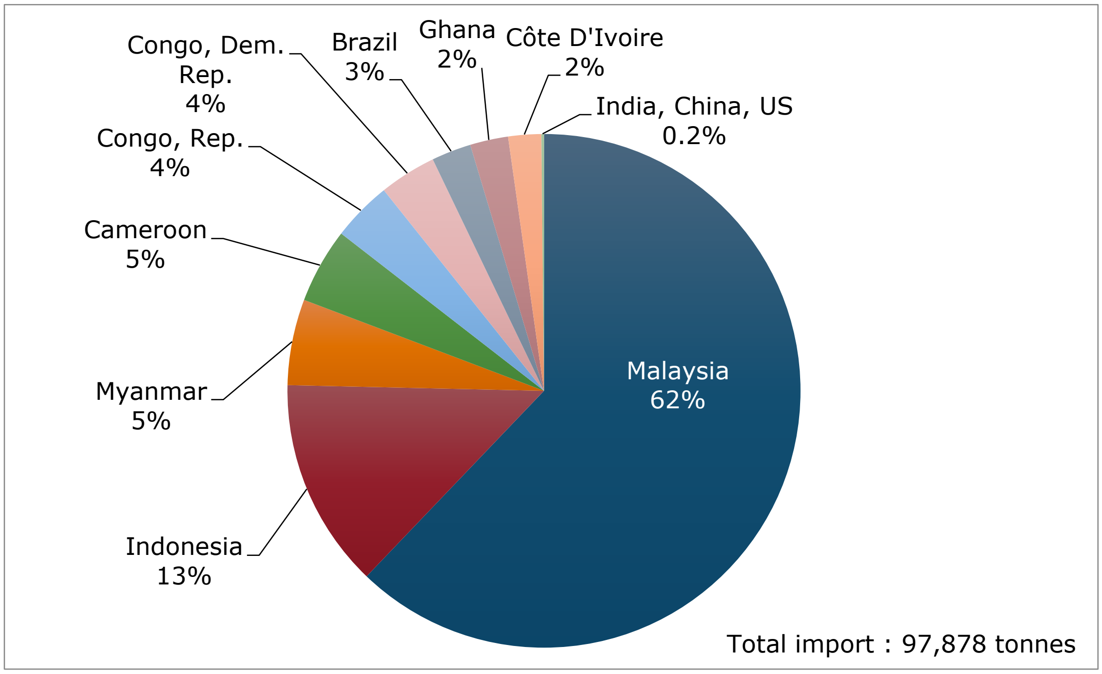


Figure 164: EU imports of teak, average 2010-2014 (Data from Eurostat Comext, 2016)

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.

No trade restrictions were reported over the 2010-2014 period (OECD, 2016). No free trade agreements are in place between the EU and its suppliers (European Commission, 2016).

20.2.4 EU supply chain

The EU has many manufacturers of boats and furniture that are produced from raw wood. At the same time, Europe and North America are the world's largest importers of teak wood furniture and parts of furniture (ACIAR, 2015).

The EU relies for the supply of teak for 100% on its imports. The EU sourcing is therefore provided in Figure 164.

Although several tropical woods are subject to trade restriction, the product group containing teak has no associated trade restrictions with it.

20.3 Demand

20.3.1 EU consumption

The EU average consumption of extracted teak wood between 2010 and 2014 was 94.6 kt.

20.3.2 Applications / End uses

Used extensively in India and within its natural range for centuries, teak has grown into a worldwide favourite. With its superb stability, good strength properties, easy workability and most of all, its outstanding resistance to decay. It resulted in teak ranking among the most desired lumbers in the world. (Wood-database, 2016). The heartwood is rated as very durable with respect to decay fungi and termites; not immune to marine borers (USDA, 2016). The EU use of teak wood is shown in Figure 165.

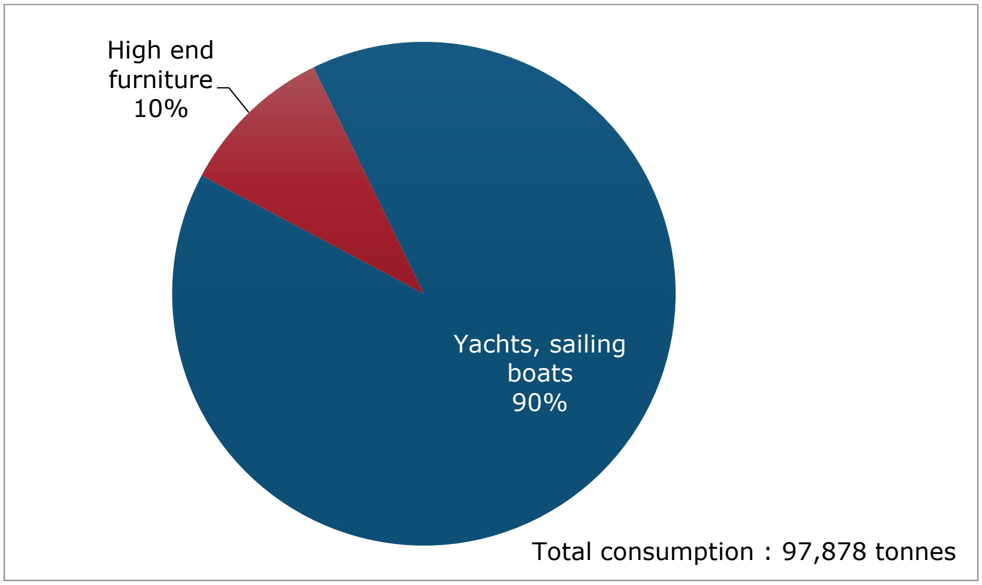


Figure 165: EU end uses of teak. Average 2010-2014 (Data from Houtvademecum, 2011)

An unusual disparity is observed between teak use 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 population is utilized that way. Surprisingly, it is also used locally as firewood. Immature trees are said to be preferred for building materials, thus threatening the reproductive survival of the population (IUCN, 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 98). The value added data correspond to 2013 figures.

Table 98: Teak applications, 2-digit NACE sectors associated 4-digit NACE sectors and value added per sector (Data from the Eurostat database, Eurostat, 2016)

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (millions €)
Yachts	C30 - Manufacture of other transport equipment	C30.12 - Building of pleasure and sporting boats	53,644.5
High-end furniture	C31 - Manufacture of furniture	C31.09 - Manufacture of other furniture	28,281.7

20.3.3 Prices

Apart from being among the costliest woods available, teak is also volatile in price. On average, prices of teak seem to be between 2,000 and 5,000 US$ per m^3 in the EU. Markets in smaller Member States seem to set much higher prices than EU-28 countries with main seaports (ITTO, 2014).

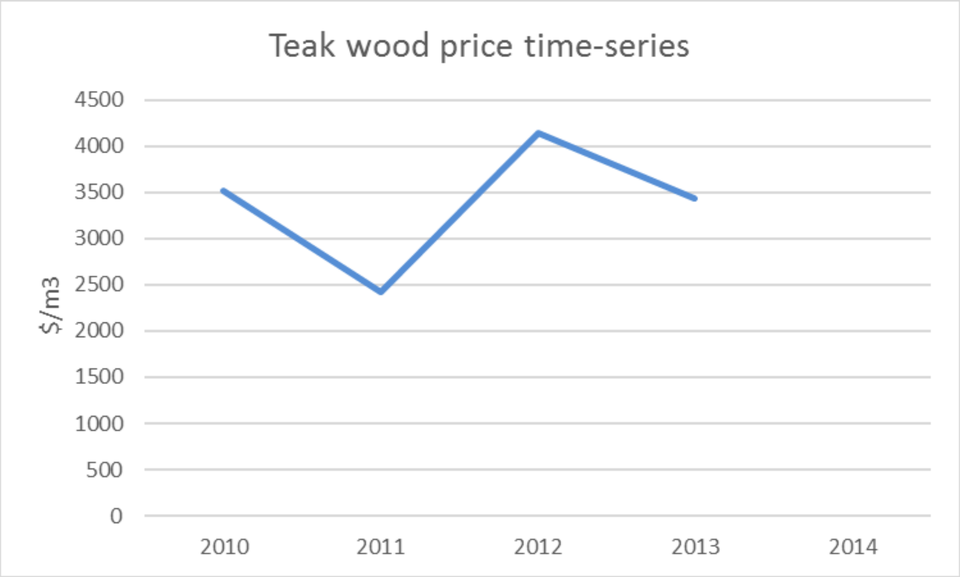


Figure 166: Global developments in price of teak wood on the Korean market, average 2010-2014 (Data from ITTO, 2014)

20.4 Substitution

Tropical wood can is generally considered to be never unique, and teak is no exception. There is in a vast majority of the times another wood available that has similar properties (FAO 2010; ITTO 2014; TNO, 2016; USDA, 2016). The only limitation is availability and price of the wood, the technical performance will be virtually equal.

20.5 Discussion of the criticality assessment

20.5.1 Data sources

The first four out of five CN codes used for the 2017 assessment are 4407 2915, 4407 2925, 4407 2945 and 4407 2960. They all comprise many tropical timbers. 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, 2016). The last product group 4403 4995, only lists wood in the rough.

The data is 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. No consistent global time series for production can be created.

The rise of imports of teak wood in 2014 follows from a spike in the imports of product group 44034995 to the EU-28 (an increase of close to 400% in one year). Other wood types could have disproportionally contributed to this rise, but no evidence could be found that indicate if a certain wood type was the cause of the rise.

The production data has a quality that is below average in quality. The data used is not from an official source, but comes from governmental institutes (FAO, Australian government) that are known to produce good quality data. The data t is updated at regular 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.

20.5.2 Calculation of Economic Importance and Supply Risk indicators

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, 2010). The extraction stage is chosen for the criticality assessment.

The huge economic importance comes from the dominant use of teak in boatbuilding. This use is allocated to the “other transport equipment” NACE2 sector, which sees a huge added value in the EU-28. As a result, the product of the share of teak and value added result in a hug numerical score.

The supply risk was assessed for teak using both the global HHI and the EU-28 HHI as prescribed in the revised methodology.

20.5.3 Comparison with previous EU assessments

Natural teak is being assessed for the first time in 2017 with the EI and SR results presented in the following table. Natural teak was not assessed in 2011 or in 2014, therefore, it is not possible to make any comparisons with the previous assessments.

Table 99: Economic importance and supply risk results for natural teak in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Teak	Not assessed			Not assessed			2.0	0.9

20.6 Other considerations

20.6.1 Forward look for supply and demand

Philippine teak may have potential as a genetic resource for future teak breeding programmes aimed at improving supplies of this highly popular wood (IUCN, 2016). See Table 100.

Table 100: Qualitative forecast of supply and demand of teak

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
Teak		x	+	+	0	+	+	0

20.6.2 Environmental and regulatory issues

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 process leading to 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 (ACIAR, 2015).

Teak wood species are not listed in the CITES Appendices (CITES, 2016) but is the philippinensis in is listed as critically endangered on the IUCN Red list (IUCN, 2016). A conservation program is needed to re-establish a stable natural population of particularly 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 program, public education, community consultation and resource stewardship, and policy initiatives (IUCN, 2016).

20.6.3 Supply market organisation

Demand for teak has fallen reflecting end-users concern for the economy and due to the annual monsoon during which time sales regularly slip. Because of this importers cut back on plantation teak purchases (FORDAQ, 2016).

Over the past month a new plantation teak supplier has emerged, Angola which recently shipped a small consignment (357m, length units) of plantation teak logs worth US 44,610 (FORDAQ, 2016).

20.7 Data sources

20.7.1 Data sources used in the factsheet

Arkive (2016). Teak [online] Available at: http://www.arkive.org/philippine-teak/tectona-philippinensis/

CITES (2016). Convention of International Trade in Endangered Species of Wild Fauna and Flora. [online] Available at: https://www.cites.org/eng/app/appendices.php

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 (2016)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

FAO (2010). Global Forest Resources Assessment 2010 Main report. Available at: http://www.fao.org/docrep/013/i1757e/i1757e.pdf

FORDAQ (2016). Latest prices of teak logs, sawnwood and plywood. [online] Available at: http://hout.fordaq.com/fordaq/news/India_teak_sawnwood_plywood_prices_43584.html

ITTO (2011) Annual review and assessment of the timber situation. ISBN 4-902045-92-3. Available at: http://www.itto.int/annual_review/

ITTO (2012) Annual review and assessment of the timber situation. ISBN 978-4-86507-007-1. Available at: http://www.itto.int/annual_review/

ITTO (2014) Biennial Review 2013-2014. ISBN 978-4-86507-020-0. Available at: http://www.itto.int/annual_review/

IUCN (2016). Teak. Assessed by Madulid, D.A., Agoo, E.M.G., Caringal, A.M. 2008. [online] Available at: http://www.iucnredlist.org/details/33051/0

Kollert W. & Cherubini L. (2012). Teak resources and market assessment 2010 (Tectona grandis Linn. f.). Planted Forests and Trees Working Paper FP/47/E. FAO: Rome, Italy. Available at: http://www.fao.org/3/a-an537e.pdf

USDA (2016). Wood Properties (Tech sheets) - Tropical Hardwoods. 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 (2016). Teak [online] Available at: http://www.wood-database.com/teak/

20.7.2 Data sources used in the criticality assessment

ACIAR (2015). Australian Centre for International Agricultural Research. Midgley, S., Somaiya, R.T,, Stevens, P.R., Brown, A., Nguyen, D.K., Laity, R. Planted teak: global production and markets, with reference to Solomon Islands. Available at: http://aciar.gov.au/files/tr85-web.pdf

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

Houtvademecum (2011) Centrum Hout Almere. Sdu uitgevers bv, den Haag. ISBN 978 90 125 82162, NUR 833/835.

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

TNO (2016). Jan de Jong, expert consultation.

20.8 Acknowledgments

This Factsheet was prepared by the Netherlands Organisation for Applied Scientific Research (TNO). The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials and all other stakeholders for their contributions to the preparation of this Factsheet.

21. NICKEL

Key facts and figures

Material name and Element symbol	Nickel, Ni	World/EU production (ktonnes)[1]	Refined: 1,750/ 115
Parent group	-	EU import reliance[1]	59%
Life cycle stage assessed	Refined material	Substitution index for supply risk [SI (SR)][1]	0.96
Economic importance (EI) (2017)	4.8	Substitution Index for economic importance [SI(EI)][1]	0.94
Supply risk (SR) (2017)	0.3	End of life recycling input rate	34%
Abiotic or biotic	Abiotic	Major end uses in the EU[1]	Metal building products (34%), Base metal alloys (16%), Batteries (16%)
Main product, co-product or by-product	Main product	Major world producers[1] (refining)	China (31%), Russia (14%), Japan (10%)
Criticality results	2011	2014	2017
	Not critical	Not critical	Not critical

[1] average for 2010-2014, unless otherwise stated

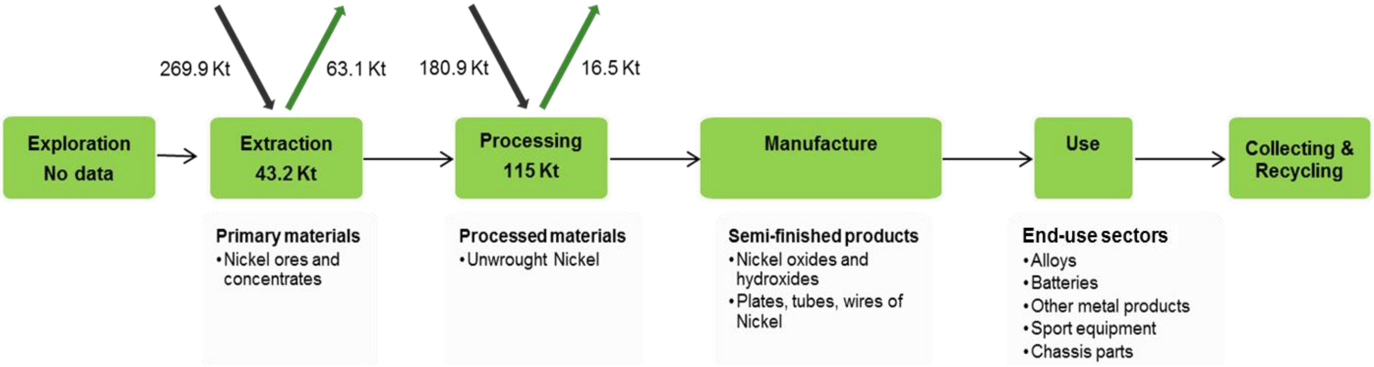


Figure 167: Simplified value chain for nickel

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU. EU reserves are displayed in the exploration box.

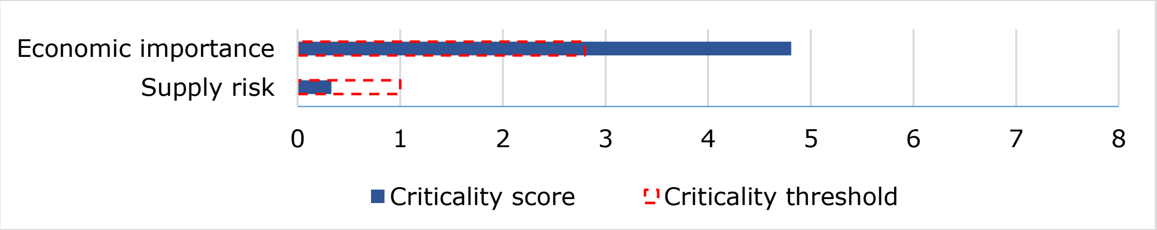


Figure 168: Economic importance and supply risk scores for nickel

21.1 Introduction

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. The principal ore deposits of nickel are magmatic sulphides and of lateritic origin. Main Ni use is for alloy production (stainless steel accounts for about 65% of nickel first-use). Nickel alloys are characterized by strength, toughness and corrosion resistance over a wide temperature range. For instance, they played a key role in the development of materials for the aerospace industry and are essential to the iron and steel industry to this day.

21.2 Supply

21.2.1 Supply from primary materials

21.2.1.1 Geological occurrence/exploration

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 is carried out in Greenland, the UK, Sweden, Sapin, Portugal, Poland, Ukraine and Kosovo (Minerals4EU, 2014).

21.2.1.2 Processing and refining

Ore beneficiation comprises the metal concentration and refining of the above mentioned nickel ores, to ultimately obtain nickel matte. The specific processes are defined depend on whether the ore is a sulphide or a laterite.

21.2.1.2.1 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.

21.2.1.2.2 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).

21.2.1.2.3 Nickel matte refining

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 ferro-nickel, nickel oxides and other chemicals, and as nickel metal with a concentration of over 90%. Ferronickel 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. NPI is made of low-grade lateritic nickel ore, coking coal, and a mixture of gravel and sand as an aggregate (Eurofer, 2016).

21.2.1.3 Resources and reserves

There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of nickel 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.

---

[20] www.crirsco.com

For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for nickel. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for nickel, 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 nickel at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU, 2015).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.

According to USGS, identified land-based resources averaging 1% nickel or greater contain at least 130 million tons of nickel, with about 60% in laterites and 40% in sulphide deposits (USGS, 2016). 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. Resource data for some countries in Europe are available in the Minerals4EU website (Minerals4EU, 2014) but cannot be summed as they are partial and they do not use the same reporting code.

The USGS reports about 79 million tonnes of world known nickel reserves (USGS, 2016). The global reserves are largely reported in Australia, Brazil, New Caledonia (France) and Russia (Table 101). Many other smaller countries have nickel reserves, resulting in a high position of an aggregated group of countries with respect to reserves. Reserve data for some countries in Europe are available in the Minerals4EU website (Minerals4EU, 2014) but cannot be summed as they are partial and they do not use the same reporting code.

Table 101: Estimated global reserves of nickel (Data from USGS, 2016)

Country	Estimated Nickel Reserves (tonnes)	Percentage of total (%)
Australia	19,000,000	24%
Brazil	10,000,000	13%
New Caledonia (France)	8,400,000	11%
Russia	7,900,000	10%
Others	6,500,000	8%
Cuba	5,500,000	7%
Indonesia	4,500,000	6%
South Africa	3,700,000	5%
Philippines	3,100,000	4%
China	3,000,000	4%
Canada	2,900,000	4%
Guatemala	1,800,000	2%
Madagascar	1,600,000	2%
Colombia	1,100,000	1%
USA	160,000	0%
World total (rounded)	*79,160,000*	*100*

Table 102: Reserve data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Quantity	Unit	Grade	Code Reserve 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

21.2.1.4 World production

The global production of nickel metal between 2010 and 2014 was annually 1.75Mt on average. China is the largest world producer of refined nickel metal, followed by Russia, Japan, Canada and Australia. Other producing countries (which together represent 31% of the world production as well) are Brazil, New Caledonia (France), Indonesia and the Philippines; they take a slightly smaller share of world production in this producer ranking compared to the previous assessment. Between 1994 and 2011, world production doubled from 0.9 million tonnes to almost 1.8 million tonnes. The world production remained more or less stable in recent years.

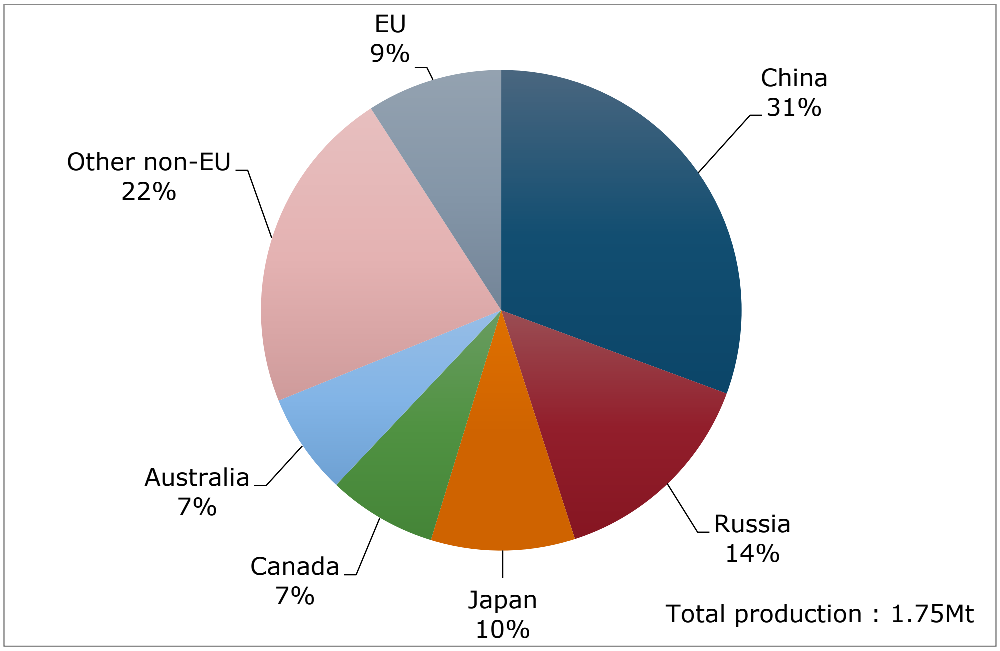


Figure 169: Global production of nickel metal, average 2010–2014 (Data from BGS World Mineral Statistics database, 2016)

21.2.2 Supply from secondary materials

In the 2017 criticality assessment, the UNEP methodology (UNEP, 2011) is applied resulting in a recycling input rate of 34%. This method leads to the End-of-life recycling rate that replaces primary nickel.

The dominant use of nickel as alloying element in stainless steels as well as other nonferrous 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 2016b). 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, 2016b). In the 2017 criticality assessment, the UNEP methodology (UNEP, 2011) is applied resulting in a recycling input rate of 34%.

The material-for-material substitution options of nickel are limited. Even where stainless steels and other nickel alloys can potentially be substituted with other materials such as e.g. coated steel, aluminium, copper based alloys or plastics, and nickel content may be reduced using other stainless steel qualities (e.g. ferritics, which contain no or very little nickel), any substitution ultimately results in a reduction in performance (e.g. less efficiency and functionality, lower life time, higher maintenance requirements). The replacement of some super-alloys with ceramics in certain applications is still under research. The significant, but short-lived, increase in nickel price in 2007 caused some stainless steel producers to review nickel use. Already existing stainless steel qualities with low /no nickel content were considered as possible substitutes but, due to inferior performance, substitution remained limited

21.2.3 EU trade

The imports of nickel metal to the EU have significantly increased in recent years, see Figure 170. This rise can be attributed to the rebound of the European manufacturing sectors, base metal, metal products and electrical equipment manufacturing especially.

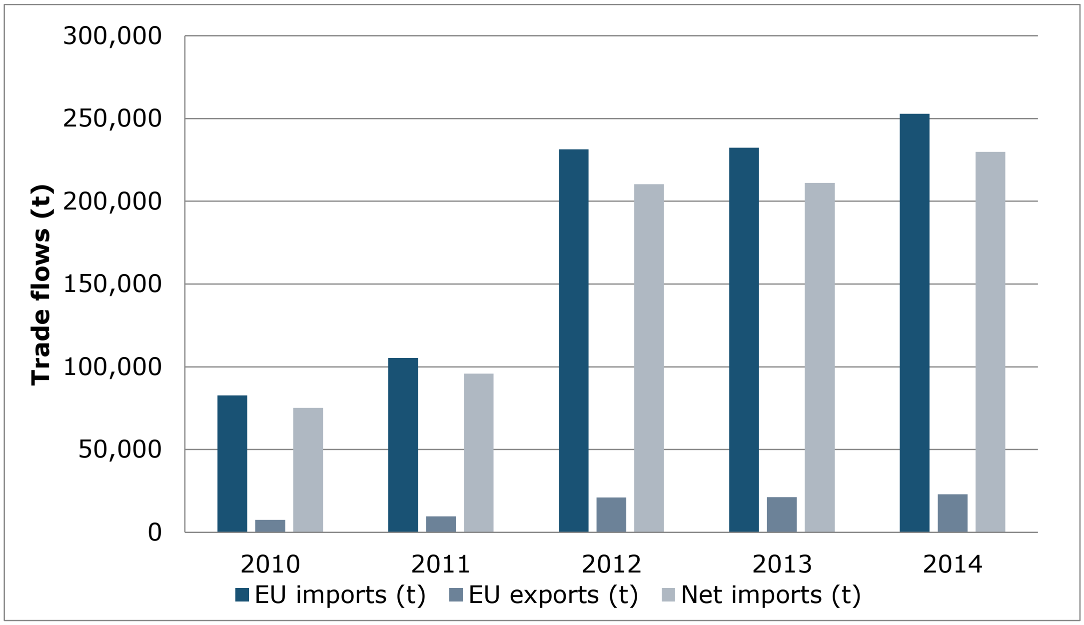


Figure 170: EU trade flows for nickel. (Data from Eurostat Comext, 2016)

The origins of nickel flows are relatively diverse (see Figure 171), resulting in a large share for “Other” suppliers. The “largest” important suppliers that are within this group are China, the Korean republic, South Africa, Japan, that nevertheless each represent only between 1% and 2% of non-EU imports of nickel metal to the EU.

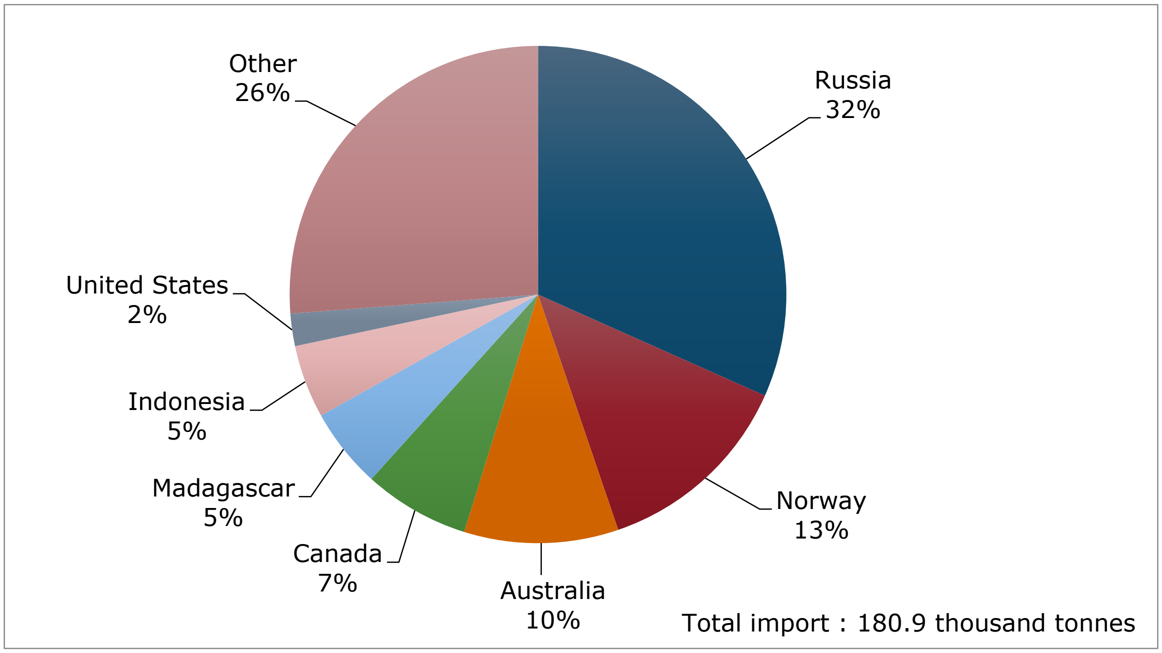


Figure 171: EU imports of nickel, average 2010-2014. (Data from Eurostat Comext, 2016)

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.

21.2.4 EU supply chain

Refining, smelting and processing of nickel takes place in the EU, several percentage points on a world scale. Especially Finland, France and the United Kingdom, but also Austria and Greece host economic activities in this part of the chain. There are several enterprises in the EU active in the recycling of nickel. Major recycling activities of nickel, however, 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 import reliance of nickel is estimated to be at 59%. This number implies that in case of supply disruptions, the supply from EU is significant and potentially can grow to cover the demand.

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, Russia, Nigeria, Morocco, Indonesia, Brazil) imposing trade restrictions on nickel related products. These are either ores or concentrates, or downstream products such as plates, wires etc. However, none of these restrictions apply on nickel unwrought metal.

The Figure 172 shows the EU sourcing (domestic production + imports) for nickel.

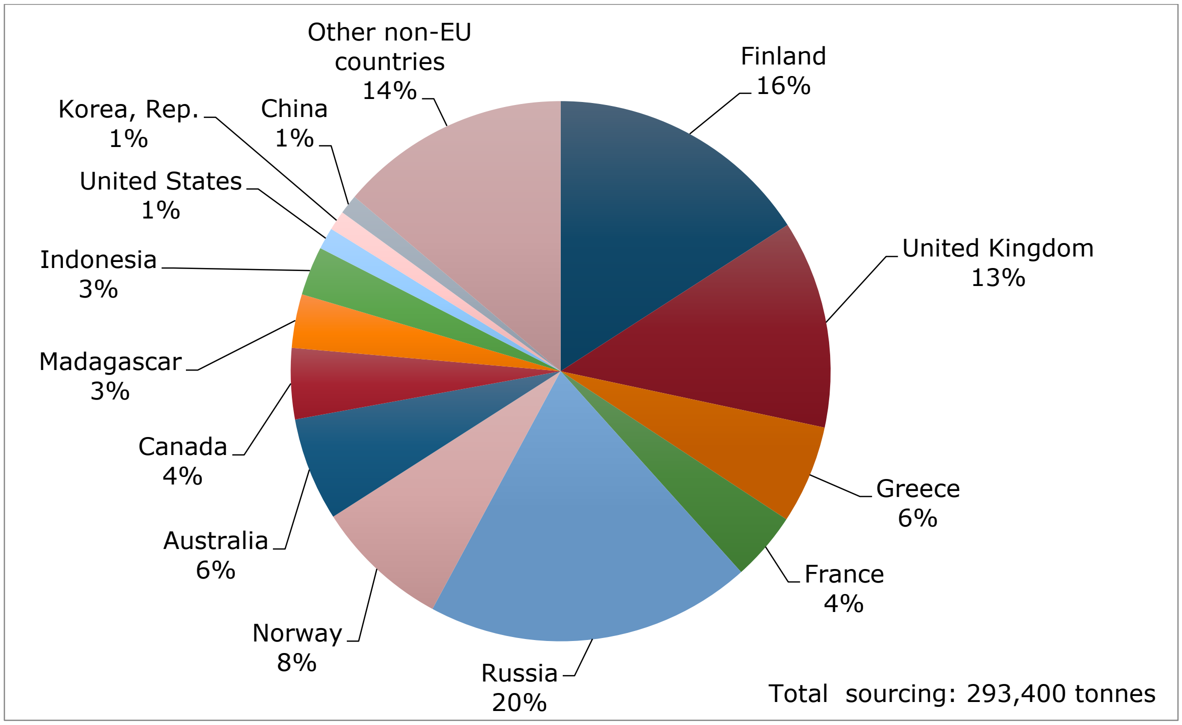


Figure 172: EU sourcing (domestic production + imports) of nickel, average 2010-2014. (Eurostat, 2016)

21.3 Demand

21.3.1 EU consumption

The annual average EU consumption between 2010 and 2014 use of nickel metal was found to be just under 300kt in the 2017 criticality assessment. Other sources (Nickel Institute 2016b) expect this number to be higher. The difference can be caused by the volume of nickel in relevant the product groups (metal products especially) and the decline in some manufacturing output of relevant materials after 2008. The nickel consuming using product groups manufactured in the EU (plates, tubes, bars etc.) amounting to 40kt of sold products, indicating an important volume of nickel to be used as well in nickel containing alloys such as stainless steel or high-nickel alloys.

21.3.2 Applications / End uses

Short explanations of selected end-uses are given below, with relative market shares for these applications shown in Figure 173:

- 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.

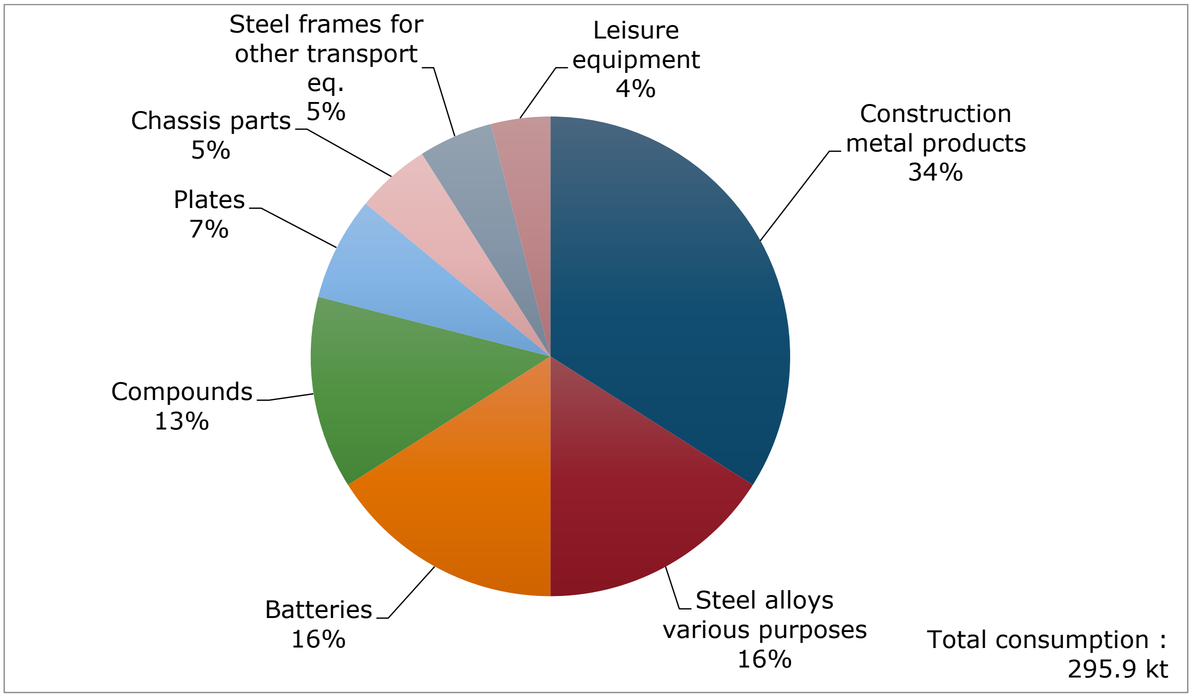


Figure 173: Global/EU end uses of nickel, average 2010-2014 (Data from Nickel Institute, 2016a)

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 103). The value added data correspond to 2013 figures.

A socio-economic study of nickel in the EU (APEC, 2012) finds that nickel is an "enabling technology", not simply an important primary material. In the past its particular properties pushed developers to new products, industries and new user benefits, with enhanced performance in a wide range of advanced manufacturing sectors. Using the widest definition of the impact of nickel on the EU economy, the total value added by the nickel industry and its value chain is estimated to be in excess of 80-100 billion Euro, of which around 50 billion Euro is estimated to be generated by industries and applications that are critically dependent on nickel. The nickel value chain also supports a large number of mostly high-skill manufacturing jobs, estimated to be in the order of 1.25-1.50 million. Of this, an estimated 690,000 jobs in the EU are critically dependent on nickel. Nickel and nickel-based platform technologies also contribute additional benefits to the EU and its citizens that are often not apparent to policy-makers and the general public. Nickel compounds, for instance, play an important role in underpinning the competitiveness of major industrial and service sectors such as aerospace, automotive, oil refining, and optical media. Economic efficiency and innovation across large parts of the EU's economy, and the achievement of European environmental goals are based on a noncritical nickel supply (The Weinberg Group LLC, 2004).

Table 103: Nickel applications, 2-digit NACE sectors associated 4-digit NACE sectors and value added per sector (Data from the Eurostat database, Eurostat, 2016)

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (millions €)
Oxides and dopants	C20 - Manufacture of chemicals and chemical	C20.59 - Manufacture of other chemical products n.e.c.	110,000.0

	products		
Alloys	C24 - Manufacture of basic metals	C24.45 - Other non-ferrous metal production	57,000.0
Other metal products	C25 - Manufacture of fabricated metal products, except machinery and equipment	C25.12 - Manufacture of doors and windows of metal	159,513.4
Batteries	C27 - Manufacture of electrical equipment	C27.20 - Manufacture of batteries and accumulators	84,608.9
Plates	C28 - Manufacture of machinery and equipment n.e.c.	C28.13 - Manufacture of other pumps and compressors	191,000.0
Chassis parts	C29 - Manufacture of motor vehicles, trailers and semi-trailers	C29.20 - Manufacture of bodies (coachwork) for motor vehicles	158,081.4
Steel frames	C30 - Manufacture of other transport equipment	C30.99 - Manufacture of other transport equipment n.e.c.	53,644.5
Sport equipment	C32 - Other manufacturing	C32.50 - Manufacture of medical and dental instruments and supplies	41,612.6

21.3.3 Prices

Figure 174 shows how the different supply and demand situations worldwide influenced nickel prices during the last century. Prices had been overall rising during that period, but price peaks had been induced or increased several times by strikes in Canada – with the last strong price peak induced by both strikes in Canada and a high demand in Asia. The average price of primary Nickel (>99.8%) on the London Metal Exchange between 2011 and 2015 was 16,827.82 US$/tonne - see Figure 175 (DERA, 2016).

Figure 174: Development of real nickel prices (constant prices 2011 = 100) (DERA 2013)

Figure 175: Monthly average cash price for nickel in US$ per tonne (data from LME, 2017)

21.4 Substitution

For nickel used in metal products such as plates, tubes, beams etc., other steel alloy materials such as titanium, chromium and cobalt are mentioned as substitutes (EC, 2014). 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 material-for-material substitution for nickel in battery applications, mostly the Nickel Metal Hydride (NiMH) batteries, are limited. (Terceiro et al., 2013). Lithium (Lithium-ion) batteries can serve as an alternative, but are essentially different products with different technical requirements . Moreover, it has to be noted that many Li-ion based battery technologies still 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).

Nickel is commonly named as a material that can substitute other raw materials in catalysts. Substitution sometimes means a compromise; improved performance but with higher cost, or some loss of performance associated with lower cost.

21.5 Discussion of the criticality assessment

21.5.1 Data sources

The CN codes of the two product groups used in the criticality assessment are 7502 10 00 and 7502 20 00, labelled respectively “Nickel, not alloyed, unwrought” and “Unwrought nickel alloys”. It is suggested that ferronickel (CN8 code 7202 60 00) also needs to be assessed as refined material (Eurofer, 2016). We refrained from taking nickel containing alloys into the assessment to avoid analysing activities that beyond the refinery stage in the value chain.

Nickel being one of the important non-ferrous metals, the data has a very strong coverage, on EU level, is available for time series and updated at regular intervals and is publicly available. Nickel and the nickel content can be identified in the labels of product groups.

21.5.2 Calculation of Economic Importance and Supply Risk indicators

The criticality assessment of nickel is performed for the refined material. The reason for this lies in the large number of suppliers to the EU of nickel ores and concentrates. On the other hand, the refined material, metal with a nickel content of over 99%, is most relevant for assessing the economic importance, substitution options and realistic recycling input rates.

In the criticality assessment, the role of New Caledonia is documented with a French overseas territory WGI, specifically labelled as French New Guinea. This has no effect on the criticality scores.

The supply risk was assessed on nickel metal using both the global HHI and the EU-28 HHI as prescribed in the revised methodology.

21.5.3 Comparison with previous EU assessments

Nickel has seen a backdrop in economic importance as compared to the previous two assessments. This is due to the allocation of nickel to the NACE-2 sectors opposed to the megasectors used in previous assessments. The "weights" representing the amount of material being used in a sector, together with the value added of that particular sector, result in a significantly lower numerical value. This result is also observed for several other metals important for manufacturing steel alloys. See Table 104.

Table 104: Economic importance and supply risk results for nickel in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Nickel	9.54	0.27		8.83	0.24		4.8	0.3

21.6 Other considerations

21.6.1 Forward look for supply and demand

The use of nickel in the coming years will strongly depend on the markets for batteries and building materials whilst some high-tech uses such as super alloys are expected to grow steadily at around 5% per year (Marscheider-Weidemann e.a., 2016). The technology development of batteries applied in automotive and electronics is especially uncertain (Mining technology, 2016). The supply of nickel might be influenced by the stock policies in China, where possibly large quantities of nickel metal are ready to be sold on markets without being documented officially (Metal bulletin, 2016). See Table 105.

Table 105: Qualitative forecast of supply and demand of nickel

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
Nickel		x	+	++	++	++	+	+

21.6.2 Supply market organization

Nickel is a globally traded commodity with prices set at the London Metal Exchange (LME). Warehouses can be found in major EU harbours (Rotterdam, Hamburg, Antwerp) where nickel is stored and from where nickel is sold into the entire world. There is a significant impact on trade statistics which needs to be taken into consideration.

21.7 Data sources

21.7.1 Data sources used in the factsheet

APEC (2012) Socio-Economic Study of Impact of EU Nickel Compounds Classification on APEC Economies. Available at: http://publications.apec.org/publication-detail.php?pub_id=1288

Bide, T. Hetherington, L. , Gunn, G. (2008) BGS. Nickel Commodity profile. Available at: https://www.bgs.ac.uk/search/home.html?q=nickel&qSearchBtn=Search

Brittanica (2009). Nickel processing. [online] Available at: https://www.britannica.com/technology/nickel-processing

Chen X, Liang C (2012) Nickel silicides: an alternative and high sulfur resistant catalyst for hydrodesulfurization. http://events.dechema.de/Tagungen/Materials+for+Energy+_+EnMat+II/Congress+Planer/Datei_Handler-tagung-564-file-1082-p-127866.html. Accessed 19 July 2013

DERA (2013). Rohstoff informationen. Ursachen von Preispeaks, -einbrüchen und -trends bei mineralischen Rohstoffen. Available at : http://www.deutsche-rohstoffagentur.de/DE/Gemeinsames/Produkte/Downloads/DERA_Rohstoffinformationen/rohstoffinformationen-17.pdf?__blob=publicationFile&v=2

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

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

Eurostat (2016)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

Jébrak, M., Marcoux, E., Géologie des ressources minérales - Soc. Industrie Minérale, Paris, 2008

London Metal Exchange (2017). Nickel pricing. https://www.lme.com/metals/non-ferrous/nickel/#tab2

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

Metal bulletin (2016) Available at: https://www.metalbulletin.com/Article/3538408/NORTH-AMERICAN-MORNING-BRIEF-1703-Fanya-investors-fret-nickel-premiums-fall-molybdenum-prices-down.html

Minerals4EU (2014). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

Mining technology (2016) Available at: http://www.mining-technology.com/features/featurethe-future-for-nickel-slow-and-steady-or-battery-boom-4647099/

Nickel Institute (2016b). Nickel in the European Union. Available at: https://www.nickelinstitute.org/MediaCentre/Publications/NickelIntheEuropeanUnion.aspx

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.

The Weinberg Group LLC (2004). The socio-economic impact of the nickel industry: A baseline analysis, Final Report. https://www.nickelinstitute.org/~/media/Files/SocioEconomicWeinbergReports/SocioEconomicImpactNickel-29Jan04-FinalReport-logo_.ashx

USGS (2013). Kuck, P.H. Minerals Yearbook 2013. Available at: http://minerals.usgs.gov/minerals/pubs/commodity/nickel/myb1-2013-nicke.pdf

USGS (2016). Mineral Commodity Summaries: Nickel. Available at: https://minerals.usgs.gov/minerals/pubs/mcs/2016/mcs2016.pdf

WBG (1998). World Bank Group Environment, Health and Safety Guidelines. https://www.ifc.org/wps/wcm/connect/469da18048855b7f891cdb6a6515bb18/nickel_PPAH.pdf?MOD=AJPERES

21.7.2 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

Nickel Institute (2016a). About nickel. Available at: https://www.nickelinstitute.org/NickelUseInSociety/AboutNickel/WhereWhyNickelIsUsed.aspx

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

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

21.8 Acknowledgments

This Factsheet was prepared by the Netherlands Organisation for Applied Scientific Research (TNO). The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials for their contributions to the preparation of this Factsheet. Specific experts that have contributed their input and feedback to the factsheet and criticality assessments are listed in the data sources section.

22. PERLITE

Key facts and figures

Material name	Perlite	World/EU production (million tonnes)[1]	4.2/ 1
Parent group (where applicable)	N/A	EU import reliance[1]	0%
Life cycle stage/ material assessed	Mine production/ Perlite (crude)	Substitution index for supply risk [SI(SR)][1]	0.92
Economic importance (EI)(2017)	2.1	Substitution Index for economic importance [SI(EI)][1]	0.87
Supply risk (SR) (2017)	0.4	End of life recycling input rate[2]	EU: 42%
Abiotic or biotic	Abiotic	Major end uses in EU[1]	Building construction products (59%), Filter aid (24%), Horticultural aggregates (11%)
Main product, co-product or by-product	Main product	Major world producers[1]	Greece (20.6%), Turkey (20.5%), Iran (19.5%)
Criticality results	2011	2014	2017 (current)
	Not critical	Not Critical	Not critical

[1] average for 2010-2014, unless otherwise stated; 2 This is not the recycling input rate, but the EOL Recycling rate of all major applications that perlite finds use

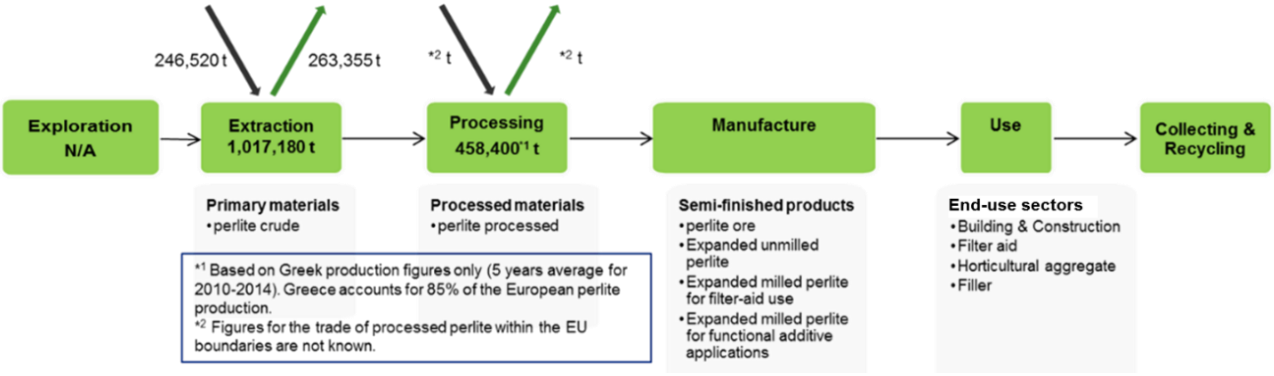


Figure 176: Simplified value chain for perlite

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU. A quantitative figure on recycling is not included as the EOL-RIR is below 70%. EU reserves are displayed in the exploration box.

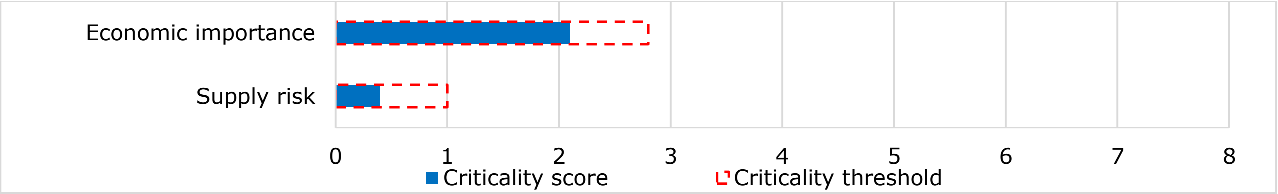


Figure 177: Economic importance and supply risk scores for perlite

22.1 Introduction

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.

Europe is an important global supplier of perlite. Approximately 24% of the global production is European. Europe is a net exporter of perlite hence the sector is a positive contributor to the European economy.

22.2 Supply

22.2.1 Supply from primary materials

22.2.1.1 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).

22.2.1.2 Mining and processing

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).

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).

22.2.1.3 Perlite resources and reserves

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[21], 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.

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 data 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 (Minerals4EU, 2015).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.

Resource data for some countries in Europe are available in the Minerals4EU website (see Table 106) (Minerals4EU, 2014) but cannot be summed as they are partial and they do not use the same reporting code.

Table 106: Resource data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

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

Some reserve figures of perlite in 2016 are shown in Table 107. A global reserve figure cannot be estimated as data from several important producing countries are missing. Reserve data for some countries in Europe are available in the Minerals4EU website (see Table 108) but cannot be summed as they are partial and they do not use the same reporting code.

---

[21] www.crirsco.com

Table 107: Global reserves of perlite in 2015 (Data from USGS, 2016)

Country	Perlite Reserves (tonnes)
United States	50,000,000
Greece	50,000,000
Hungary	28,000,000
Turkey	57,000,000

Table 108: Reserve data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Quantity	Unit	Grade	Code reserve type
Slovakia	None	4.43	Mt	-	Verified Z1
Ukraine	Russian Classification	2980.753	Thousand m^3	-	A

22.2.1.4 World mine production

World mine production of perlite is about 4.2 million tonnes per year in average between 2010 and 2014, summarized in Figure 178. Greece, Turkey, Iran and China are the major producing countries, but production of perlite takes place in several other countries in a much smaller scale. Greece and Turkey together account for 41% of the global production, with each country accounting for approximately 860,000 tonnes per annum on average for the period 2010 to 2014. 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.

Other European countries except from Greece producing perlite include, Hungary with a production share of 1.6%, Italy with a share of 1.4%, Slovakia with a share of 0.5% and Bulgaria with a share of less than 0.1%.

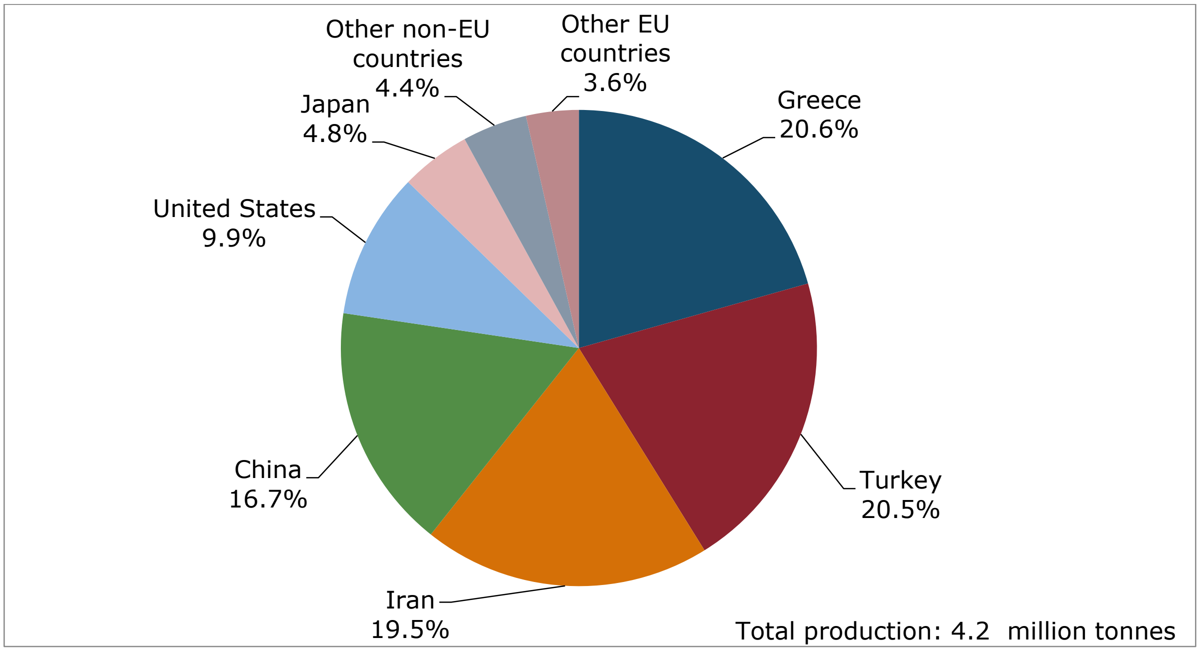


Figure 178: Global mine production of perlite, average 2010–2014 (Data from BGS World Mineral Statistics database)

22.2.2 Supply from secondary materials

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-28. The recycling of mineral-based waste in EU-28, 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.

22.2.3 Trade

22.2.3.1 EU trade

Europe is a net exporter of perlite with an average net export figure in the period 2010-2014 of 17 thousand tonnes (Figure 179). In the same five years period, it is recorded an average import figure per annum of 246.75 thousand tonnes from extra-EU28 countries. Considering that Europe produced between 2010 and 2014 approximately 1.02 million tonnes of crude perlite ore per annum suggests that imports of perlite to Europe represent a small flow. Europe imports perlite primarily from South Africa (31%) and small quantities from China, Mozambique and the United States (Figure 180). Several other countries provide perlite to EU-28, but in very small quantities. EU-28 exports perlite primarily to the United States, Israel and Canada.

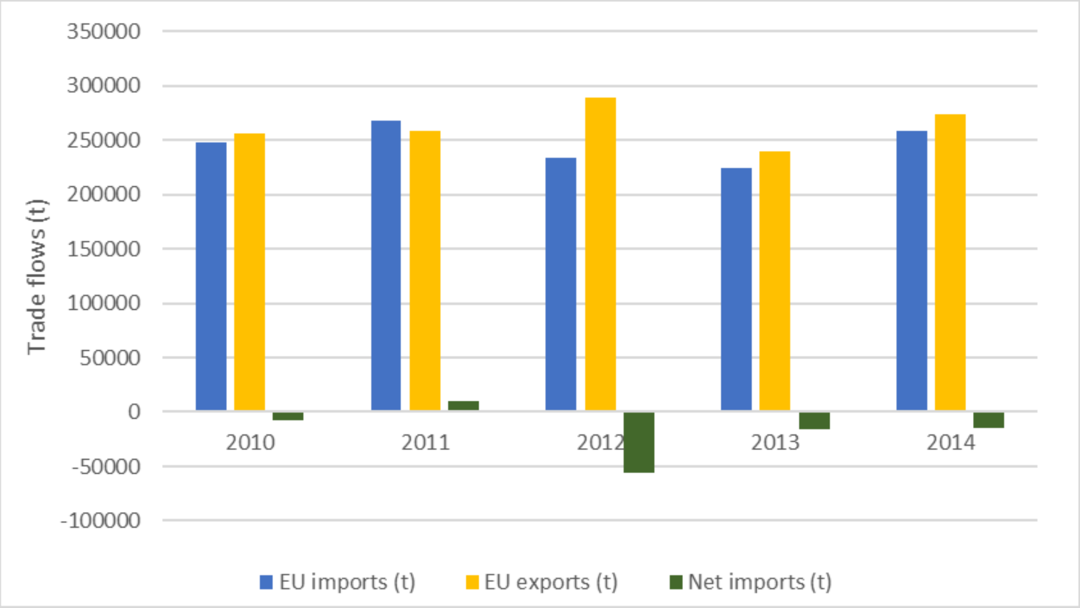


Figure 179: EU trade flows for perlite. (Data from Eurostat, 2016a)

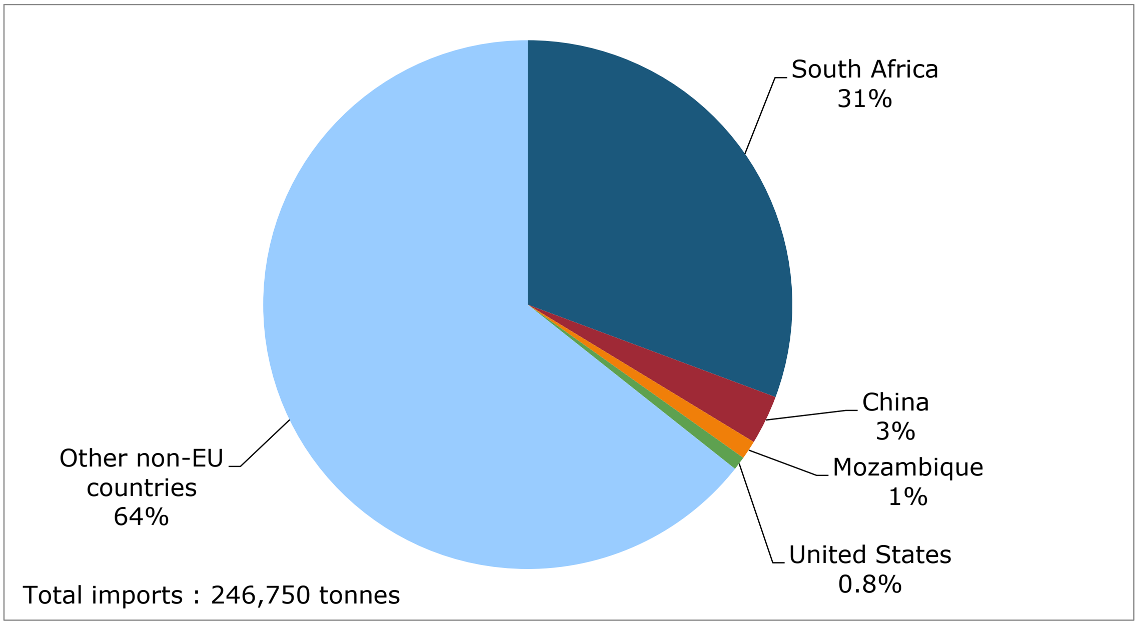


Figure 180: EU imports of perlite, average 2010-2014. (Data from Eurostat, 2016a)

22.2.3.2 Global trade

At global level, the United States is the World largest importer of perlite accounting for 13% of the world imports per annum for the period 2011 to 2014. China, Greece and Turkey appear to be the World largest exporters of perlite. 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, 2016). Turkey exports perlite to Europe and the Russian Federation.

22.2.4 EU supply chain

The 5 years average European production of perlite between 2010 and 2014 was 1.02 million tonnes per year, which accounts for 24% of the global production. Producing countries include Greece, Hungary, Italy, Slovakia and Bulgaria (based on data from BGS, 2016).

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 Figure 181 represents the EU sourcing (domestic production + imports) of perlite. The import reliance is negative but set at 0% in the 2017 criticality assessment for the sake of harmonisation. There are no export restrictions, quotas or prohibitions identified that may impact on the availability of perlite.

Perlite is not recovered during waste management and therefore it is not available from secondary sources.

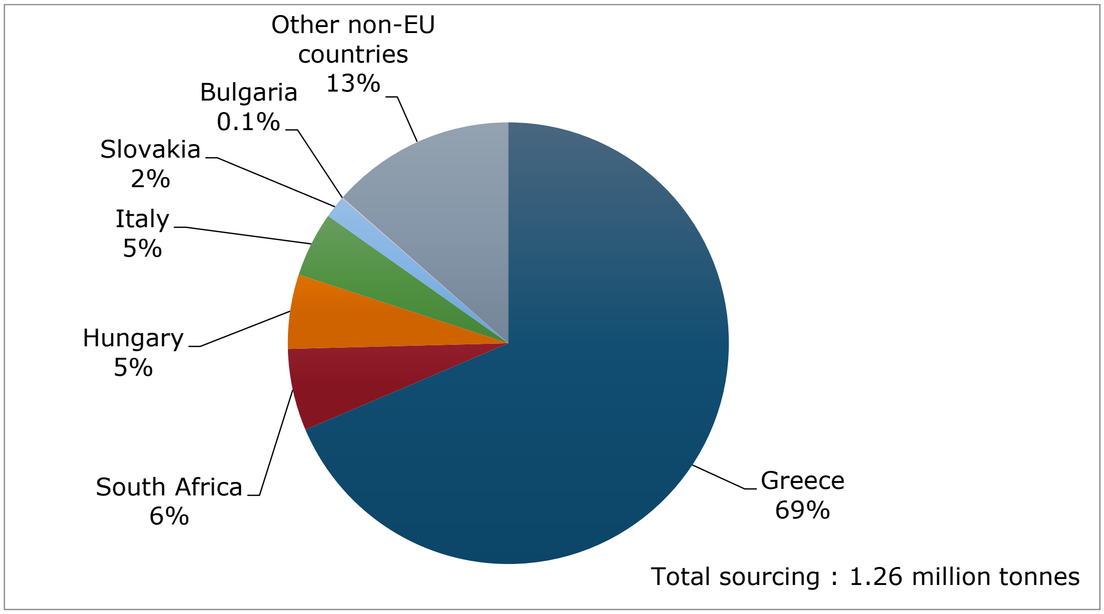


Figure 181: EU sourcing (domestic production + imports) of perlite, average 2010-2014. (Data from Eurostat, 2016a; BGS, 2016)

22.3 Demand

22.3.1 EU consumption

The European apparent consumption in the period 2010 and 2014 (5 year average figure) is estimated at 1 million tonnes per year, of which 1.02 million tonnes per annum is the domestic production, 247 thousand tonnes per annum is the imports to the EU from extra EU-28 countries and 263 thousand tonnes per annum is the exports from the EU to extra EU-28 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 it can sufficiently satisfy the EU industry demand for perlite, without import reliance issues. At global level, the United States is the leading single country consumer of crude and expanded perlite in the examined period. Europe is a substantial contributor to the United States perlite flows as most EU perlite export are to the United States.

22.3.2 Applications / end uses

Perlite is used in building construction products, as a filler in several applications, as a horticultural aggregate and in filter aid applications. The EU market shares of the above mentioned applications are presented in Figure 182.

Relevant industry sectors are described using the NACE sector codes provided in Table 109.

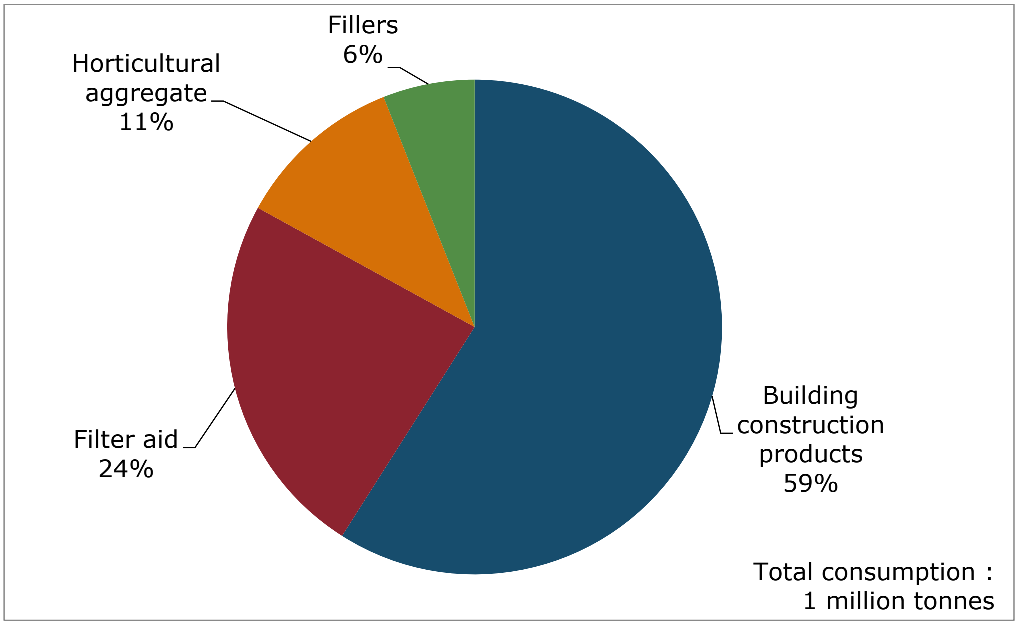


Figure 182: EU end uses of perlite. Average figures for 2010-2014. (Data from Industrial Minerals Association (IMA-Europe), 2016).

Table 109: Perlite applications, 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2016c).

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	59,166.0	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	59,166.0	C2920 - Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semi-trailers
Horticultural aggregate	C23 - Manufacture of other non-metallic mineral products	59,166.0	C2811 - Manufacture of engines and turbines, except aircraft, vehicle and cycle engines
Filter aid	C11 - Manufacture of beverages	37,636.4	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 to a range of different products (Perlite Institute, 2009).

Perlite is used in horticulture as a 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 utilized (Perlite Institute, 2009; Patel and Torrisi, 2014).

Perlite finds use as a filler in explosives, caulking media, paints, plastics and packing for shipping products (Perlite Institute, 2009).

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 is lower in 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).

22.4 Prices and markets

The price of perlite depends on the end use and the grade of perlite required. The price of raw perlite in bulk form ranges from 75 to 95 € per tonne, depending on the grade and producer. This price has remained quite stable over the past two years (Industrial Minerals, 2016). According to USGS, the average value of expanded perlite in the United States was $332 per tonne in 2014. During the past 10 years, the prices for expanded perlite have not presented major fluctuations, but a steady increase since 2009 has been observed (USGS, 2016). The price of perlite, milled filter –aid grade in the United States may range from $850 to $1100 per tonne (Industrial Minerals, 2016).

22.5 Substitution

Substitutes are identified for the applications and end uses of the commodity of interest. In the case of perlite, substitutes have been identified for the applications of 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 and pumice. Several other materials could be used as a 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 somehow the performance of the end product. Cost wise however, expanded clay is a cheaper material than perlite. Vermiculite may substitute perlite in flame retardant products. Vermiculite however tends to be more expensive than perlite and provides similar performance. Pumice may also substitute perlite in some cases. Pumice has a lower cost than perlite, but it 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 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, which comprises a popular filter media. Cellulose and rice husk ash are also often used, including explanded clay and pumice. .Filter aid is used in solid-liquid separation. 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.

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. The literature used to identify substitutes for perlite is listed in section 22.8.

22.6 Discussion of the criticality assessment

22.6.1 Data sources

Market shares are based on the statistical data provided by the Industrial Minerals Association and they represent the European market (Industrial Minerals Association (IMA-Europe) (2016)). Production data for perlite are from World Mineral Statistics dataset published by the British Geological Survey (BGS, 2016). Trade data was extracted from the Eurostat Easy Comext database (Eurostat, 2016a). 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, 2016).

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 2010 to 2014. Another issue with the current trade data concerns the aggregated EU-28 extra import figure, which appears to be around three times larger (246,5 thousand tonnes)than the sum of import data reported by individual countries (88 thousand tonnes). This is not uncommon regarding trade data. Often due to confidentiality rules individual country data are not available, but they are included in the aggregated EU-28 extra figures.

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.

Other data sources used in the criticality assessment are listed in section 22.8.

22.6.2 Economic importance and supply risk calculation

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 109). The value added data correspond to 2013 figures.

The supply risk was assessed on perlite using both the global HHI and the EU-28 HHI as prescribed in the revised methodology.

22.6.3 Comparison with previous EU criticality assessments

A revised methodology was introduced in the 2017 assessment of critical raw materials in Europe. Both the calculations of economic importance and supply risk are now different therefore the results with previous assessments are not directly comparable.

The results of this review and earlier assessments are shown in Table 110.

Table 110: Economic importance and supply risk results for perlite in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

Assessment	2011		2014		2017	
Indicator	EI	SR	EI	SR	EI	SR
Perlite	4.20	0.31	4.55	0.28	2.1	0.4

Although it appears that the economic importance of perlite has reduced between 2014 and 2017 this is a false impression created by the change in methodology. The value added used in 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 primarily due to the methodological modification and the way the supply risk is calculated. It is not possible to quantify what proportion of these changes is due to the methodology alone, as new data have been used in the assessment.

22.7 Other considerations

One of the key issues with the assessment of perlite undertaken is the availability of trade data on perlite alone. As explained previously, trade flows of perlite are agglomerated together with trade flows of vermiculite and chlorites and several assumptions are required to enable the use of existing data in a meaningful way. A Combined Nomenclature code for perlite alone exists, but no data is reported against this code.

Information and data regarding the production and price of perlite in China are not reliable. China is one of the leading producing countries of the world and in order to understand the trade flows better as well as estimate world production and price unit values more reliably, access to this information and data is needed.

22.7.1 Forward look

There are 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 especially in the United States which represents the largest consumer globally. Building and infrastructure construction related projects are expected to increase in the future and as such the consumption of perlite is likely to increase too. Perlite expanded plants in the United States rely on imports of perlite from Europe and this trend is expected to continue (USGS, 2016).

Table 111: Qualitative forecast of supply and demand of perlite

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
Perlite		x	+	+	?	+	+	?

22.8 Data sources

22.8.1 Data sources used in the factsheet

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 (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 (2016)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

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/

Evans, A. M. (1993). Ore Geology and Industrial Minerals. An Introduction. . Third Edition Oxford and Northampton Blackwell Science

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

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.

Minerals4EU (2014). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

OECD (2016). OECD Export restrictions on Industrial Raw Materials database. [online] Available at: http://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 (2009). Applications of perlite [online] Available at: https://www.perlite.org/

Sulpizio, T. E. (1999). Advances in filter aid and precoat filtration technology. American Filtration & Separation Society Annual Technical Conference.

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

22.8.2 Data sources used in the criticality assessment

Alibaba (2016). Alibaba - The World's Leading Platform for Global Trade. [online] Available at: www.alibaba.com

American Filtration & Separation Society (2016). What are filter aids [online] Available at: http://www.afssociety.org/filtration-media/61-what-are-filter-aids

American Filtration & Separation Society (2016). Filter aids [online] Available at: http://www.afssociety.org/filtration-media/57-filter-aids-

Sulpizio, T. E. (1999). Advances in filter aid and precoat filtration technology. American Filtration & Separation Society Annual Technical Conference.

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 (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

European Manufacturers of Expanded Polystyrene (EUMEPS) (2016). EUMEPS - Construction [online] Available at: http://www.eumeps.construction/eps_4105.html

Eurostat (2016). International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

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 (2016). Eurostat Waste Statistics [online] Available at: http://ec.europa.eu/eurostat/statistics-explained/index.php/Waste_statistics

Glass Alliance Europe (2016). Industries [online] Available at: http://www.glassallianceeurope.eu/en/industries

Greenhouse product news (2004). Alternative hydroponic substrates [online] Available at: http://www.gpnmag.com/article/alternative-hydroponic-substrates/

GreenSpec (2016). Aggregates for concrete. [online] Available at: http://www.greenspec.co.uk/building-design/aggregates-for-concrete/

Homeguides (2016). Alternatives to vermiculite and perlite [online] Available at: http://homeguides.sfgate.com/alternatives-vermiculite-perlite-43502.html

Indianmart (2016). Rice Husk Ash [online] Available at: http://dir.indiamart.com/impcat/rice-husk-ash.html

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/

Jelu (2016). Cellulose filter aid: ecological and economical. [online] Available at: https://www.jelu-werk.com/technical-industry/applications/cellulose-filter-aid/

Kleih, U. a. H., A.C. (1993). Production of high quality rice husk ash. Technical Report. [online] Chatham, UK: Available at: https://core.ac.uk/download/pdf/42390183.pdf

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

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

The Schundler Company (Perlite plant guide). [online] Available at: http://www.schundler.com/polystyrene.htm

USGS (2013). Bentonite. 2013 Minerals Yearbook. [online] Available at: https://minerals.usgs.gov/minerals/pubs/commodity/clays/

USGS (2014). Diatomite. 2014 Minerals Yearbook. [online] Available at: https://minerals.usgs.gov/minerals/pubs/commodity/diatomite/

USGS (2014). Pumice. 2014 Minerals Yearbook. [online] Available at: https://minerals.usgs.gov/minerals/pubs/commodity/pumice/

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

USGS (2016). Mineral Commodity Summary - Pumice and Pumicite. [online] Available at: https://minerals.usgs.gov/minerals/pubs/commodity/pumice/

USGS (2016). Mineral Commodity Summary - Iron and Steel Slag. [online] Available at: https://minerals.usgs.gov/minerals/pubs/commodity/iron_&_steel_slag/

22.9 Acknowledgments

This Factsheet was prepared by the British Geological Survey (BGS). The authors would like to thank the Industrial Minerals Association and 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. POTASH

Key facts and figures

Material name and Formula	Potash, K_2O	World / EU production (tonnes)[1]	33,980,686/ 4,254,936
Parent group	n.a.	EU import reliance[1]	23%
Life cycle stage assessed	Extraction	Substitution index for supply risk [SI(SR)][1]	1.00
Economic importance (EI)(2017)	4.8	Substitution Index for economic importance [SI(EI)][1]	1.00
Supply risk (SR) (2017)	0.7	End of life recycling input rate (EOL-RIR)	0%
Abiotic or biotic	Abiotic	Major global end uses (2014)	Fertilisers (92%), Chemicals (8%)
Main product, co-product or by-product	Mainly primary production	Major world producers[1]	Canada (30%), Russia (17%), Belarus (15%)
Criticality results	2011	2014	2017
	Not assessed	Not Critical	Not critical

[1] average for 2010-2014, unless otherwise stated.

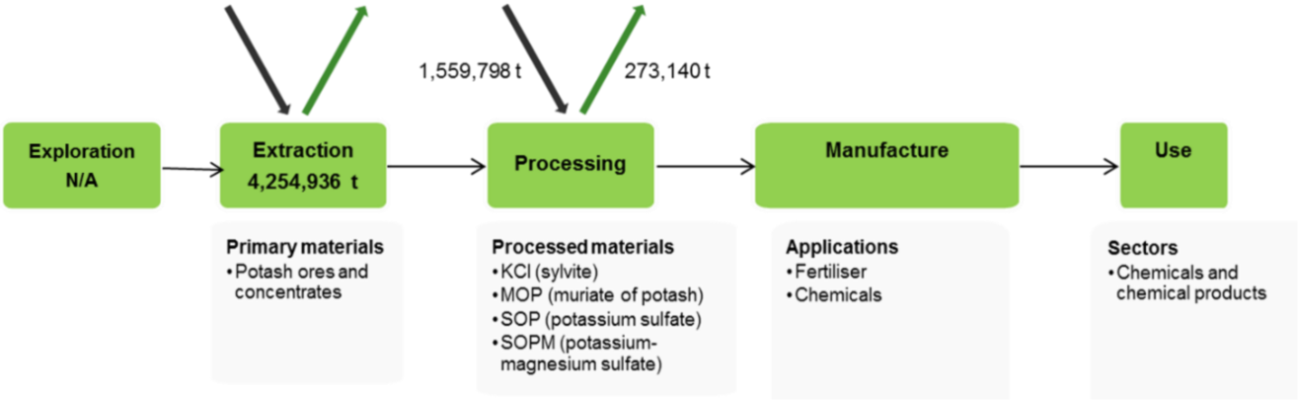


Figure 183: Simplified value chain for potash

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the extraction and processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU. A quantitative figure on recycling is not included as the EOL-RIR is below 70%. EU reserves are displayed in the exploration box.

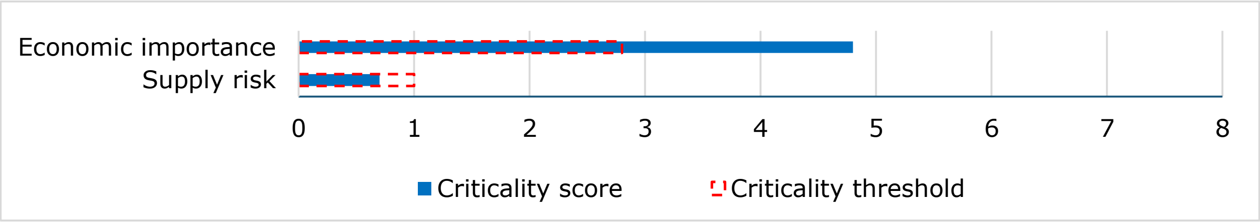


Figure 184: Economic importance and supply risk scores for potash

23.1 Introduction

The term potash (expressed as K2O content) is commonly use in agriculture and horticulture to describe the nutrient form of elemental potassium (K). Potassium is an abundant element in the Earth's uppercrust with an abundance of about 2.8 wt. % (Rudnick, 2003). Potash minerals occur in bedded-evaporite deposits. They are typically chloride (Cl) or sulphate (SO4) based compounds that contain varying amounts of K and/or Mg and Ca. Potash minerals are typically pinky-red in colour, soft and extremely water soluble. Economically important potash minerals include: Carnallite, Sylvite and Sylvinite. Potassium has many essential biological roles in animals, plants and humans, such as metabolism and growth. Hence the main application of potash is in the manufacture of fertilisers. Potash minerals are used in the manufacture of numerous potassium-based compounds such as potassium hydroxide (KOH), potassium nitrate (KNO3) and potassium carbonate (K2CO3). These compounds are used in a wide range of applications that include: medicine; glass; explosives; pyrotechnics; ink; bleaching agents; soaps; dyes; textiles, etc.

In Europe an average 4.3 million tonnes of potash is extracted per annum in Germany, Spain and the United Kingdom, or about 13% of the global total. Apparent consumption of potash in the EU is about 5.5 million tonnes per annum, the majority of which was used in the production of fertiliser for the agriculture industry. According to the EC agricultural crop output was valued at €200 million in 2015 (EC, 2016).

23.2 Supply

23.2.1 Supply from primary materials

23.2.1.1 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 (Dill, 2010). 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 nonmarine, or mixed marine-nonmarine 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 (Prud’homme and Krukowski, 1994; Dill, 2010; Pohl, 2011).

European potash production is primarily from the Zechstein Formation, a large (c. 200,000 km^3) 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 a cap rock for the North Sea oilfield (Pohl, 2011).

23.2.1.2 Exploration

The Minerals4EU project identified that potash exploration in the EU, in 2013, was primarily taking place in Spain and the UK. However, exploration may have taken place in other EU countries where no information was provided during the survey (Minerals4EU, 2015).

Global exploration for potash is currently focused in Canada, parts of Africa (e.g. Ethiopia, Eritrea and Republic of Congo), Australia, the US and Brazil. Although, the current eight year low-price of potash may put some of these projects on hold for the foreseeable future (Mining Journal, 2016).

23.2.1.3 Mining, processing and extractive metallurgy

Potash is primarily extracted from deep underground deposits by conventional mining methods similar to those used for extracting coal (i.e. mechanised longwall mining). 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 recrystallised by evaporation (PotashCorp, 2016). This process is known as solution mining.

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, which may be used in the production of fertilisers and potassium-chemicals (PotashCorp, 2016).

23.2.1.4 Resources and reserves

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[22], 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.

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 at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU, 2015).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] www.crirsco.com

Global resources of potash are geographically widespread and very substantial. The USGS estimates that worldwide resources of potash are likely to be about 250 billion tonnes (USGS, 2016). In Europe three countries are known to have potash resources, namely Spain, Germany and the United Kingdom. However, data for these are not reported in accordance with the UNFC system of reporting. Data for Germany are not reported at all because data collection in that country is the responsibility of sub-national level authorities (Minerals4EU, 2015). Resource data for some countries in Europe are available in the Minerals4EU website (see Table 112) (Minerals4EU, 2014) but cannot be summed as they are partial and they do not use the same reporting code.

Table 112: Resource data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Quantity	Unit	Grade	Code resource type
UK	JORC	11.5	Mt	K_2O content	Indicated and Inferred
Spain	None	117.5	Mt	Potash	Historic resource estimate

Global reserves of potash are also sizeable (Table 113) and widely distributed, but are notably concentrated in Canada, Belarus and Russia. Reserve data for some countries in Europe are available in the Minerals4EU website (see table 114) but cannot be summed as they are partial and they do not use the same reporting code.

Table 113: Global reserves of potash in 2016 (Data from USGS, 2016)

Country	Potash (K_2O equivalent) Reserves (tonnes)	Percentage of total (%)
Canada	1,000,000,000	27
Belarus	750,000,000	20
Russia	600,000,000	16
Israel	270,000,000	7
Jordan	270,000,000	7
China	210,000,000	6
Chile	150,000,000	4
Germany	150,000,000	4
United States	120,000,000	3
United Kingdom	70,000,000	2
Spain	20,000,000	<1
Brazil	13,000,000	<1
Other countries	90,000,000	2
World total (rounded)	*3,700,000,000*	*100*

Table 114: Reserve data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Quantity	Unit	Grade	Code reserve type
UK	JORC	4	Mt	K_2O content	Proven & probable
Spain	-	2.6	Mt	Potash	Proven
Italy	None	500	Mt	Potash salts	Estimated
Ukraine	Russian classification	5,212	kt	Potassium salts, K_2O contained	A

23.2.1.5 World potash production

On average, almost 34 million tonnes (K2O content) of potash is extracted each year from 12 countries worldwide. However, a large proportion (c. 60 %) of production occurs in just three countries, Canada (30 %), Russia (17 %) and Belarus (15 %) (Figure 185). Other important global producers include, China, Israel, Jordan and Chile. European production, chiefly from Germany (9%), Spain (2%) and the United Kingdom (1%), accounts for about 13 % of total global supply, i.e. around 4.2 million tonnes (BGS, 2016).

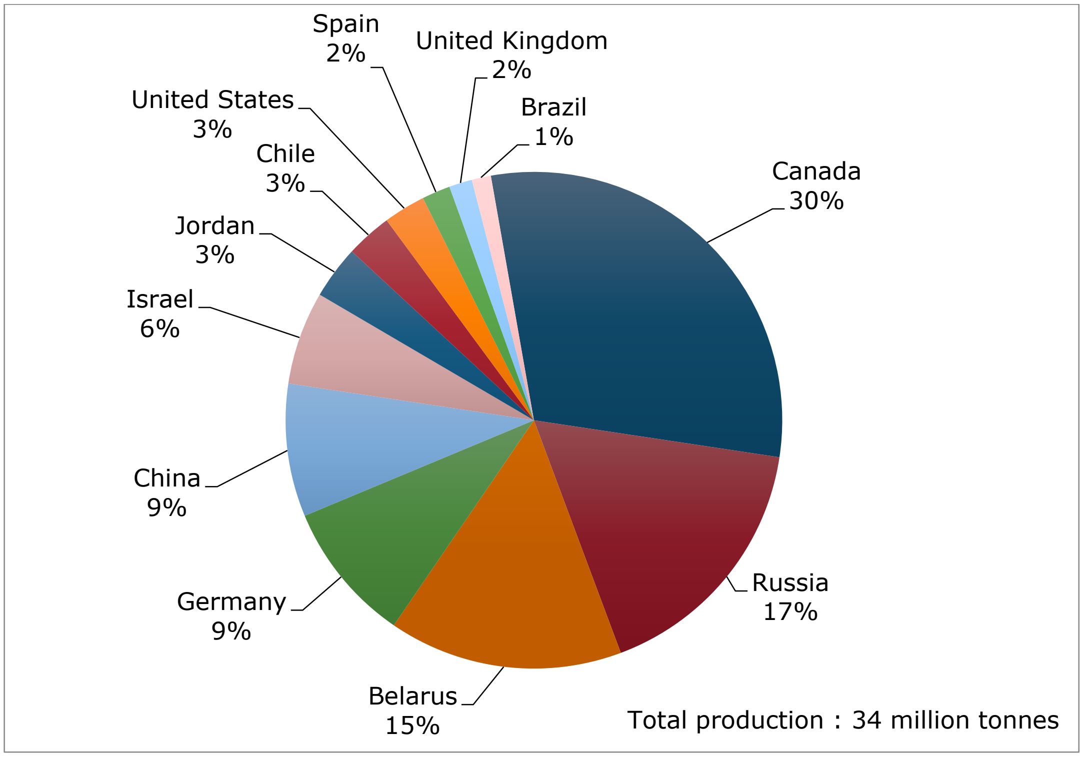


Figure 185: Global mine production of potash, average 2010–2014 (Data from BGS World Mineral Statistics database - BGS, 2016)

23.2.2 Supply from secondary materials

Potash minerals are highly-water soluble, which results in them becoming widely dispersed in the natural environment, they are thus irrecoverable and non-recyclable (Harben, 1999; EC, 2014). The End-of-life recycling input rate is thus 0%.

23.2.3 EU trade

Trade data for potash minerals (i.e. carnallite and sylvite) in the EU are not available from Eurostat. As a result it was only possible to calculate a global supply risk for potash ores and concentrates.

However, trade data for processed potassium chloride reveal that on average the EU imports just over 1.5 million tonnes of potassium chloride (as K2O) each year, but exports only about 300 thousand tonnes. The EU is therefore a net importer of potassium chloride, which may indicate that domestic production is not sufficient to meet current EU demand alone. The import reliance is 23%.

More than half (ca. 71 %) of EU imports come from just two countries, Russia and Belarus. The remainder comes from Chile, Canada, Israel and Jordan (Figure 186). Imports of potassium chloride into the EU have been relatively consistent during the same period, although notable exceptions are Chile and Israel, which have decreased their exports to the EU by 34 % and 55 % respectively. Spain is Europe's most significant exporter of potassium chloride, on average accounting for 77 % of all European exports during the period 2010–2014.

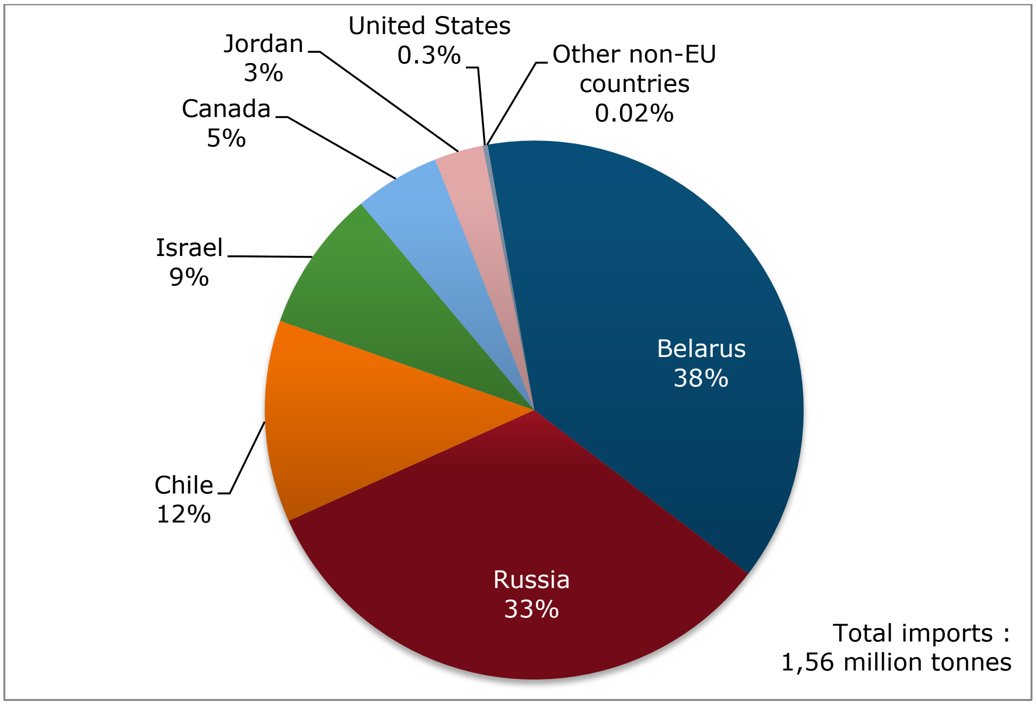


Figure 186: EU imports of processed potassium chloride (K_2O content), average 2010–2014 (Data from Comext database - Eurostat, 2016a)

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 % (OECD, 2016).

23.2.4 EU supply chain

Primary potash is extracted in only three EU countries, Germany, Spain and the United Kingdom. Combined production from these three countries accounts for about 13 % of the global total, or on average about 4.3 million tonnes (as K2O) per annum during the 2010–2014 period. This explains the relatively low import reliance of 23 % for potash in the EU. The EU sourcing (domestic production + imports) is shown in the Figure 187.

Based on averages during the period 2010–2014 just over 1.5 million tonnes (as K2O) per year of potassium chloride was imported into the EU, almost all of which went to only seven EU countries, namely Belgium, Germany, Spain, the United Kingdom, the Netherlands, France and Ireland. These countries account for a significant amount (ca. 70 %) of European agricultural output, and hence drive European demand for potassium chloride as a fertiliser (EC, 2016).

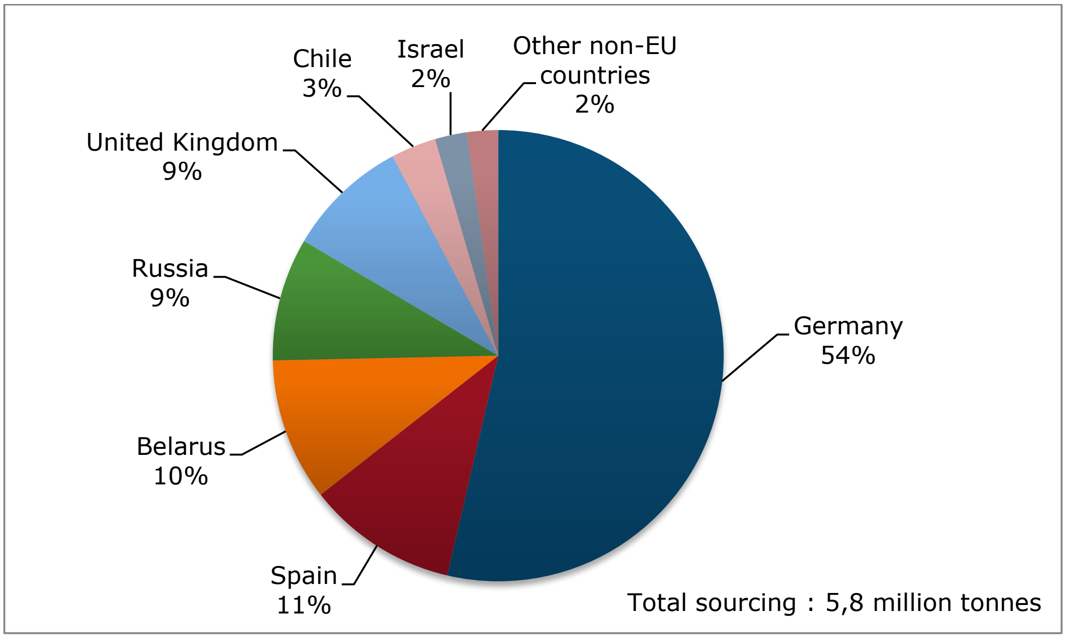


Figure 187: EU sourcing (domestic production + imports) of processed potassium chloride (K_2O content), average 2010–2014 (Data from Comext database - Eurostat, 2016a; BGS, 2016)

23.3 Demand

23.3.1 EU consumption

EU consumption of potash and concentrates in the EU was about 5.5 million tonnes (as K_2O) per year during the period 2010–2014. About 72 % of this (on average almost 4 million tonnes of K_2O per year) came from within the EU. The remainder was imported from outside the EU. This explains the relatively low estimated import reliance of 23 %.

23.3.2 Applications/end-uses

Global end-uses of potash in 2014 are shown in Figure 188 and relevant industry sectors are described using the NACE sector codes in Table 115.

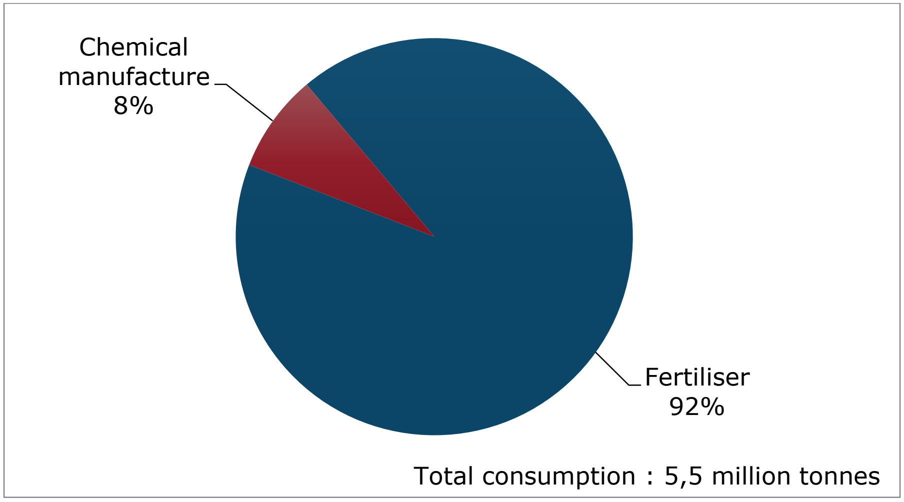


Figure 188: Global end uses of potash. Figures for 2014 (Data from USGS, 2014)

Table 115: Potash applications, 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2016c)

Application	2-digit NACE sector	Value added of NACE 2 sector (millions €)	4-digit NACE sector
Fertiliser	C20 - Manufacture of chemicals and chemical products	110,000	C2015 – Manufacture of fertilisers and nitrogen compounds
Chemicals	C20 - Manufacture of chemicals and chemical products	110,000	C2013 – Manufacture of other inorganic basic chemicals

About 92 % of potash is used in the production of fertilisers. Potassium is one of three key macro-nutrients required for plant growth, the other two being phosphorous and nitrogen. It has a number of key biological roles in plants, including enzyme activation, water usage, photosynthesis and transport of sugars, starch formation and improved resistance to diseases (Harben, 1999).

Only a small amount (ca. 8 %) of potash is used in the production of potassium-bearing chemicals; however, they are used in a wide array of applications, a few of which are shown in Table 116. Many of these chemicals are strong oxidising agents (e.g. potassium persulphate, potassium permanganate and potassium nitrate) that are used for bleaching, water treatment and in the production of explosives.

Table 116: A selection of potassium-based chemicals and their applications and uses (Harben, 1999)

Chemical	Formula	Applications and uses
Potassium sulphate	K_2SO_4	Fertiliser; medicines; glass; accelerator in gypsum products
Potassium bisulphate	$KHSO_4$	Fertiliser; food preservative
Potassium persulphate	$K_2S_2O_8$	Bleaching agent; photography
Potassium nitrate	KNO_3	Fertiliser; explosives; glass; ceramics; plastics; medicines
Potassium oxide	K_2O	Fertiliser; explosives; glass; ceramics; medicines
Caustic potash	KOH	Synthetic rubber; batteries; soap; bleaching agent; water treatment
Potassium permanganate	$KMnO_4$	Bleaching agent; catalyst; water treatment; pigment
Potassium carbonate	K_2CO_3	Optical glass; ceramics; dehydrating agent
Potassium cyanide	KCN	Gold and silver recovery; fumigant; insecticide; photography

23.3.3 Prices and markets

United States potash prices rose sharply from almost US$200 per metric ton in 2004 to a high of over US$800 per metric ton in 2009. Since then they have been generally declining to just over US$600 per metric ton tonne in 2015 (Figure 189). The general decline in potash price is related to weak demand and increased competition, which has led to oversupply in some markets (Mining Journal, 2016).

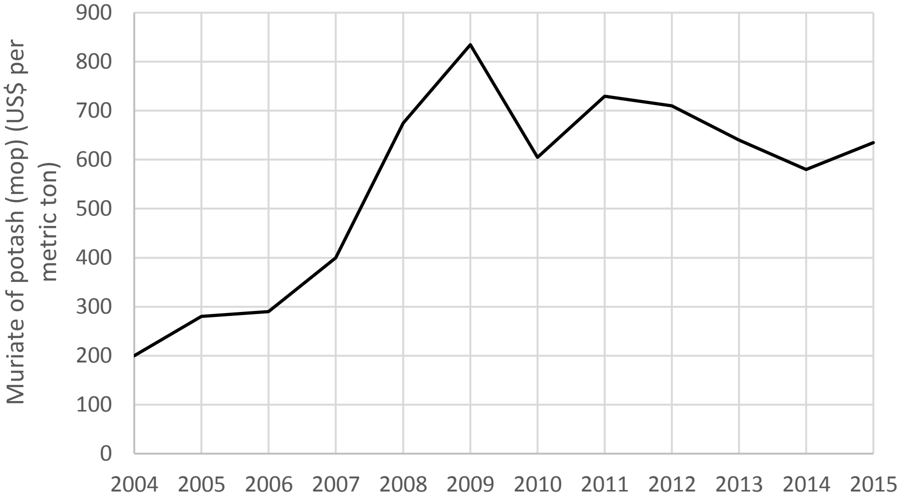


Figure 189: United States potash (muriate of potash – mop) price trend. (Data from USGS, 2015; 2016)

23.4 Substitution

Potash is one of three essential macronutrients required for plant growth and currently has no cost-effective substitutes. Alternatives, such as manure and glauconite (i.e. green sand) are available. However, they typically have much lower potassium contents and cost more per tonne of nutrient to transport (Harben, 1999; USGS, 2016).

23.5 Discussion of the criticality assessment

23.5.1 Data sources

Production data for potash ores and concentrates was taken from the British Geological Survey's World Mineral Statistics dataset (BGS, 2016). Trade data for crude (raw) potash minerals were unavailable from Eurostat. As such potassium chloride (as K2O) trade data were taken from the Eurostat COMEXT online database instead (Eurostat, 2016) using the Combined Nomenclature (CN) code 310 420 (potassium chloride for use as fertiliser). Data were averaged over the five-year period 2010–2014 inclusive. Other data sources have been used in the assessment and are listed in section 23.7.

23.5.2 Calculation of economic importance and supply risk indicators

The calculation of Economic Importance (EI) was based on the 2-digit NACE sectors shown in Table 115. For information about the application share of each sector see section on applications and end-uses. Figures for value added were the most recently available at the time of the assessment (i.e. 2013) and are expressed in thousands of Euros.

The calculation of Supply Risk (SR) was calculated at the ores and concentrates stage of the life cycle using the global HHI calculation due to the unavailability of EU trade data on potash ores and concentrates.

23.5.3 Comparison with previous EU criticality 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 117.

Table 117: Economic importance and supply risk results for potash in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Potash	n.a.	n.a.		8.61	0.21		4.8	0.7

Although it appears that the economic importance of potash has reduced between 2014 and 2017 this is a false impression created by the change in methodology. 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).

23.6 Other considerations

Potash (K_2O) is one of three key macro-nutrients required for plant growth, as such it is hard to imagine that future demand for potash will cease altogether. In fact, according to the Food and Agricultural Organisation of the United Nations (FAO) fertiliser demand is forecast to increase in the short term. This increase is largely driven by demand in China, India and Indonesia (FAO, 2015).

Polyhalite (K2Ca2Mg(SO4)4·2H2O) is an important evaporite mineral that is ustilised as a multi-nutrient (i.e. K2O, Mg, S, Ca) fertiliser, particularly for chloride sensitive crops. The world's largest polyhalite deposit (containing almost 2.7 billion tonnes of polyhalite resource) is currently being developed below the North Sea, off the North Yorkshire coast, in the United Kingdom by Sirius Minerals Plc (Sirius Minerals Plc, 2016). If successfully developed there is potential for the United Kingdom to become a globally important supplier of polyhalite.

The future demand and supply for potash is presented in Table 118.

Table 118: Qualitative forecast of supply and demand of potash

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
Potash		x	+	+	?	+	+	+

23.7 Data sources

23.7.1 Data sources used in the factsheet

BGS (2016). World Mineral Production 2010-2014 [online]. Keyworth, Nottingham British Geological Survey, Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.html

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). Agriculture in the European Union and the Member States – Statistical Factsheets [online] Brussels European Commission, Available at: http://ec.europa.eu/agriculture/statistics/factsheets_en

Eurostat (2016)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

FAO (Food and Agriculture Organisation of the United Nations). (2015). World fertiliser trends and outlook to 2018 [online]. Available at: www.fao.org/3/a-i4324e.pdf

Harben, P.W. (1999). The Industrial Minerals Handybook, 3rd ed. Worcester: Industrial Minerals Information Ltd. 296.

InfoMine Commodity and Metal Prices [online]. Available at: http://www.infomine.com/investment/metal-prices/

Minerals4EU (2014). European Minerals Yearbook [online]. Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

Mining Journal. (2016). Tough times persist in potash [online]. Available at: http://www.mining-journal.com/commodities/industrial-minerals/tough-times-persist-in-potash/

Pohl, W.L. (2011). Economic Geology, Principals and Practice. Oxford. Wiley-Blackwell, 678.

Potash Corp. (2016). The Potash Journey – Potash Profile [online]. Available at: www.potashcorp.com/media/POT_Journey_Brochure.pdf

Prud’homme, M. and Krukowski, S.T. (2006). Potash *in* Kogel, J.E., Trivedi, N.C., Barker, J.M. and Krukowski, S.T. ed., Industrial Minerals and Rocks, 7th ed. Colorado: Society for Mining, Metallurgy and Exploration (SME), 1548.

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.

Sirius Minerals Plc. (2016). Our Project, The Deposit [online]. Available at: http://siriusminerals.com/our-project/the-deposit/

USGS (2014). Minerals Yearbook. Potash [online]. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/potash/

USGS (2015). Mineral Commodity Summary. Potash [online]. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/potash/

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

23.7.2 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

Eurostat COMEXT database [online]. Available at: http://ec.europa.eu/eurostat/data/database

OECD Export Restriction database [online]. Available at: http://www.oecd.org/tad/benefitlib/export-restrictions-raw-materials.htm

23.8 Acknowledgments

This Factsheet was prepared by the British Geological Survey (BGS). The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this Factsheet.

24. RHENIUM

Key facts and figures

Material name and Element symbol	Rhenium, Re	World/EU production (tonnes)[1]	Refining : 42.5 / 7
Parent group (where applicable)	-	EU import reliance[1]	18%
Life cycle stage /material assessed	Processing / Re metal (99.9%)	Substitute index for supply risk [SI(SR)]	0.99
Economic importance score EI (2017)	2.0	Substitute Index for economic importance [SI(EI)]	0.98
Supply risk SR (2017)	1.0	End of life recycling input rate	50%
Abiotic or biotic	Abiotic	Major end-uses[1]	Aerospace superalloys (78%), Petrochemical Catalysts (14%)
Main product, co-product or by-product	By-product of copper and molybdenum	Major world producers[1] (refining)	Chile (44%), USA (19%), Poland (16%)
Criticality results	2010	2014	2017
	Not critical	Not critical	Not critical

[1] average 2010-2014 unless otherwise stated

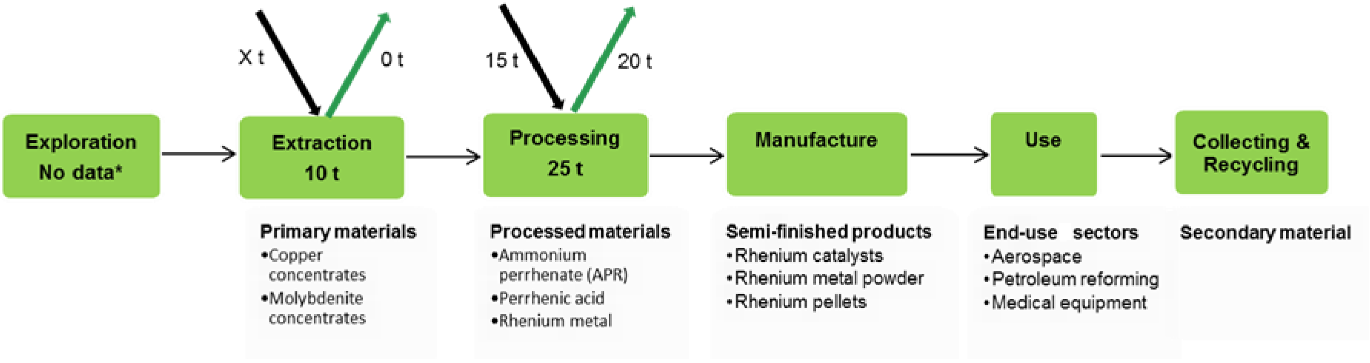


Figure 190: Simplified EU value chain for rhenium

Numbers are only indicative. Green boxes in the above figure indicate activities that are undertaken within the EU. The black arrows represent imports of material to the EU and the green arrows represent exports of materials from the EU. A quantitative figure on recycling is not included as the EOL-RIR is below 70%. It is however an important part of rhenium value chain taking place within the EU.*EU reserves data is partial and cannot be summed (cf.2.1.2).

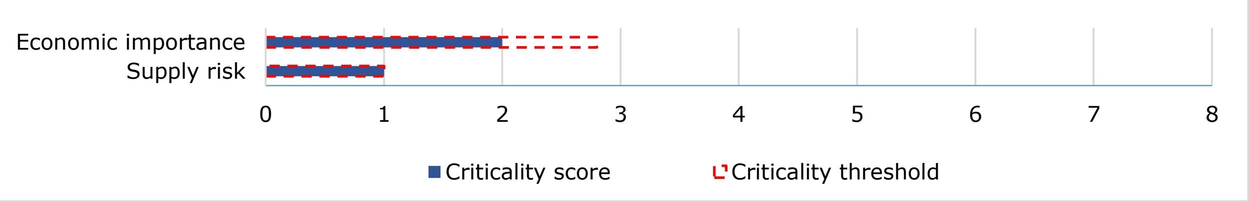


Figure 191 : Economic importance and supply risk scores for rhenium

24.1 Introduction

Rhenium (chemical symbol Re) is a greyish white metal. It has the third-highest melting point (3,185°C) and highest boiling point (5,596°C) of any element. It is ductile, dense (20.3 g/cm^3) and highly resistant to corrosion. It doesn't occur as a free element and is mostly found as trace impurities in Mo and Cu sulphide ores. It is one of the rarest elements in the upper continental crust with 0.2 ppb estimated concentration (Rudnick, 2003). Production levels are low (less than 50 tonnes /year worlwide) and rhenium products are destined to very specific markets. Its two major uses, including in the EU, are aerospace superalloys and petrochemical catalysts.

Poland has become one of the major players in the world rhenium market with full vertical integration and capacities of 7 tonnes /year, ensuring secure supply to the EU. Bulgaria and Romania are also minor producers (0.5 tonnes /year). Recycling activities with high added-value are also an important part of rhenium value chain taking place within the EU.

24.2 Supply

24.2.1 Supply from primary materials

24.2.1.1 Geology, mining and processing

Rhenium does not occur in any specific mineral but only as trace impurities in some sulphide ores. Rhenium is mostly obtained through recovery from copper concentrates and molybdenum concentrates (themselves by-product of copper). The two main sources of those concentrates are from porphyry-copper deposits primarily located in Chile and the United States, but also from sediment-hosted stratabound copper ores (Poland, Kazakhstan).

Hydrometallurgical routes are the only ones to recover rhenium. The gases released during the roasting of molybdenite concentrates from porphyry-copper deposits and from the refinery of copper sulphide ores contain oxidised rhenium and sulphurous gases. Rhenium capture from these gases uses a purifier (scrubber) with an efficiency of 80%, to produce sulphuric acid and other fluids containing dissolved rhenium. Further steps lead to the precipitation of rhenium in the form of *Ammonium perrhenate (APR)* which can be purified by recrystallization and marketed as a white powder or reduced in the presence of hydrogen at high temperatures to produce rhenium metal (Lipmann, 2016).

24.2.1.2 Rhenium resources and reserves

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[23], 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.

---

[23] www.crirsco.com

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 at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU, 2015).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.

During the Minerals4EU project, no information was reported concerning resources of Re in the EU. Data from Poland is not accessible in the public domain. Only one project is known in Turkey (Minerals 4EU, 2014). It refers to the Muratdere project with 2011 published JORC-compliant Inferred Resource of at least 51 million tonnes grading 0.36% copper, 0.12 g/t gold, 2.40 g/t silver, 0.0125% molybdenum, and 0.34 ppm rhenium . Another feasibility study was completed in May 2015, with no further notice or on any scheduled start of production (Stratex International, 2015). At this stage, it seems unlikely to become a new rhenium producer.

Reserves from Polyak (USGS, 2016) are the only global reference available, which give that world rhenium reserves are approximately 2,500 tonnes, although this does not include the reserves in Poland and Uzbekistan. From this perspective, half of global known rhenium reserves would be located in Chile (Table 119).

Table 119: Global reserves of rhenium (USGS, 2016)

Country	Reserves (tonnes Re metal contained)
Chile	1,300
USA	390
Russia	310
Kazakhztan	190
Armenia	95
Peru	45
Canada	32
Poland	N.A.
Uzbekistan	N.A.
Others	91
Total	*2,500*

24.2.1.3 World rhenium production

Warning: Quantities expressed below only refer to “primary production” i.e. the transformation from concentrates into APR or Re metal. Total supply available, which includes recycled quantities and producers’ stocks, could be much higher, as high as 70.5 tonnes for 2015 (Lipmann, 2016).

The world rhenium production amounts 42.5 tonnes on average over the period 2010-2014, where Chile remained the largest producer of rhenium products (18.5 tonnes on average), followed by the USA and Poland (8 and 7 tonnes respectively), see Figure 192. Following most important producers in order are South Korea, Japan and China, which are partly dependent on Chilean raw material (concentrates) for their production. None of the rest of the others has great critical mass, but they provide useful additional available supply. Others include Kazakhstan, Russia, Armenia, Uzbekistan, Iran and Mongolia.

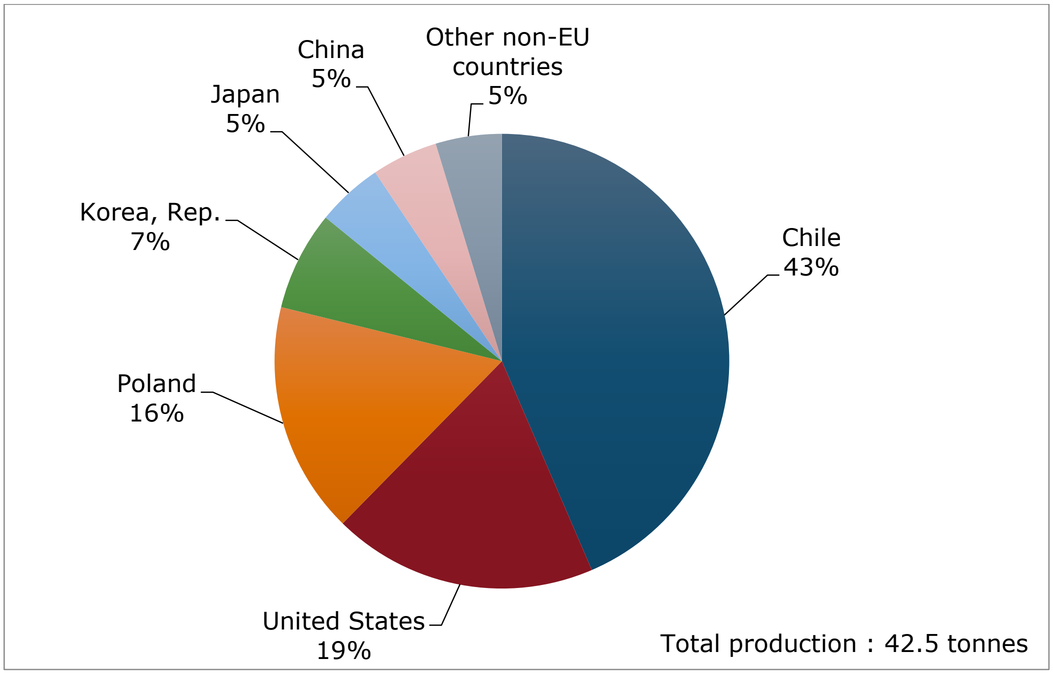


Figure 192: Global production of rhenium (expressed in metal content). Average 2010-2014 (Data from Lipmann, 2016)

24.2.2 Supply from secondary materials

The rate of recovery of rhenium from end-of-life products is superior to 50% (UNEP, 2011). Rhenium is recycled from two main types of end-finished products: spent catalysts and end-of-life turbine blades, casting, or grindings. However, this recycling is primarily 'pre-consumer' that is, from within the upstream supply chain itself, rather than from end-users. Those materials find their way back into the catalysts or superalloys production loop. This type of recycling is however an important and critical source of supply in the market and has become even more important over time. The catalysts industry has an 80% recovery efficiency, reducing the virgin rhenium needs to replace spent catalysts. A. Lipmann estimates that in 2015, 19.7 tonnes of rhenium were coming from recycled and revert materials, representing 28% of total supply of rhenium available (Lipmann, 2016). In Europe, Germany is an important secondary producer (companies such as Aurubis and Heraeus).

24.2.3 EU trade and supply chain

EU Import reliance for rhenium is only 18%. No figure is available for trade of rhenium in Eurostat Comext database. The reason is that in customs statistics, rhenium is reported in a single category along with gallium, hafnium, indium or niobium. Thus, figures obtained based on this category are neither reliable nor representative of EU rhenium consumption which is known to be much smaller than other products (such as niobium), either for trade values or net weights.

Expert communication allows assuming that most rhenium supply to the EU comes from Poland (producing 6-7 tonnes a year) which is the world's third largest producer and is integrated from mine to final product. EU imports also come from Iran, Uzbekistan (around 500 kg each annually) or neighbouring countries, such as Russia, Kazakhstan, Uzbekistan, Armenia, Romania (Lippman, 2016). Relatively easy supply comes from South Korea as well, via an EU free trade agreement, conferring duty-free status compared to 5.5% due on APR (Ammonium perrhenate) imports for countries from outside of EU (OECD, 2016). The Figure 193 shows the EU sourcing (domestic production + imports) for rhenium.

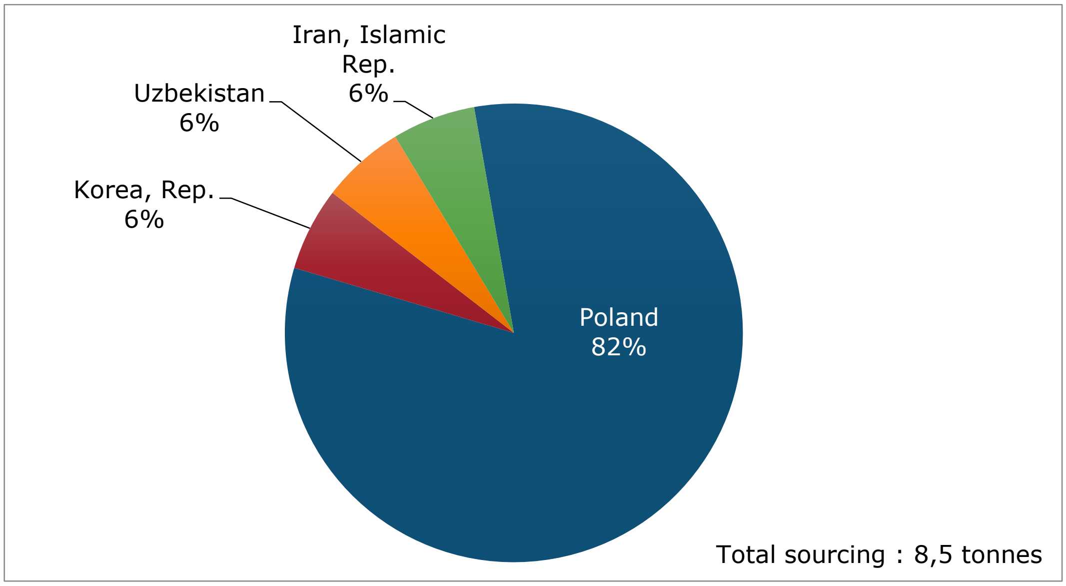


Figure 193: EU sourcing (domestic production + imports) of rhenium. Average 2010-2014. (Lipmann, 2016)

Finally, Europe also benefits from easy access to rhenium supplies originating via recycling (both from spent catalysts and alloy recovery) with Germany being a major player. An important part of high quality reforming catalysts containing recycled Re are exported to Russia, Kazakhstan, Middle East and other oil producing countries (10-20 tonnes/year). Due to high costs, superalloys are now sent outside Europe for the recycling of rhenium (1-5 tonnes).

There are no known government stockpiles or significant trade restrictions for rhenium. Corporate stockpiles are likely to exist though because of the strategic importance of rhenium to superalloy manufacturers in particular.

No trade restrictions have been reported over the 2010-2014 period (OECD, 2016). The EU has a free trade agreement in place with South Korea (European Commission, 2016).

24.3 Demand

24.3.1 EU consumption

Apparent consumption figures derived from adding EU production and imports and subtracting exports are not reliable because of uncertainties on total traded quantities. It is very difficult to assess these numbers precisely, but they are likely to be of the order of a few tonnes.

24.3.2 Applications/end uses

Rhenium world demand was estimated about 60-65 tons in 2015 (unchanged from several years) (Lipmann, 2016) of which 78% for aerospace super-alloys, 14% for catalysts and the remaining 8% for minor uses (anodes for medical equipment, thin filaments for spectrographs and lighting, alloy spray powders, etc.), see Figure 194.

In the EU like in the rest of the world, rhenium's use in aerospace remains the main driver of prices and market. Growth of demand for engines in both commercial and military jets is expected to continue rising strongly over the next 20 years, and is likely to sustain demand for rhenium superalloys. Demand for rhenium in reforming catalysts remains stable, because inroads of platinum-only catalysts, which took market share at the first part of this century, have not increased (Lipmann, 2016).

The rhenium annual EU demand for advanced fossil fuel power generation (use in industrial gas turbines blades) is forecasted at 0.6 tonnes/year by 2020-2030 and could represent an important material requirement (Moss et al., 2013).

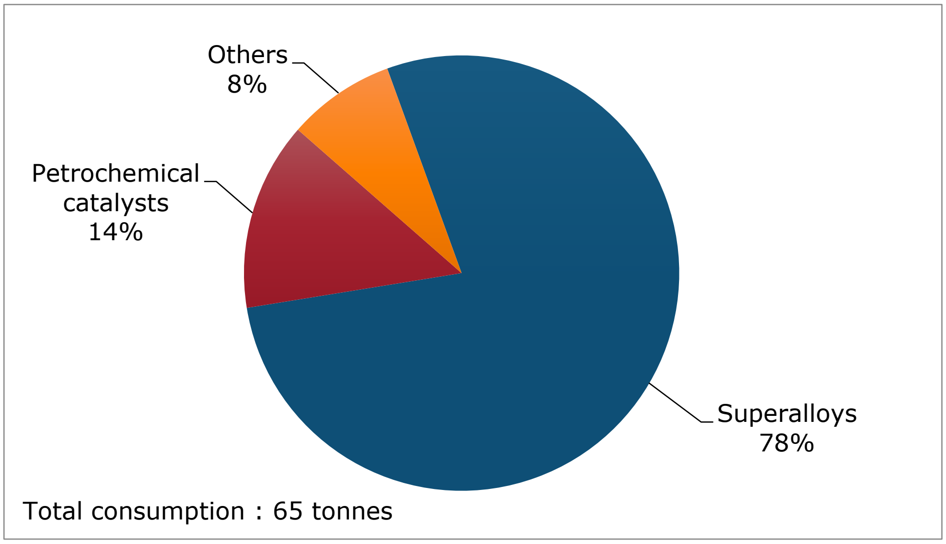


Figure 194: End uses of rhenium. Average 2010-2014 (Data from Lipmann, 2016)

The calculation of economic importance of gallium is based on the use of the NACE 2-digit codes. Relevant industry sectors are the following:

Table 120: Rhenium applications, 2-digit NACE sectors and associated 4-digit NACE sectors and value added [Data from the Eurostat database, (Eurostat, 2016)].

Applications	2-digit NACE sector	Value added of sector (millions €)	4-digit NACE sectors
Aerospace	C30 - Manufacture of other transport equipment	53,645	C3030- Manufacture of air and spacecraft and related machinery
Catalysts in petroleum industry	C19 - Manufacture of coke and refined petroleum products	13,547	C1920- Manufacture of refined petroleum products

24.3.3 Prices and markets

Rhenium is not traded on any metals exchange, and there are no terminal or futures markets where buyers and sellers can fix an official price. References for prices are obtained through averages of past deals between private parties, generally available through paid subscription (e.g. Asian Metal, Metal Pages).

The highest prices for rhenium were historically reached in August 2008 (12,000 US $/kg), after a massive purchase by Exxon (10 tonnes) for the development of a formula for Gas to

Liquid Catalysts which had an important effect on the supply-demand balance. Prices have continuously dropped since (see Figure 195), almost back to 2005-levels since 2016 (below 2,000 US $/kg) which might be the bottom limit according to experts (Lipmann, 2016).

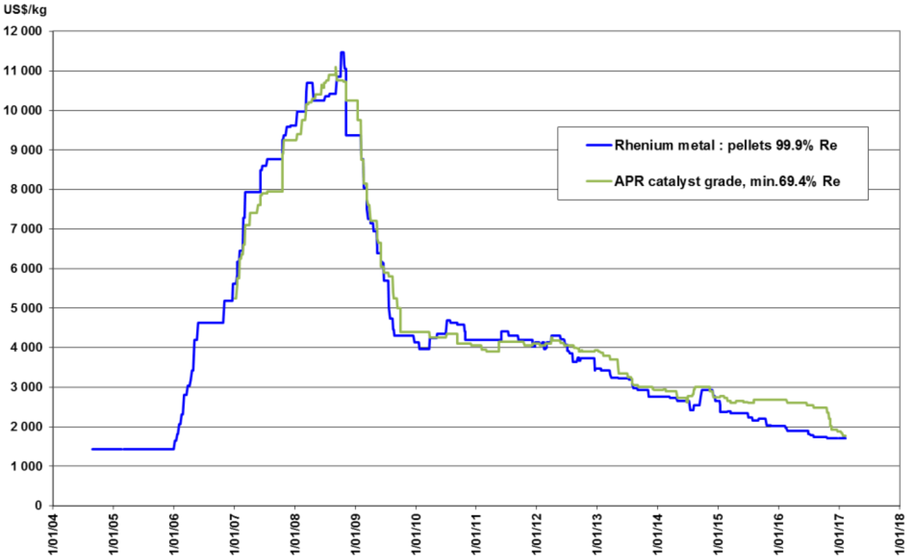


Figure 195: Rhenium prices (Data from USGS, 2004-2016)

24.4 Substitution

Since the price spike in 2008, attempts were made to substitute rhenium in many of its applications.

For aerospace superalloys, various strategies were adopted: the main one was to reduce rhenium's use only to the most critical parts and/or to reduce its share in superalloys from 6% to 3% by weight (e.g. General Electric). Other manufacturers have chosen to use rhenium-free superalloys for their engine and turbines (e.g. Safran). In some new generation of engines, such as the CFM-Leap, certain parts that once would have used rhenium are said to have been replaced by ceramic matrix composites (CMCs) for vanes for instance. Another solution is to add ruthenium as well as rhenium in 4th generation superalloys. However, by doing so, the fear of increasing exposure to another element which is high in value and low in volume still exists. It is important to notice that even though rhenium quantities can be reduced, this element is difficult to eliminate due to its performances.

For some of its other end-uses, materials that can substitute for rhenium are as follows. Some of them are even more critical in terms of availability and price:

- cobalt and tungsten for coatings on copper x-ray targets
- rhodium and rhodium-iridium for high-temperature thermocouples
- tungsten and platinum-ruthenium for coatings on electrical contacts
- tungsten and tantalum for electron emitters

24.5 Discussion of the criticality assessment

24.5.1 Data sources

Market shares and production data are particularly difficult to obtain due to the size and nature of the market, information coming from public sources were completed based on expert consultation (Lipmann, 2016). Data on imports and exports are taken from Eurostat Comext, 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 derived from the OECD Export restrictions on the Industrial Raw Materials database (OECD, 2016).

24.5.2 Economic Importance and Supply Risk calculation

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 120). The value added data correspond to 2013 figures. The supply risk was assessed using the global HHI and the EU-28 HHI as prescribed in the revised methodology.

24.5.3 Comparison with previous EU assessments

Both Economic Importance (EI) and Supply Risk (SR) scores are lower than in previous assessments. Part of the explanation comes from the change in methodology. To evaluate EI, 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. The way the supply risk is calculated in the new methodology (taking into account global HHI and the EU-28 HHI, for instance) also explains why SR score is lower than in the previous years (Table 121), together with the fact that the EU is a key player on the rhenium market.

Table 121: Economic importance and supply risk results for rhenium in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Rhenium	7.7	0.8		4.5	0.8		2.0	1.0

24.6 Other considerations

24.6.1 Forward look for supply and demand

The market outlook is that rhenium's use in aerospace will remain the main driver of demand and growth can be expected. Asia is still renewing its fleets and Boeing's projection is that at least 30,000 new planes will be needed by 2035 (Lipmann, 2016). The push of legislation for lower emissions is one argument to believe that these planes will need rhenium (and possibly ruthenium) in the engines because those high-temperature superalloys remain one of the best proven means to achieve fuel-efficiency.

Furthermore, despite the attempt to reduce dependency on this supply-constrained by-product, the largest engine makers (General Electric, Pratt&Whitney, Rolls Royce) are still committed to rhenium for the foreseeable future, at least the next 20-30 years. An evidence for this was provided in September 2014 when Pratt&Whitney wrote a single contract with the world's largest supplier, Molymet, for the value of 690 milllion dollars the objective to double production and guaranteeing safety of supply on the long term (United Technologies , 2014; Lipmann, 2014).

On the supply side, extension of capacities can be expected from Codelco (Chile), with its project to recover rhenium (additional 8 tonnes/year forecasted) from a new roaster established at Mejillones. Production shall begin in March 2017 after many delays (Codelco, 2016).

In conclusion, the biggest change since 2008 is a greater awareness of rhenium's precarious supply-chain and the maturing of the recycle and revert industry. The gap between supply and demand in recent years has been made up by tributaries and streams of saved units, rescued from rhenium to be wasted in the past. While rhenium prices were low and some substitutions have taken place, the demand volume for unsubstitutable applications alone is enough to keep the market close to balance.

Table 122: Qualitative forecast of supply and demand of rhenium

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
Rhenium		x	+	+	?	+	+	?

24.6.2 Environmental and regulatory issues

No REACH registrations are required for rhenium or rhenium containing substances until 2018. However, the Precious Metals and Rhenium Consortium has already registered the six substances; they are not substances of very high concern (ECHA, 2016).

24.7 Data sources

24.7.1 Data sources used in the factsheet

Anderson C.D., Anderson C., Taylor P.R. (2013), Extractive metallurgy of rhenium: A review in *Minerals & Metallurgical Processing*, 30(1), p. 59-73.

Audion A.S., Martel-Jantin B. (2011). Panorama mondial 2010 du marché du rhénium. Rapport final. BRGM/RP-60205-FR, 76 p., 23 fig., 15 tabl.

Codelco (2016) Molyb concretó su primer embarque de molibdeno [online] Available at : https://www.codelco.com/prontus_codelco/site/edic/base/port/prensa.html

ECHA (2014). European Chemicals Agency. [online] Available at: https://echa.europa.eu/substance-information/

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

European Commission (2014)b. 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/

Eurostat (2016)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

Lippman Walton&Co (2014) Pratt & Whitney and Molymet write largest deal in rhenium history [online] Available at: http://www.lipmann.co.uk/articles/metal-matters/pratt-whitney-molymet-write-largest-deal-in-rhenium-history/

Lipmann A. (personal communication, November 2016)

Moss R.L., Tzimas E., Willis P., Arendorf J., Tercero Espinoza L. et al. (2013). Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector. European Comission Joint Research Centre – Institute for Energy and Transport. Oakdene Hollins Ltd, Fraunhofer ISI. pp. 246 [online] Available at: http://www.oakdenehollins.com/media/308/Critical_Metals_Decarbonisation.pdf

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.

Stratex International (2015) Update on Turkish projects [online]Available at : http://www.stratexinternational.com/news/update-on-turkish-projects-2015-05-05

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/

United Technologies (2014) Molymet Expands Relationship with Pratt & Whitney with $690 Million Deal [online] Available at : http://www.utc.com/News/PW/Pages/Molymet-Expands-Relationship-with-Pratt-Whitney-with-690-Million-Deal.aspx

USGS (2016) Polyak D.E. , Rhenium - Mineral Commodity Summaries. United States Geological Survey. Ed., Washington DC, pp.2

World Mining Data (2016). Bundesministerium für Wissenschaft, Forschung und Wirtschaft. Austrian Ministry of Science, Research and Economy. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx

24.7.2 Data sources used in the criticality assessment

Audion A.S., Martel-Jantin B. (2011). Panorama mondial 2010 du marché du rhénium. Rapport final. BRGM/RP-60205-FR, 76 p., 23 fig., 15 tabl.

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

European Commission (2014)b. 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/

Eurostat (2016)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

Polyak D.E. (2016) Rhenium - Mineral Commodity Summaries. United States Geological Survey. Ed., Washington DC, pp.2

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.

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/

World Mining Data (2016). Bundesministerium für Wissenschaft, Forschung und Wirtschaft. Austrian Ministry of Science, Research and Economy. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx

24.8 Acknowledgments

This factsheet was prepared by the French Geological Survey (BRGM). The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this Factsheet.

25.SAPELE WOOD

Key facts and figures

Material name	Sapele	World/EU production (tonnes)[1]	500,000/0
Parent group (where applicable)	N/A	EU import reliance[1]	100%
Life cycle stage assessed	Extraction	Substitution index for supply risk [SI (SR)][1]	0.90
Economic importance (EI)(2017)	1.3	Substitution Index for economic importance [SI(EI)][1]	0.90
Supply risk (SR)(2017)	1.4	End of life recycling input rate	15%
Abiotic or biotic	Biotic	Major end uses in the EU[1]	Construction material: 80% Furniture: 10% Boats: 10%
Main product, co-product or by-product	Main product	Major world producers[1]	Cameroon: 33% Congo, Dem. Rep.: 30% Congo, Rep.: 23%
Criticality results	2011	2014	2017
	Not critical	Not critical	Not critical

[1] Average for 2010-2014, unless otherwise stated.

[2] See corresponding section in present factsheet for assumptions about major producers.

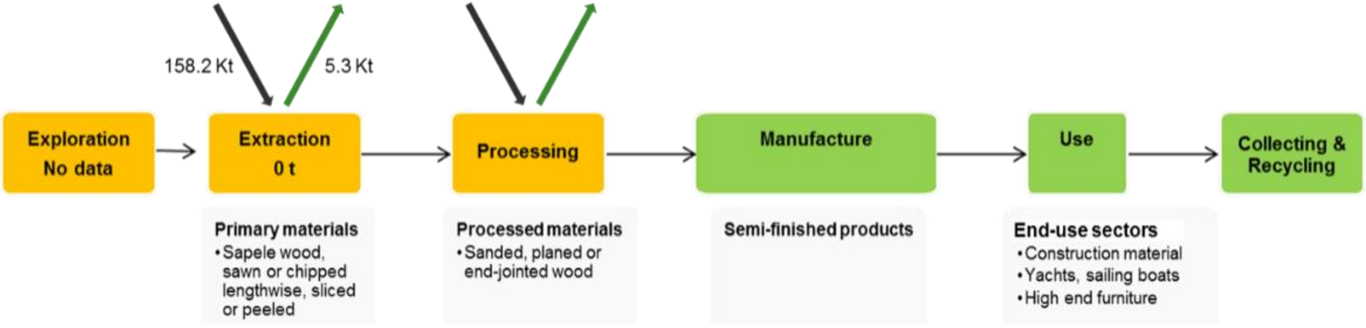


Figure 196: Simplified value chain for sapele wood

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU.

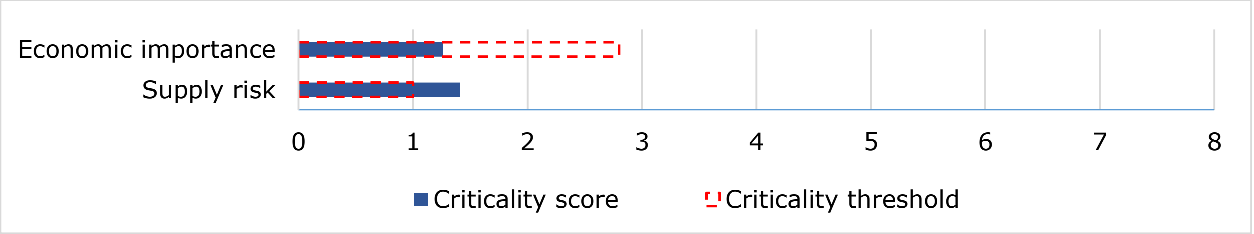


Figure 197: Economic importance and supply risk scores for sapele wood

25.1 Introduction

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 (Houtvademecum, 2011), which is another type of tropical wood entirely.

The wood at the heart is a golden to dark reddish brown. Color 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, 2016).

Common uses in the EU of sapele wood are in the shape of veneer or plywood, for applications such as flooring, boatbuilding and furniture.

25.2 Supply

25.2.1 Supply from primary materials

25.2.1.1 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 (Arkive, 2016). 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 (IUCN, 2016).

25.2.1.2 Processing

Sapele can be troublesome to work in some machining operations, (i.e., planing, routing, etc.), resulting in tear out due to its interlocked grain. It will also react when put into direct contact with iron, becoming discoloured and stained. Sapele has a slight blunting effect on cutters, but it turns, glues, and finishes well (Wood-database, 2016).

25.2.1.3 Resources and reserves

Reliable, public and updated information about acreage of sapele wood has not been found. As a rule of thumb, it is stated that sapele trees grow in a density of 3 to 4 trees per hectare (Borota, 2012).

25.2.1.4 World production

Actual data sources of the distribution of the world’s production is not found. The total world production is estimated at 500Kt on average between 2010 and 2014 (TNO, 2016).

A proxy for major producing countries can be deduced from trade data. These indicate the expected 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 Comext, 2016).

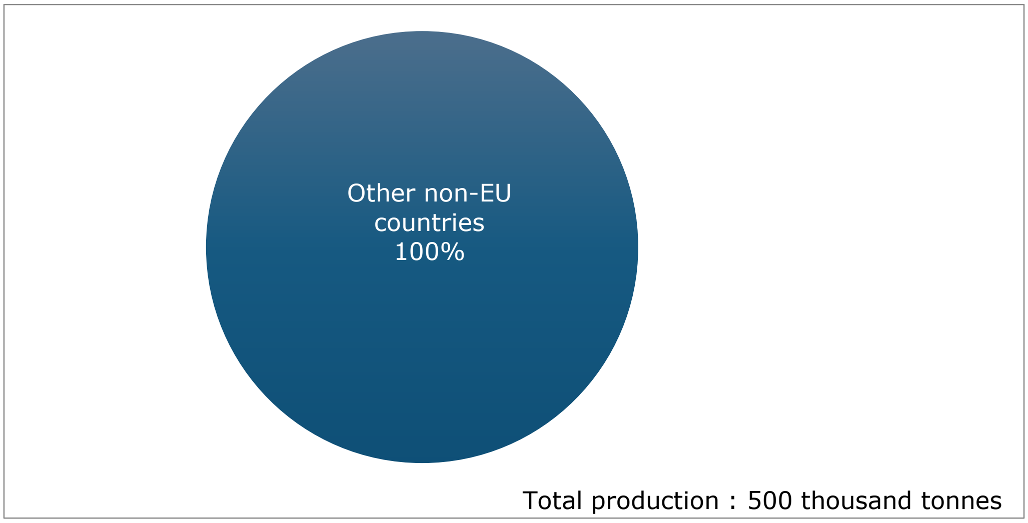


Figure 198: Global production of sapele wood, average 2010–2014 (Data from TNO, 2016)

25.2.2 Supply from secondary materials

The expected lifetime of sapele products is usually between 40 and 50 years (Houtvademecum, 2011). 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. The exact replacement rate cannot be ascertained, a 15% value can be used for the end of life recycling input rate but should be treated with caution (TNO, 2016).

25.2.3 EU trade

The trend in recent years in international trade by the EU in sapele wood is slowly but consistently downward. This is an illustration of the interchangeable use of tropical wood. In 2014, European importers noted that reduced supplies and better demand had led to rising export prices of several species of African wood, including framire, iroko, and sipo in the second quarter of 2014, with prices of sapele and wawa remaining stable at relatively high levels (ITTO, 2014).

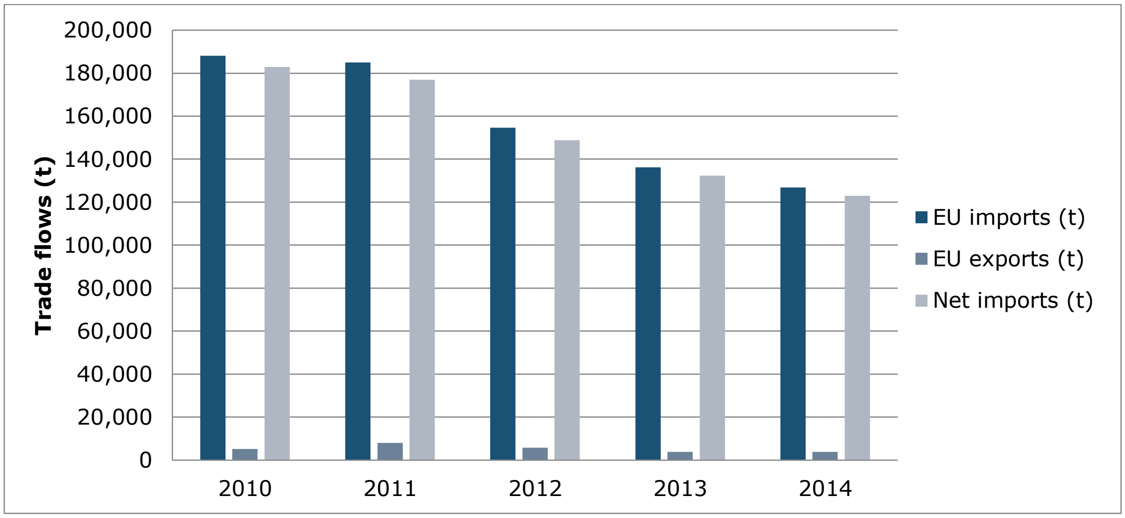


Figure 199: EU trade flows for sapele wood (Data from Eurostat Comext, 2016)

As mentioned previously, data sources on world production are not found to be available. The origin of EU-28 imports can however give not only information about trading partners, but also about sourcing countries, since extensive trading is not assumed to be significant (ITTO, 2014).

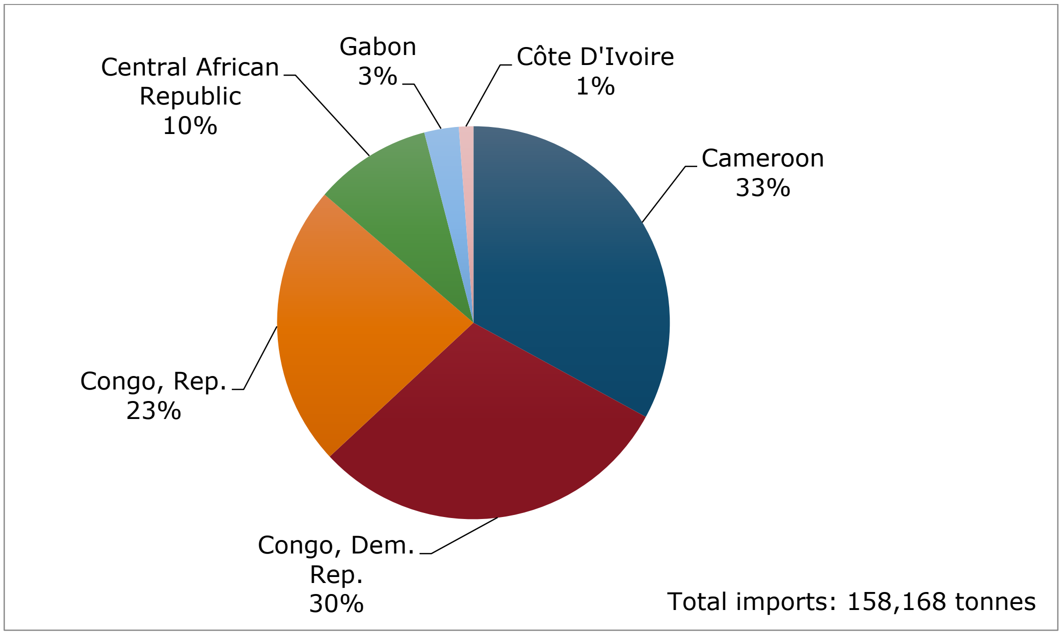


Figure 200: EU imports of sapele wood, average 2010-2014 (Data from Eurostat Comext, 2016)

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.

25.2.4 EU supply chain

The EU is rich with specialised businesses adding value to the sapele wood. These are for instance furniture makers, artisanal wharfs building wooden sailboats. Wooden products for construction purposes are produced in mostly larger businesses (Eurostat, 2016). 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 for the supply of sapele wood for 100% on its imports. Since there is no domestic production in the EU, the EU sourcing (domestic production + imports) for sapele wood is displayed in Figure 200.

Nigeria and Indonesia raised export prohibitions for sapele wood throughout 2010-2014. On top of that, Indonesia taxed some sapele products at 5%, and demanded a minimum export price for 2012 and 2013. Vietnam raised an export tax on sapele wood, which increased from 10 to 20% tax between 2011 and 2014.

25.3 Demand

25.3.1 EU consumption

The total EU consumption of sapele wood on average between 2010 and 2014 was 152Kt, corrected for around 5 Kt worth of re-exports to destinations outside the EU.

25.3.2 Applications / End uses

Sapele wood is in the EU mainly used for construction material, as well as for furniture and boats, see Figure 201. It is also reported that specific objects such as music instruments benefit from the use of sapele.

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, 2016).

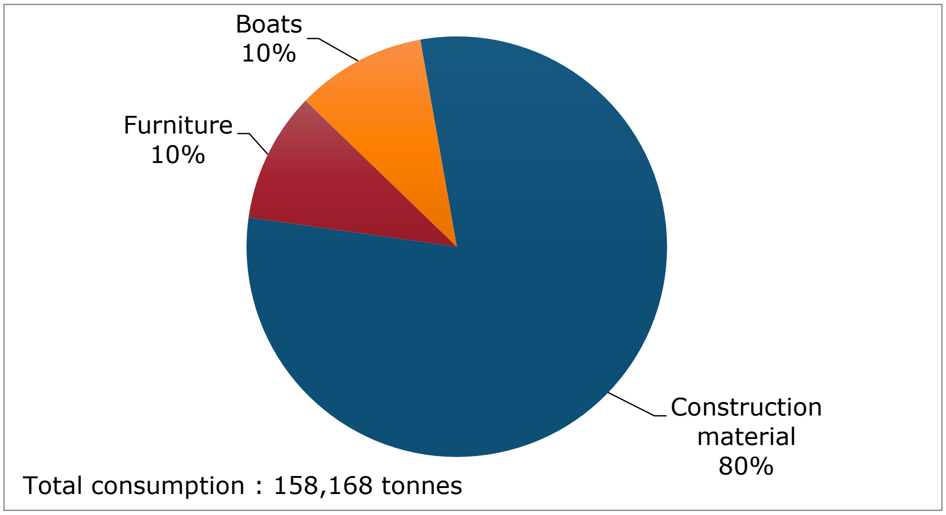


Figure 201: EU end uses of sapele wood, average 2010-2014 (Data from Houtvademecum, 2011)

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 123). The value added data correspond to 2013 figures.

Table 123: Sapele applications, 2-digit NACE associated 4-digit NACE sectors and value added per sector (Data from the Eurostat database, Eurostat, 2016)

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (millions €)
Construction material	C16 - Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	C16.23 -Manufacture of other builders' carpentry and joinery	29,584.8
Yachts	C30 - Manufacture of other transport equipment	C30.12 -Building of pleasure and sporting boats	53,644.5
High-end furniture	C31 - Manufacture of furniture	C31.09 -Manufacture of other furniture	28,281.7

25.3.3 Prices

On average, prices of sapele seem to be between 400 and 2000 EUR per m^3 in the EU. Markets in smaller Member States seem to set much higher prices than EU-28 countries with main seaports (ITTO, 2014).

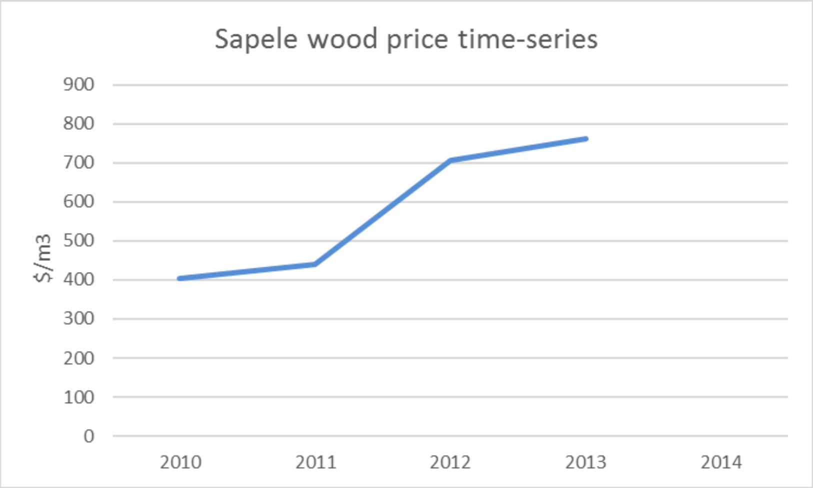


Figure 202: Global developments in price of sapele wood on the French market, average 2010-2014. (Data from ITTO, 2011/2012/2014)

25.4 Substitution

Tropical wood can is generally considered to be never unique, and sapele is no exception. There is in a vast majority of the times another wood available that has similar properties (FAO 2010; ITTO 2014; TNO, 2016; Arkive, 2016). The only limitation is availability and price of the wood, the technical performance will be virtually equal.

25.5 Discussion of the criticality assessment

25.5.1 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. These products can still be regarded as non-processed goods (TNO, 2016). The last product group 4403 4910, only lists wood in the rough.

The data has a 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. No consistent global time series for production can be created.

25.5.2 Calculation of Economic Importance and Supply Risk indicators

The bottleneck for supply of sapele wood is, for any tropical wood, associated with the land use, extensive production times and environmental and social issues (FAO, 2010). The extraction stage is chosen for the criticality assessment.

The supply risk was assessed for sapele wood using both the global HHI and the EU-28 HHI as prescribed in the revised methodology.

25.5.3 Comparison with previous EU assessments

Sapele wood is 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 not possible to make any comparisons with the previous assessments.

Table 124: Economic importance and supply risk results for Sapele in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Sapele wood	Not assessed			Not assessed			1.3	1.4

25.6 Other considerations

25.6.1 Forward look for supply and demand

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 Japan domestic market prices have limited Japanese buyers' commitments to future purchasing, suggesting that imports in 2015 are likely to decline (ITTO, 2014). It is therefore expected that supply and demand will fall in the long term given persistent problems with sustainable supply of sapele wood. See Table 125.

Table 125: Qualitative forecast of supply and demand of sapele wood

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
Sapele		x	+	+	0	+	+	0

25.6.2 Environmental and regulatory issues

This wood species is not listed in the CITES Appendices (CITES, 2016), but is on the IUCN Red List. 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, 2016)

Sapele wood is listed on the IUCN Red list (IUCN, 2016). A reason for this is the heavy exploitation throughout its range. Genetic erosion caused by the large-scale depletion of mature individuals from populations has taken place in some countries.

25.6.3 Supply market organisation

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, 2014).

Infrastructure problems at Douala Port greatly reduced exports from Cameroon in 2015.

25.7 Data sources

25.7.1 Data sources used in the factsheet

Arkive (2016). Sapele [online] Available at: http://www.arkive.org/sapele/entandrophragma-cylindricum/

Borota, J. (2012). Tropical Forests: Some African and Asian Case Studies of Composition and Structure Elsevier publishing. Technology & Engineering - 287 pages. Available at: https://books.google.nl/books?id=Z9ppaCz7BUQC&dq=sapele+wood+land+area&source=gbs_navlinks_s

CITES (2016). Convention of International Trade in Endangered Species of Wild Fauna and Flora. [online] Available at: https://www.cites.org/eng/app/appendices.php

Eurostat (2016). Structural Business Statistics by size class. [online] available at: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=sbs_sc_ind_r2&lang=en

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 (2016)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

FAO (2010). Global Forest Resources Assessment 2010 Main report. Available at: http://www.fao.org/docrep/013/i1757e/i1757e.pdf

ITTO (2011) Annual review and assessment of the timber situation. ISBN 4-902045-92-3. Available at: http://www.itto.int/annual_review/

ITTO (2012) Annual review and assessment of the timber situation. ISBN 978-4-86507-007-1. Available at: http://www.itto.int/annual_review/

ITTO (2014) Biennial Review 2013-2014. ISBN 978-4-86507-020-0. Available at: http://www.itto.int/annual_review/

IUCN (2016). Sapele. Assessed by Hawthorne, W. 1998. [online] Available at: http://www.iucnredlist.org/details/33051/0

Lourmas, M., Kjellberg, F., Dessard, H., Joly, H.I. and 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: 151 - 160. Available at: https://www.researchgate.net/publication/6355946_Reduced_density_due_to_logging_and_its_consequences_on_mating_system_and_pollen_flow_in_the_African_mahogany_Entandrophragma_cylindricum

Meier, E. (2016). Mahagony mixups. [online] Available at: http://www.wood-database.com/wood-articles/mahogany-mixups-the-lowdown/

USDA (2016). Wood Properties (Tech sheets) - Tropical Hardwoods. 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 (2016). Sapele [online] Available at: http://www.wood-database.com/sapele/

25.7.2 Data sources used in the criticality assessment

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

Houtvademecum (2011) Centrum Hout Almere. Sdu uitgevers bv, den Haag. ISBN 978 90 125 82162, NUR 833/835.

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

TNO (2016). Jan de Jong, expert consultation.

25.8 Acknowledgments

This Factsheet was prepared by the Netherlands Organisation for Applied Scientific Research (TNO). The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this Factsheet.

26. SELENIUM

Key facts and figures

Material name and Element symbol	Selenium, Se	World/EU production (tonnes)[1]	Refining: 2,700 / 1,130
Parent group (where applicable)	N/A	EU import reliance	17%
Life cycle stage/material assessed	Refined material	Substitution index for supply risk [SI (SR)]	0.94
Economic importance (EI)(2017)	4.5	Substitution Index for economic importance [SI(EI)]	0.89
Supply risk (SR)(2017)	0.4	End of life recycling input rate (EOL-RIR)	1%
Abiotic or biotic	Abiotic	Major end uses in EU	Metallurgy (40%); Glass manufacture (25%); Electronics (10%)
Main product, co-product or by-product	Almost always a by-product	Major world producers[1] (refining)	Japan (29%); Germany (25%); Belgium (8%)
Criticality results	2011	2014	2017
	Not assessed	Not critical	Not critical

[1] average for 2010-2014

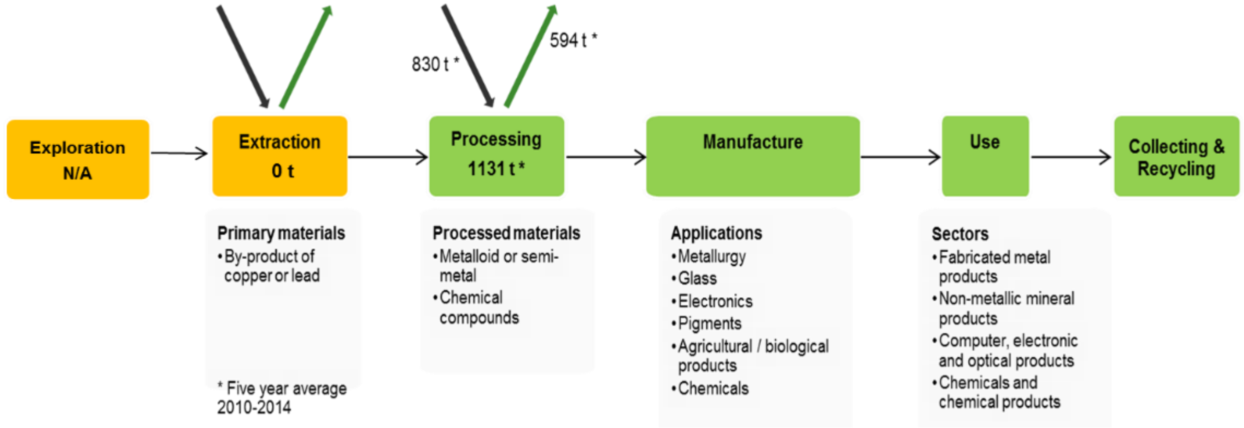


Figure 203: Simplified value chain for selenium

The orange box of the production stage in the above figure suggests that activities are not undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU. A quantitative figure on recycling is not included as the EOL-RIR is below 70%. EU reserves are displayed in the exploration box.

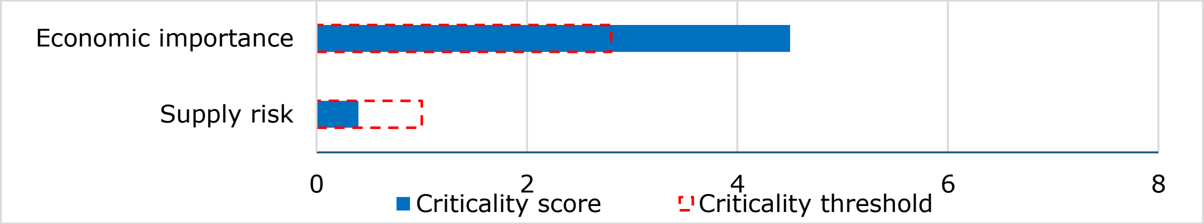


Figure 204: Economic importance and supply risk scores for selenium

26.1 Introduction

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 (similar to gypsum) and a melting point of 220.8 °C (494 K). It is photoconductive, meaning that its electrical conductivity increases when exposed to light, and photovoltaic, it converts light into electricity. It is rare in the Earth's crust, with an abundance of 30–90 parts per billion, which is similar to mercury and less than silver or indium. In the uppercrust, its abundance is 90 ppb (Rudnick, 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 most of the remainder obtained from the processing of lead ores. Selenium is used in metallurgy (primarily in the production of electrolytic manganese but also to improve the machinability of other metals), the manufacture of glass (both as a decolouriser and a pigment), in electronics (e.g. photoreceptors, rectifiers, photovoltaic cells), as a pigment for plastics or ceramics, in agricultural or biological products (e.g. animal feeds supplements, veterinary preparations, fungicides) and other minor uses (e.g. catalysts, rubber vulcanising agents). It is an essential trace element for human health but in very large quantities it can also be harmful.

The EU-28 countries have both copper mines where the deposit contains selenium and copper refining facilities that are recovering selenium from domestic and imported materials. There are also companies within EU-28 countries that are undertaking further refining of extracted selenium into products suitable for manufacturers. Globally refined selenium production is believed to be in the order of 2,700 tonnes, of which production in the EU-28 is approximately 42%.

26.2 Supply

26.2.1 Supply from primary materials

26.2.1.1 Geological occurrence

Selenium is relatively rare in the Earth's crust with an average abundance of only 30–90 parts per billion – 90 ppb in the uppercrust (Rudnick, 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 these compounds and can occur in a relatively large number of these minerals 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.

26.2.1.2 Exploration

During the Minerals4EU project it was identified that in 2013 exploration was taking placed in Slovakia for a suite of precious metals, base metals and associated by-products that included selenium. In total 19 exploration licences were active, covering an area of more than 140 km^2 but exploration expenditure was confidential.

Exploration that included selenium was not known to be taking place in any other of the European countries that responded to the survey. However, exploration may have taken place in countries where no information was provided (Minerals4EU, 2015).

26.2.1.3 Mining, processing and extractive metallurgy

More than 90% of selenium production globally is as a by-product of electrolytic refining of copper. To reach this stage the copper, and its associated by-products including selenium, will have undergone a number of processing stages. These will 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 selenium will have been lost in tailings or residues (Kavlak & 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 to 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 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 & 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 will be on recovering copper or other base metals which will be more economically rewarding due to the larger quantities available. In contrast, where recovery of selenium from anode slimes is carried out the equipment used will be optimised to ensure the highest possible recovery rate of selenium as this has become the focus.

Once recovered, selenium will normally need to be refined further to obtain the high purity levels needed for many applications. These refining methods may involve selective precipitation; selective leaching and recystallisation; or oxide, hydride or chloride purification (Willig, 2014).

26.2.1.4 Resources and reserves

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 by application of the CRIRSCO template[24], 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.

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 at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU, 2015).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.

During the Minerals4EU project, no selenium resources were reported by any of the 40 European countries surveyed, irrespective of the difference 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 (Minerals4EU, 2015).

Similarly, during the Minerals4EU project, none of the 40 European countries surveyed reported selenium reserves, but reserves may exist in countries that did not respond to the survey. Nine of the European countries reported reserves of copper (Minerals4EU, 2015).

---

[24] www.crirsco.com

The United States Geological Survey (USGS) does not report figures for global selenium resources. Global selenium reserves reported by the USGS are shown in Table 126 (USGS, 2016a).

Table 126: Global reserves of selenium in 2015, data does not sum due to rounding (Data from USGS, 2016a).

Country	**Selenium Reserves (tonnes)**	**Percentage of total (%)**
China	26,000	22
Chile	25,000	21
Russia	20,000	17
Peru	13,000	11
U.S.A.	10,000	8
Canada	6,000	5
Poland	3,000	3
Other countries*	21,000	18
World Total (rounded)	*120,000*	*100*

*Other countries includes India, Serbia, and Sweden

26.2.1.5 World refinery production

Selenium is known, or believed, to be produced in 20–23 countries, but reliable data are not reported for all of them. Data from the British Geological Survey was used, which contains figures for 16 countries (BGS, 2016). Total worldwide production, averaged over 2010–2014, amounted to 2,697 tonnes per year and the largest producers are shown in Figure 205. The segment for 'other countries' includes China, Peru, Uzbekistan, Armenia and Serbia. Production may also have occurred in Australia, Chile, South Korea and Zimbabwe.

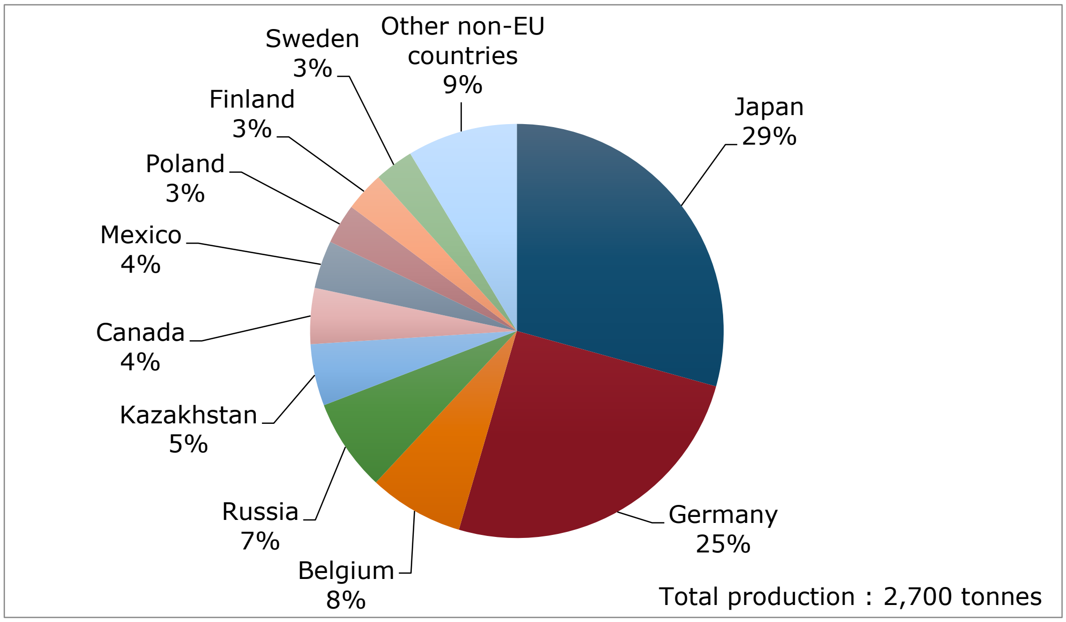


Figure 205: Global refined production of selenium, average 2010–2014 (Data from BGS World Mineral Statistics database). Other countries include Philippines, China, Peru, Uzbekistan, Armenia and Serbia

The most recently published figures from the USGS give a global total of between 2,150 and 2,310 tonnes per year for 2010 to 2014 but these only include production from 12 countries (USGS, 2016b). The report also lists the following as producers but with inadequate information available to make reliable estimates of output: Australia, China, Iran, Kazakhstan, Mexico, the Philippines and Uzbekistan.

Willis et al. (2012) reported refinery production figures amounting to 2,600–2,700 based on industry sources, with data shown by company rather than country and 16 different countries listed. The list of countries shown does not match that of either BGS or USGS.

Because all of the available data sources do not include figures for every producing country, the figures quoted are likely to be an under-estimation of the actual global production total.

26.2.2 Supply from secondary materials

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 & 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 & Wagner, 2004). As a consequence the availability of source material for recycling 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 reach 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.

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 selenium ‘ new scrap’ represents the largest source of material for recycling but the quantities involved with both types of scrap are very small (personal communication from industry sources).

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. The UNEP report also 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).

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 & 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.

26.2.3 EU 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-28 during 2010–2014 are shown in Figure 206. The largest importing countries are the United Kingdom, the Netherlands, Germany, Belgium and Swedens. The main originating countries for these imports are shown in Figure 207. Brazil is shown as the largest originating country for EU-28 imports (26%) but this is slightly distorted due to a large import figure for 2010. Brazil was followed by Russia (14%), Japan (12%), China (10%) and South Korea (8%). The EU-28 imports originated in 23 different countries in total.

In the years 2011–2014, exports from the EU-28 have been similar to the imports, with the EU-28 being a small net exporter in 2012 (Figure 206). The leading EU-28 exporting countries are Germany, the United Kingdom, the Netherlands, Italy, Poland, Denmark and Sweden.

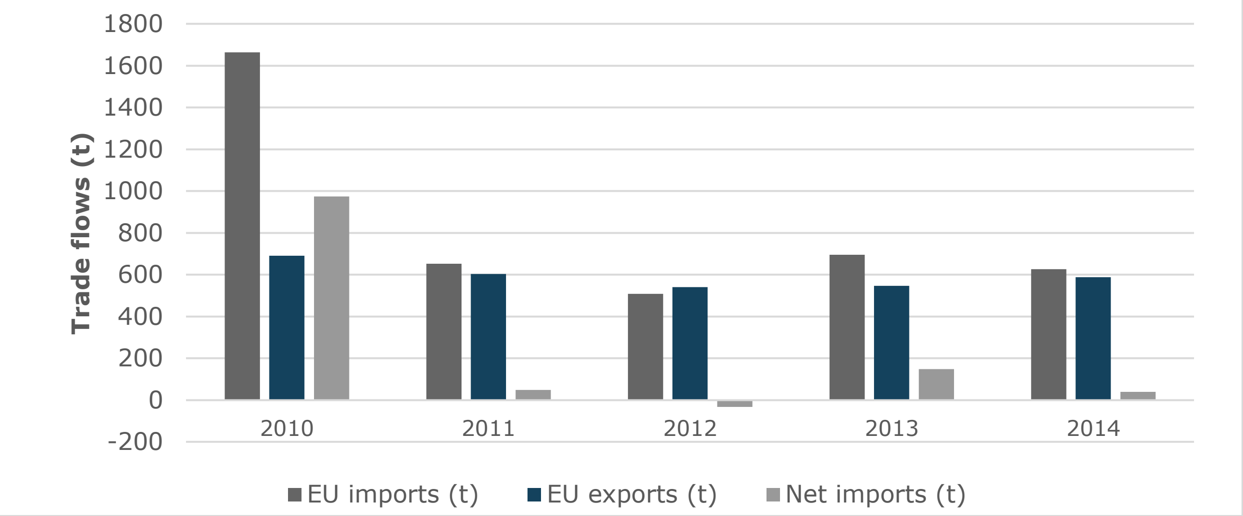


Figure 206: EU trade flows for selenium (Data from Eurostat, 2016a)

No trade restrictions were reported over the 2010-2014 period (OECD, 2016). Some EU free trade agreements are in place with suppliers such as Peru, Mexico, Serbia, Norway and South Korea (European Commission, 2016).

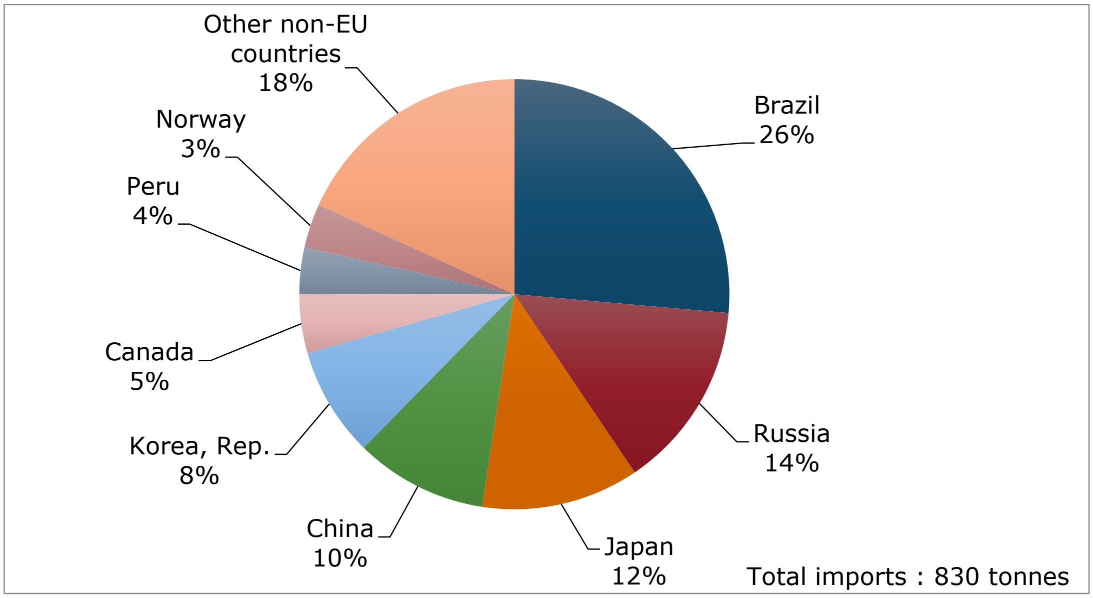


Figure 207: EU imports of selenium, average 2010-2014 (Data from Eurostat, 2016a)

26.2.4 EU supply chain

Reported selenium production within the EU-28 amounted to 1,131 tonnes per year, averaged over 2010–2014. Imports to the EU-28 from the rest of the world were 835 tonnes per year, while total exports (i.e. from both producing and non-producing countries) were 594 tonnes per year (again both averaged over the 2010–2014 period). Figure 208 represents the EU sourcing (domestic production + imports) for selenium.

Within the EU, refined selenium production is reported in Belgium, Finland, Germany, Poland and Sweden (BGS, 2016). In addition, copper refining takes place in Austria, Bulgaria, Cyprus, Italy and Spain but it is not always reported whether the anode slimes from these operations contain any selenium.

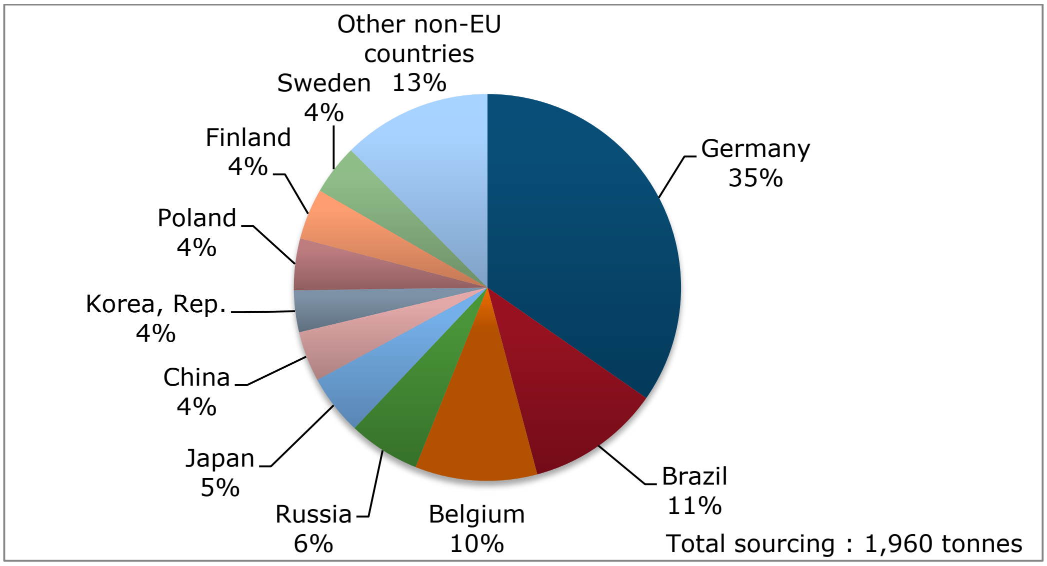


Figure 208: EU sourcing (domestic production + imports) of selenium, average 2010-2014 (Data from Eurostat, 2016a; BGS, 2016)

Within Belgium, selenium is present in anode slimes at Metallo Chemique's refinery at Beerse but this is sold as 'tankhouse slimes' to specialist metal refiners elsewhere. Umicore's precious and speciality metals refinery at Hoboken produces refined selenium amongst other metals from 'tankhouse slimes' sourced elsewhere and has an annual capacity of 600 tonnes of selenium.

Boliden reports production of by-product selenium from its copper refineries at Rönnskär in Sweden and Pori in Finland. The source material 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 do 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-28. Retorte, a subsidiary of Aurubis located in Rothenbach a.d. Pegnitz and Kirchheim, 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 99.94% from refining copper at its Głogów Smelter and Refinery in Poland. KGHM operates three copper mines in Poland but also one in Canada, two in the USA and one in Chile. It is not clear from the company website which of these mines feeds material into the Głogów Smelter and Refinery and therefore contains the selenium.

26.3 Demand

26.3.1 EU consumption

During the criticality assessment, EU-28 apparent consumption of selenium was calculated as 1,366 tonnes per year. Of this 536 tonnes per year came from within the EU (calculated as EU production – exports to non-EU countries) with the remaining 830 tonnes imported from outside the EU-28. Based on these figures the import reliance was calculated as 17%.

26.3.2 Applications / end uses

The main categories of end uses for selenium are shown in Figure 209 and relevant industry sectors are described using the NACE sector codes in Table 127.

The category labeled 'metallurgy' includes the production of electrolytic manganese (high purity manganese metal) where the addition of selenium dioxide improves energy efficiency (Anderson, 2016b); 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.

In the manufacture of glass selenium is used both 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 (STDA, 2010).

In electronics, selenium is used in rectifiers (devices that convert alternating current (AC) into direct current (DC)); in voltage surge protection devices; as the photoreceptor in photocopiers and laser printers; and in photovoltaic (solar) cells particularly the thin film CIGS cells (copper-indium-gallium-selenide).

Selenium-containing pigments have good heat stability and are resistant to ultra violet light or chemical exposure (USGS, 2016b). They are used to impart red, orange or maroon colours to plastics, ceramics, glazes and paints.

Because selenium is an essential nutrient for animal and human health, it is also used as a food additive or applied with fertilizer 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 (STDA, 2010). However, in large quantities selenium can be harmful.

Chemical uses of selenium include as a catalyst for selective oxidation; as a plating alloy to improve appearance and durability; and in a compound used to improve the abrasion resistance in vulcancised rubbers.

Table 127: Selenium applications, 2 digit and examples of associated 4-digit NACE sectors, and the value added of those sectors (Data sourced from Eurostat, 2016c)

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	159,513.4	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	59,166.0	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	75,260.3	C2611 – Manufacture of electronic components; C2660 – Manufacture of irradiation, electromedical and eletrotherepeutic equipment; C2670 – Manufacture of optical instruments and photographic equipment
Pigments	C20 – Manufacture of chemicals and chemical products	110,000.0	C2012 – Manufacture of dyes and pigments
Agricultural / biological products	C20 – Manufacture of chemicals and chemical products	110,000.0	C2015 – Manufacture of fertilisers and nitrogen compounds; C2110 Manufacture of basic pharmaceutical products
Chemical manufacture	C20 – Manufacture of chemicals and chemical products	110,000.0	C2059 – Manufacture of other chemical products n.e.c.

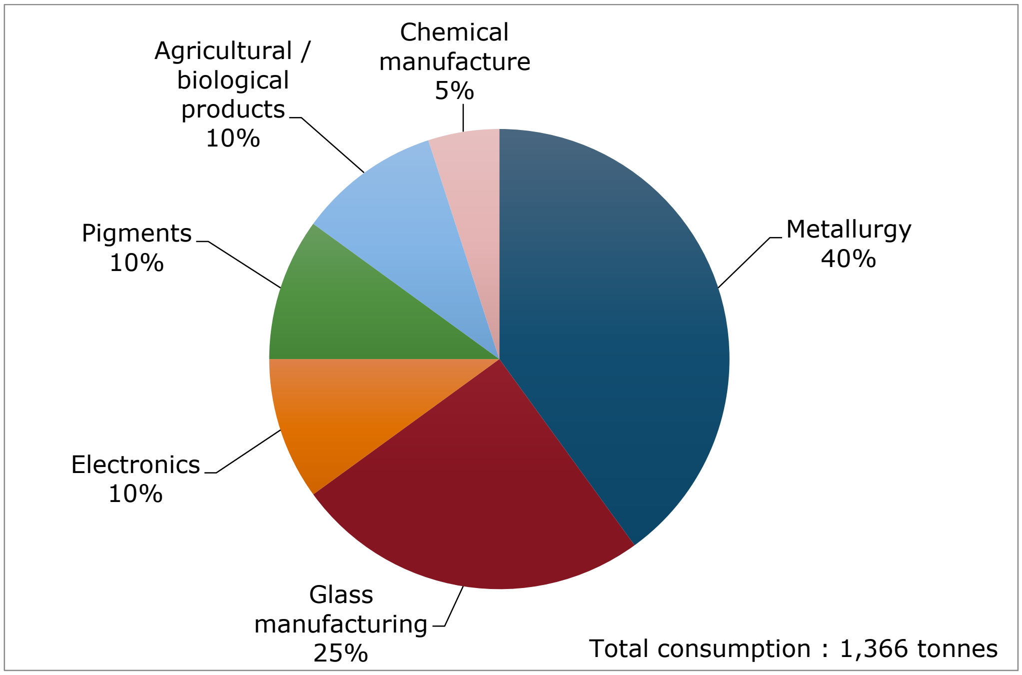


Figure 209: Global end uses of selenium. (Data from Selenium Tellurium Development Association (STDA), 2010 and USGS, 2016b)

26.3.3 Prices

Selenium prices are published by relevant trade journals, but a subscription is normally required to access the information. USGS (2016a) reported prices for refined selenium averaged US$22.80 per pound in 2015, which is down from a yearly average of US$26.78 per pound in 2014 and much lower than the US$66.35 per pound reported for 2011 (See Figure 210).

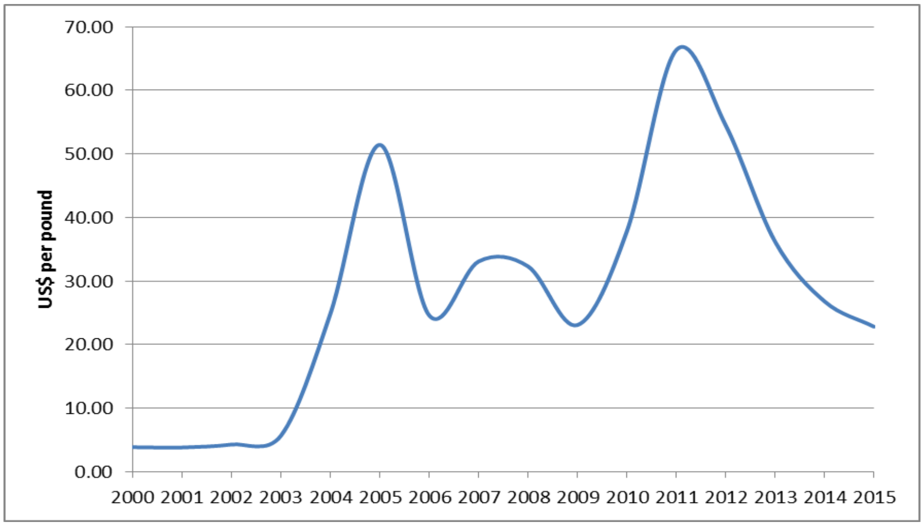


Figure 210: Price trend for selenium based on yearly averages in US$ per pound (Data sourced from United States Geological Survey)

More recent news articles suggest prices have increased significantly in December 2016 due to an increase in demand for electrolytic manganese but it has not been possible to verify any figures. Selenium prices are also affected by market supply of copper because it 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 an increasing selenium price.

26.4 Substitution

Substitution has been included in this review of the criticality assessment in a completely new way. Each application has been considered in turn with both product to product and material to material substitute included in the assessment. Consideration has been given to the cost and performance of each potential substitute in each application, relative to that of the material in question, together with the level of production, whether or not the substitute was previously considered to be 'critical' and whether the potential substitute is produced as a by-, co- or main product.

Specific data relating to all of these criteria are often difficult to find and a number of assumptions have had to be made to complete the calculations. Consequently a significant degree of uncertainty is associated with the results. The level of precision shown for the Substitution Indices does not fully reflect this uncertainty.

Not all of the materials listed can be substitutes in each of the detailed applications within a category or sector.

For the metallurgy category, bismuth, lead and tellurium can substitute for 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 are a very large number of possible additives that can be used in glass manufacture and the chemistry quickly becomes complicated. 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 a similar performance to selenium but gold chloride is considerably more expensive.

In electronics, organic photoreceptors in photocopies and printers are frequently substituting selenium-bearing ones 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.

26.5 Discussion of the criticality assessment

26.5.1 Data sources

Production data were taken from the British Geological Survey's World Mineral Statistics dataset (as published in BGS, 2016). Trade data was extracted from the Eurostat COMEXT online database (Eurostat, 2016) and used the Combined Nomenclature (CN) code

2804 9000 'Selenium'. These data were averaged over the five-year period 2010 to 2014 inclusive. Other data sources have been mentioned elsewhere in this factsheet and are listed in section 26.7.

26.5.2 Calculation of economic importance and supply risk indicators

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 127). For information relating to the application share of each category, see section on applications and end-uses. The figures for value added were the most recently available at the time of the assessment, i.e. 2013, and are expressed in thousands of Euros.

The calculation of the Supply Risk (SR) was carried out for selenium at the 'refined material' stage of the life cycle and used both the global HHI and EU-28 HHI calculation as prescribed in the methodology.

26.5.3 Comparison with previous eu criticality 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 128.

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 98,100 thousand Euros. 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 59,170 thousand Euros. 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 75,260 thousand Euros. 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 128: Economic importance and supply risk results for selenium in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Selenium	Not assessed	Not assessed		6.91	0.19		4.5	0.4

26.6 Other considerations

The future demand and supply for selenium is presented in Table 129.

Table 129: Qualitative forecast of supply and demand of selenium

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
Selenium		x	+	+	+	+	+	?

A total of 11 substances containing selenium have been registered with the European Chemicals Agency under the REACH Regulations as shown in Table 130.

Table 130: Substances containing selenium registered under the REACH regulations (Source: ECHA, 2016)

Substance name	EC / List No.	Registration Type
Selenious acid	231-974-7	Intermediate
Selenium	231-957-4	Full
Selenium dioxide	231-194-7	Full
Se-Te-Concentrate	932-075-9	Intermediate
Reaction mass of dicopper selenide and selenium	914-287-3	Intermediate
Cadmium sulphoselenite red	261-218-1	Full
Lead selenide	235-109-4	Intermediate
Reaction mass of selenious acid and sulphuric acid	932-279-8	Intermediate
Reaction mass of sodium selenite and sodium sulphate	932-279-8	Intermediate
Sodium selenite	233-267-9	Full
Zinc selenite	237-048-9	Full

26.7 Data sources

26.7.1 Data sources used in the factsheet

USGS. (2016a) Selenium Mineral Commodity Summary. January 2016. United States Geological Survey. https://minerals.usgs.gov/minerals/pubs/commodity/selenium/mcs-2016-selen.pdf

USGS. (2016b) Selenium and Tellurium in 2014 Minerals Yearbook. November 2016. United States Geological Survey. https://minerals.usgs.gov/minerals/pubs/commodity/selenium/myb1-2014-selen.pdf

BGS (2016) World Mineral Production 2010–2014. Keyworth, Nottingham: British Geological Survey, p. 81. Available at: http://www.bgs.ac.uk/mineralsuk/statistics/worldStatistics.html

European Chemicals Agency. (2016). Registered Substances. https://echa.europa.eu/information-on-chemicals/registered-substances

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. Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

Eurostat (2016)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

George, M.W. and Wagner, L.A. (2009) Selenium recycling in the United States in 2004, chapter T of Sibley, S.R., Flow studies for recycling metal commodities in the United States. United States Geological Survey Circular 1196-T, p.7. https://pubs.usgs.gov/circ/circ1196t/pdf/circ1196T.pdf

Kavlak, G. and Graedel, T.E. (2013). Global anthropogenic selenium cycles for 1940–2010. Resources Conservation and Recycling 73, 17–22. http://www.sciencedirect.com/science/article/pii/S0921344913000220

Luttrell, G.W. (1959) Annotated Bibliography on the Geology of Selenium. Bulletin 1019-M Contributions to Bibliography of mineral resources. United States Geological Survey. https://pubs.usgs.gov/bul/1019m/report.pdf

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 Willis, P., Chapman, A. and Fryer, A. (2012) Study of by-products of copper, lead, zinc and nickel. Table 62, p. 107. Oakdene Hollins for International Lead and Zinc Study Group, International Nickel Study Group and International Copper Study Group.

Minerals4EU (2015) European Mineral Yearbook – Data for bauxite, alumina and aluminium [online]. http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

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

Selenium Tellurium Development Association (2010) Sources and applications for selenium and tellurium. http://www.stda.org/se_te.html

United Nations Environment Programme. (2011) Recycling Rates of Metals A Status Report. p.44. http://www.unep.org/resourcepanel/Portals/50244/publications/UNEP_report2_Recycling_130920.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. http://umu.diva-portal.org/smash/get/diva2:703367/FULLTEXT01.pdf

Willis, P., Chapman, A. and Fryer, A. (2012) Study of by-products of copper, lead, zinc and nickel. Table 62, p. 107. Oakdene Hollins for International Lead and Zinc Study Group, International Nickel Study Group and International Copper Study Group.

26.7.2 Data sources used in the criticality assessment

Anderson, C.S. (2016a) Selenium Mineral Commodity Summary. January 2016. United States Geological Survey. https://minerals.usgs.gov/minerals/pubs/commodity/selenium/mcs-2016-selen.pdf

Anderson, C.S. (2016b) Selenium and Tellurium in 2014 Minerals Yearbook. November 2016. United States Geological Survey. https://minerals.usgs.gov/minerals/pubs/commodity/selenium/myb1-2014-selen.pdf

BGS (2016). World Mineral Production 2010-2014 [online]. Keyworth, Nottingham British Geological Survey, Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.html

Butterman, W.C. and Brown, Jr., R.D. (2004) Mineral Commodity Profiles: Selenium. United States Geological Survey Open File Report 03-018. https://pubs.usgs.gov/of/2003/of03-018/of03-018.pdf

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

European Commission. (2016) EU trade agreements webpage [online]. Directorate General for Trade. http://ec.europa.eu/trade/policy/countries-and-regions/agreements/index_en.htm

Eurostat. (2016) International trade in goods database (COMEXT) [online]. http://ec.europa.eu/eurostat/data/database

George, M.W. and Wagner, L.A. (2009) Selenium recycling in the United States in 2004, chapter T of Sibley, S.R., Flow studies for recycling metal commodities in the United States. United States Geological Survey Circular 1196-T, p.7. https://pubs.usgs.gov/circ/circ1196t/pdf/circ1196T.pdf

Green, M.A., Emery, K., Hishikawa, Y., Warta, W. and Dunlop, E.D. 2016. Solar cell efficiency tables (version 47). Progress in Photovoltaics: Research and applications, 24:3-11

Hagelstein, K. (2009) Globally sustainable manganese metal production and use. Journal of Environmental Management 90, 3736–3740.

Scoullos, M.J., Vonkeman, G.I., Thornton, I and Makuch, Z. (2001) Mercury-Cadmium-Lead: Handbook for Sustainable Heavy Metals Policy and Regulation. Environment & Policy, European Commission DG Research.

Selenium Tellurium Development Association (2010) Sources and applications for selenium and tellurium. http://www.stda.org/se_te.html

United Nations Environment Programme. (2011) Recycling Rates of Metals A Status Report. p.44. http://www.unep.org/resourcepanel/Portals/50244/publications/UNEP_report2_Recycling_130920.pdf

26.8 Acknowledgments

This Factsheet was prepared by the British Geological Survey (BGS). The authors would like to thank the members of the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this Factsheet.

27. SILICA SAND

Key facts and figures

Material name and formula	Silica sand, SiO_2	World/EU production (million tonnes)[1]	N/A / 77
Parent group (where applicable)	-	EU import reliance [1]	0%
Life cycle stage/material assessed	Extraction, silica sand	Substitute index for supply risk [SI (SR)][1]	1.00
Economic importance (EI) (2017)	2.6	Substitute Index for economic importance [SI(EI)][1]	1.00
Supply risk (SR) (2017)	0.3	End of life recycling input rate (EOL-RIR)	0%
Abiotic or biotic	Abiotic	Major end uses in EU[1]	Construction and soil (39%), Glass (flat, container and other) (39%), Foundry (12%)
Main product, co-product or by-product	Main product	Major EU producers[1]	Italy (18%), Netherlands (16%), Poland (12%), France (11%)
Criticality results	2011	2014	2017
	Not critical	Not critical	Not critical

[1] average for 2010-2014, unless otherwise stated;

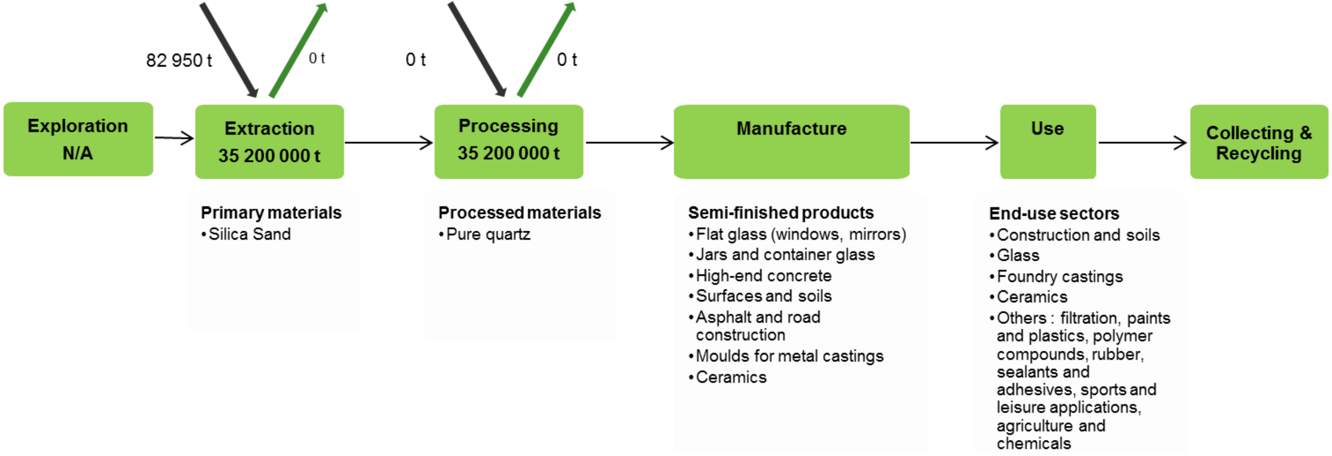


Figure 211: Simplified value chain for silica sand

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU. A quantitative figure on recycling is not included as the EOL-RIR is below 70%. EU reserves are displayed in the exploration box.

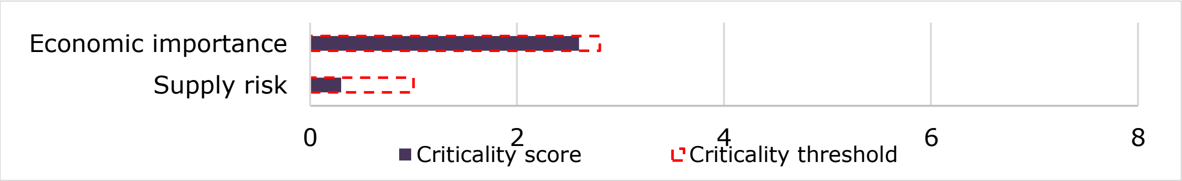


Figure 212: Economic importance and supply risk scores for silica sand

27.1 Introduction

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 the most common mineral in the Earth's continental crust, and most silica sand is made up of broken down quartz crystals. Quartz crystals are almost pure silicon dioxide, containing low quantities of impurities (European Commission, 2014).

Silica sand used for industrial applications is characterised by the high content of quartz (SiO_2) which can be up to 99.9%. For industrial purposes, silica sand with a purity of at least 95% is required. The major applications for silica sand are in the construction industry and for glass production. Other uses include foundry castings and ceramics. Extremely high-purity quartz is used to produce metallurgical grade silicon (see the factsheet on silicon metal) and products tailored for the optical and electronics industries (European Commission, 2014).

27.2 Supply

27.2.1 Supply from primary materials

27.2.1.1 Geological occurrence

Quartz makes up approximately 12% by weight of the lithosphere, making it the second most common mineral in the Earth's crust. SiO_2 accounts for 66.62% of the mass of the upper crust (Rudnick, 2003). Quartz is found in all three types of rock (igneous, metamorphic and sedimentary) but particularly in sedimentary rock given its resistance to physical and chemical weathering. 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 required. High-technology applications for quartz require extreme qualities, with specific low-ppm or sub-ppm requirements for maximum concentrations of certain trace metals (European Commission, 2014).

27.2.1.2 Extraction and industrial processing

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 is normally found in granites and in veins up to several metres thick within other rocks, commonly granite. Extremely high-grade quartz can also be produced by processing naturally pure vein quartz. Quartz for metallurgical purposes can be produced from high-quality resources of quartzite (European Commission, 2014).

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; this is generally in the range of 0.5 to 0.1 mm. The shape of the grains (rounded vs sharp grains) is also important, e.g. rounded sand grains may not be suitable for cement industry. Given the specificity of the properties for each application, the use of different types of silica sand is not interchangeable (European Commission, 2014).

Purification is achieved by washing, scrubbing, magnetic separation on the grains to remove impurities. The sand grains are screened to obtain the required particle size distribution. For uses which require extremely pure silica such as electronic applications, the sand grains are exposed to more aggressive treatment with strong acids combined with thermal shock (European Commission, 2014).

27.2.1.3 Resources and reserves of silica sand

There is no single 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. 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[25], 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.

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. 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 silica sand at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU, 2015). 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.

Silica sand is so abundant in earth that resources and reserves cannot be quantified, even in the EU. The Minerals4EU project only records data on silica resources for some countries in Europe (see Table 131) . Reserve data for some countries in Europe are also available in the Minerals4EU website (Table 132) However, these data cannot be summed as they are partial and they do not use the same reporting code.

---

[25] www.crirsco.com

Table 131: Resource data for Europe compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Quantity	Unit	Grade	Code Resource Type
Norway	None	157	Million tonnes	Quartz and quartzite	Estimated
UK	None	40,000	Million tonnes	Silica sand	Estimated
Latvia	-	18.8 2.6	? ?	moulding sand Quartz sand for glass	Stock of evaluated deposits of mineral resources
Poland	Nat. rep. code	352.89	million tonnes	Quartz sands – total	A+B+C1
Slovakia	none	10.662 0 0	Million tonnes Million tonnes Million tonnes	Foundry sands – economic Glass sands – economic Quartz – economic	Verified Z1
Czech Republic	Nat. rep. code	147,412 145,040	Thousand tonnes Thousand tonnes	Industrial sands - foundry sand Industrial sands - glass sand	Potentially economic
Ukraine	Russian classification	38,924	Thousand tonnes	Quartz sand	P2
Slovenia	Nat. rep. code	168.68	Million tonnes	Quartz sand	National
Serbia	JORC	65.63	Million tonnes	Quartz sand and silicious rocks	Total
Kosovo	Nat. rep. code	13	Million tonnes	Quartzite sand	Historic Resource Estimates
Macedonia	Ex - Yugoslavian	5,081,465	m^3	Quartz	B
Albania	Nat. rep. code	100	Million m^3	Silica Sands - 61% SiO2	A
Greece	USGS	75 3	Million tonnes Million tonnes	Quartz Silica sand	Indicated

Table 132: Reserve data for Europe compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Quantity	Unit	Grade	Code Reserve Type
Denmark	None	24.1	Million m^3	Pure quartz sand	e
Ukraine	Russian classification	41,130 14,007 11,521	Thousand tonnes Thousand tonnes Thousand tonnes	Foundry sand Glass raw materials Quartz and quartzite for refractories	A

Country	Reporting code	Quantity	Unit	Grade	Code Reserve Type
Poland	Nat. rep. code	20.45 144.54 68.11	Million tonnes Million tonnes Million tonnes	Foundry sands Glass sands and sandstones Quartz sands	-
Czech Republic	Nat. rep. code	127,937 84,755	Thousand tonnes Thousand tonnes	Industrial sands - foundry sand Industrial sands - glass sand	Economic explored
Slovakia	None	10.662 0 0.107	Million tonnes Million tonnes Million tonnes	Foundry sands Glass sands 33.64% Quartz	Verified Z1
Slovenia	UNFC	16.44	Million tonnes	Quartz sand	Proved
Croatia	Nat. rep. code	33,035.77	Thousand tonnes	Silica sands	-
Kosovo	Nat. rep. code	2,312,614	m^3	Quartzite sand	A+B
Macedonia	Ex-Yugoslavian	5,081,465	m^3	Quartz	B

27.2.1.4 Production of silica sand

Data for world production of quartz sand is not readily available. USGS data exist for worldwide sand and gravel (industrial) production (USGS, 2016) and also for Silica (includes Industrial Sand and Gravel, Quartz Crystal, and Tripoli and Special Silica); however, this data is not reliable due to the variation of reporting standards in each country. For example, this data may also include production of aggregates or even building stones such as marble (European Commission, 2014).

Moreover, the market of silica sand is a very local market due to the fact that silica sand is usually not transported over long distances due to the cost of transport; therefore the industry of use must be located close to the sand source. As there is very few trade of silica sand (except for very high grade sand for niche applications), the world production is not relevant for the EU supply (European Commission, 2014).

Approximately 77,000,000 tonnes of Silica sands (quartz sands or industrial sands) were produced in the EU in average between 2010 and 2012 according to Eurostat (Eurostat, 2016b). The Figure 213 shows the major countries extracting and manufacturing silica sand in the EU. According to IMA-Europe, annual consumption of silica sands in finished products in the EU-28 is around 66 million tonnes in 2015 (IMA-Europe, 2013), this value is lower than the ProdCom value but production and consumption are not the same indicators (exports are not taken into account in consumption).

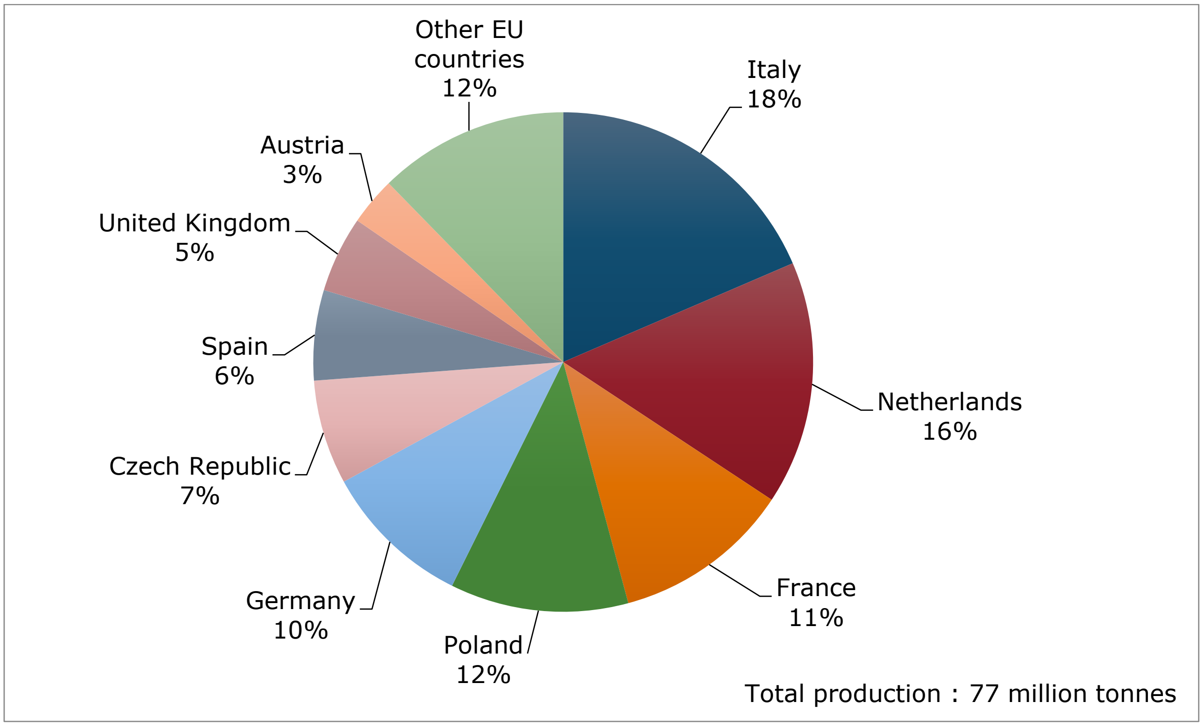


Figure 213: EU production of silica sand, average 2010–2012 (Data from (Eurostat, 2016b) CN8 code 08121150 Silica sands (quartz sands or industrial sands)). ***It must be noted that data for UK production is absent in the ProdCom database and have been added on the advice of experts***

27.2.2 Supply from secondary materials

Materials containing silica sand are widely recycled from post-consumer waste across Europe; this includes silica used in construction and soil applications, and in flat and container glass. For example, recycled glass is contributing to 95% of the raw materials for the glass industry (Research and Markets, 2016). According to IMA-Europe, 73% of silica entering the market is recycled. However, the recovery of silica sand from end applications is not performed: thus silica sand to silica sand recycling is zero (IMA-Europe, 2016a).

27.2.3 EU trade

As mentioned before, silica sand is a very local market so the imports and exports of silica sands are negligible. The Comext database recorded about 733,000 tonnes of silica sands exported (Eurostat, 2016a) but exports were assumed as zero according to IMA experts if compared to the values of imports (IMA-Europe, 2016a). Imports provided by the Comext database amounts about 182,000 tonnes (see Figure below for the breakdown of suppliers) (Eurostat, 2016a).

However, Eurostat import data appears to be also inaccurate: for example Tunisia and Egypt are not supplying silica sand to EU according to experts (IMA-Europe, 2016a), while about 4.5 million tonnes of silica sand are reported for both in the trade database (Eurostat, 2016a). Experts also believe the data from Dominica are not realistic because of the distance and transport cost (therefore they also should be neglected, as Tunisia and Egypt) (IMA-Europe, 2016a). The imports of silica sand reported in the Comext database, which amount about 182,000 tonnes, are about 3 orders of magnitude below the EU production, so they are negligible (less than few %). Therefore, the import reliance of the EU regarding silica sand supply from extra-EU countries is null (0.2%): the EU is totally independent from extra-EU supply for this commodity.

No trade restriction have been observed for the 2010-2014 period (OECD, 2016). The EU and Serbia have a free trade agreement in place (European Commission, 2016).

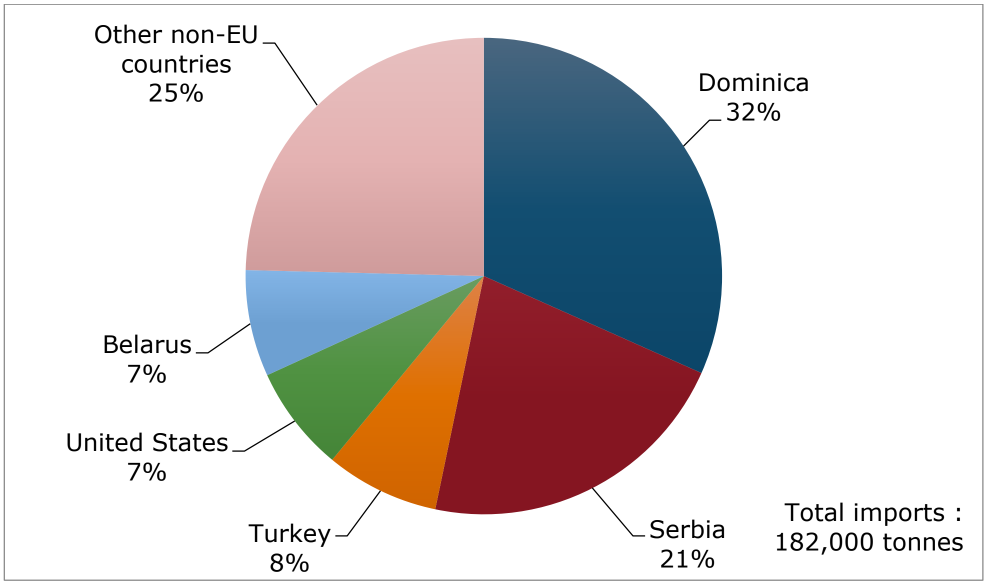


Figure 214: EU imports of silica sand, average 2010-2014. (Data from (Eurostat, 2016a) CN8 code 25051000 Silica sand and quartz sand whether or not coloured). *NB: It must be noted that imported quantities from Tunisia and Egypt have been removed on the advice of experts.*

27.2.4 EU supply chain

As mentioned before, extraction, processing and transformation of silica sand into finished products are performed is the EU. All the life cycle and the value chain of this commodity occur in the EU. The import reliance is null, and the trade is extremely limited due to the cost of transport. The Figure 215 presents the EU sourcing (domestic production + imports) for silica sands.

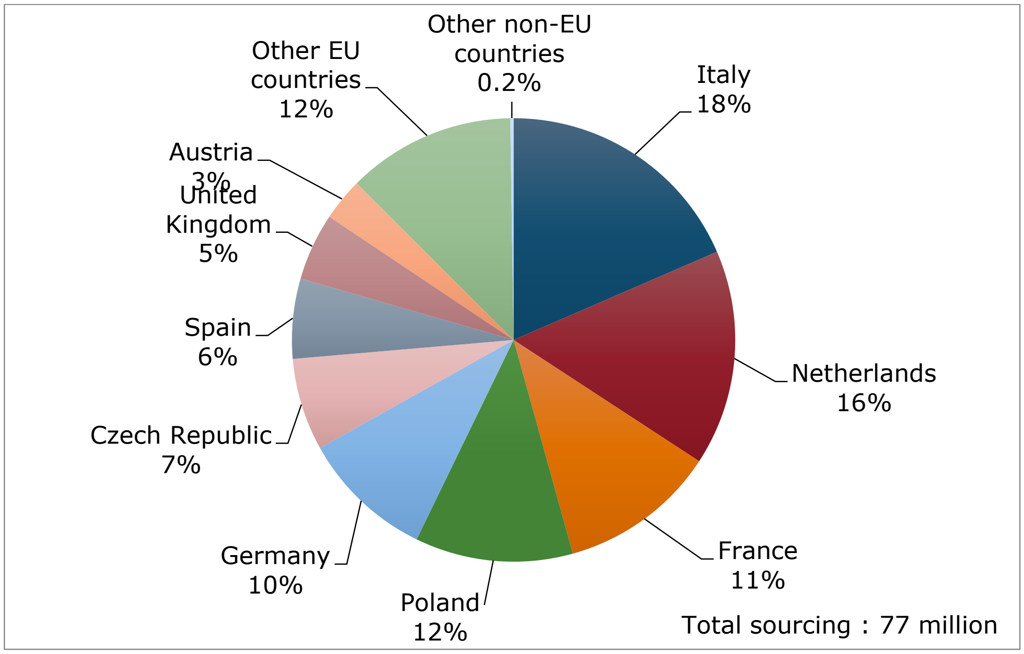


Figure 215: EU sourcing (domestic production + imports) of silica sand, average 2010-2014. (Data from Eurostat, 2016a; Eurostat, 2016b)

27.3 Demand

27.3.1 EU demand and consumption

Approximately 77,000,000 tonnes of silica sand were produced in Europe in average between 2010 and 2012 according to Eurostat (Eurostat, 2016b). According to IMA-Europe, the EU consumes each year about 66 million tonnes of silica sands in finished products (IMA-Europe, 2013).

27.3.2 Uses and end-uses of silica sand in the EU

The major end-uses of silica sand are displayed in Figure 216 (European Commission, 2014; IMA-Europe, 2016b) and relevant industry sectors are described using the NACE sector codes (Eurostat, 2016c) provided in Table 133.

- Construction and soil: Both high-quality sand and low-end by-products of silica are used for this purpose. These uses include high-end concrete, composite kitchen tops, equestrian surfaces, sports soils, asphalt, and road construction.
- Glass (flat and container): Silica is the principal ingredient in all types of glass. 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. Sand is fused with sodium carbonate to reduce fusion temperature. The size of the sand grains used in glass industry should be between 100-600 microns and the purity content should be of a minimum of 98.5% of silicon dioxide. The presence of these impurities gives colour effect in the glass.
- Foundry Casting: Crystalline silica together with a binder is used to make moulds used on the production of metal castings. 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.
- Other uses of silica sand are in ceramics, filtration, paints and plastics, polymer compounds, rubber, sealants and adhesives, sports and leisure applications, agriculture and in the chemical industry.

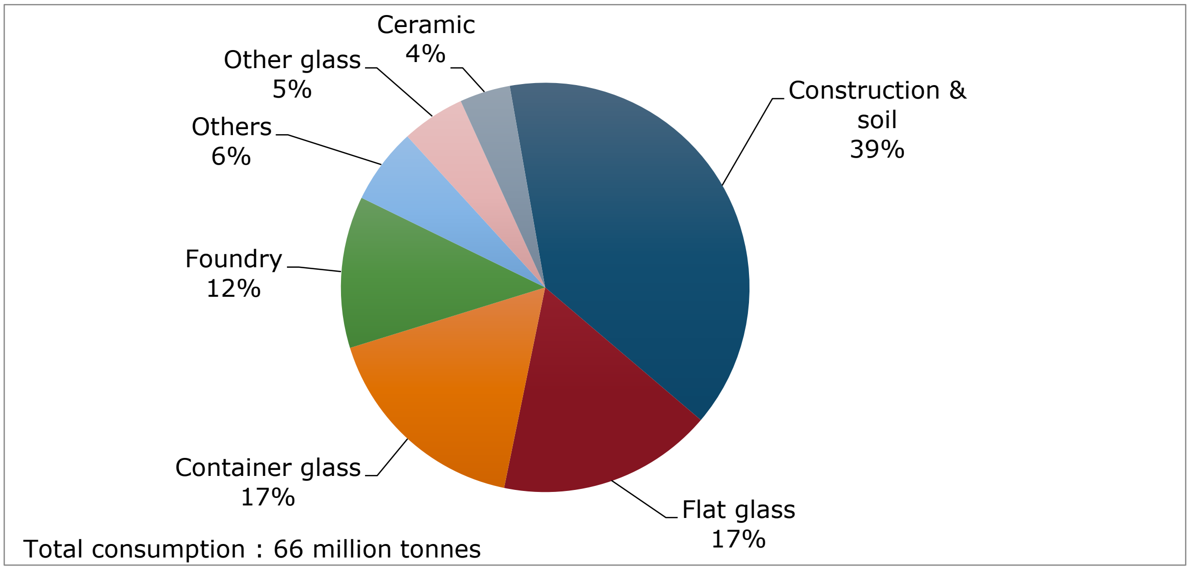


Figure 216: EU end uses of silica sand. (Data from IMA-Europe, 2016b - year 2014)

Table 133: Silica sand applications, 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2016c)

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	59,166	C2361-Manufacture of concrete products for construction purposes; C2351- Manufacture of cement; C2369-Manufacture of other articles of concrete, plaster and cement
Glass	C23 - Manufacture of other non-metallic mineral products	59,166	C2311-Manufacture of flat glass; C2312-Shaping and processing of flat glass; C2313-Manufacture of hollow glass; C2319-Manufacture and processing of other glass, including technical glassware
Foundry	C24 - Manufacture of basic metals	57,000	Too broad C241- Manufacture of basic iron and steel and of ferro-alloys; C244-Manufacture of basic precious and other non-ferrous metals
Ceramics	C23 - Manufacture of other non-metallic mineral products	59,166	Too broad C234- Manufacture of other porcelain and ceramic products

27.3.3 Prices

Silica sand can cost between $50 to over $300 per tonne over the period 2010-2016 (IMA-Europe, 2016a), equivalent to about 35 -210 € (for an average change rate at 0.7 €/$). The cost depends on location of the sand mine and delivery location.

27.4 Substitution

Silica sands are not currently substituted as any potential substitute would lead to a loss of performance and is therefore not currently used (IMA-Europe, 2016a).

27.5 Discussion of the criticality assessment

27.5.1 Data sources

Eurostat data have been used to assess the EU production and imports of silica sand. Exports that are registered in the ComExt database under the code 25051000 (Eurostat, 2016a) have not been taken into account and assumed as zero based on expert advice. Supply data have been averaged on the 2010-2014 period for imports and the 2010-2012 period as 2013 and 2014 were not provided in the ProdCom database (Eurostat, 2016b). USGS provides quantities produced worldwide for industrial sands (USGS, 2016) - which are not specific to silica sand- so they cannot be included in the assessment. Data from the 2014 criticality assessment have also been used (European Commission, 2014). Experts from IMA-Europe provided feedback to complete or correct the public data.

27.5.2 Economic importance and supply risk calculation

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 133). The value added data correspond to 2013 figures.

The life cycle stage assessed in for the SR indicator is the extraction step. The Supply Risk (SR) is calculated using only the HHI for EU supply as the import reliance is null. About 85% of the EU production is performed in the Netherlands; Italy, France, Poland, Germany, Czech Republic, the UK, Spain and Austria.

27.5.3 Comparison 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 134.

Table 134: Economic importance and supply risk results for silica sand in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017.

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Silica sand	5.83	0.18		5.76	0.32		2.6	0.3

Although it appears that the economic importance of silica sand has reduced between 2014 and 2017 this is a false impression created by the change in methodology. The value added used in the 2017 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 calculations of the Supply Risk (SR) for 2011 and 2014 lists have been performed based on global supply whereas the SR in 2017 assessment is calculated only based on the EU supply.

27.6 Other considerations

27.6.1 Forecast of future demand and supply

The analysts forecast the global silica minerals mining market to grow at a compound annual growth rate of 5.09% during the period 2016-2020 (Research and Markets, 2016) – see Table 135. Increase in demand from glass industry will a key driver for market growth. The global glass market is experiencing high growth because of increased demand from the construction and automotive sectors. Developing countries such as India, China, and South Korea account for a large demand for glass. The global flat glass market had the capacity to produce 88.26 billion square feet of flat glass in 2014; this is expected to increase to 122.3 billion square feet by 2019, growing at a compound annual growth rate of 6.76%. Sand is the major component of glass and accounted for 51% of the raw materials used in the production of flat glass. Thus, the glass industry is a major driver for the global silica minerals mining market (Research and Markets, 2016).

Moreover, the increase in the recyclability of glass is a challenge for the global silica minerals mining market (Research and Markets, 2016). This leads to a reduction in the production of new glass from primary silica sand, reducing the consumption of sand as recycled glass (known as cullet) substitutes almost 95% of the primary raw materials. The

US and Europe are the major regions for glass recycling. Indeed in 2014, the European Union recycled 74% of the glass packaging by recycling more than 25.01 billion glass containers. In the US, 35% of the glass containers were recycled in 2014. The recyclability rate will increase during the forecast period, reducing the magnitude of sand consumption in the glass industry (Research and Markets, 2016).

On the supply side, one of the major issues is that the silica sand market is regional and market dependant. 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 results in the regional market being fairly restricted (European Commission, 2014).

Table 135: 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	+	?	?	?	?	?

27.6.2 Environmental and regulatory 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 (European Commission, 2014). 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 15 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) (NEPSI, 2017). This aims at minimising exposure by applying Good Practices and increasing the knowledge about potential health effects of respirable crystalline silica dust (European Commission, 2014). NEPSI represents 15 industry sectors i.e. more than 2 million employees and a business exceeding € 250 billion (NEPSI, 2017). A reporting format was developed and included in the Agreement as Annex 3. This format allows each of the 15 signatory EU sector associations to provide the NEPSI Council with quantitative data on the application of the Agreement after it has been collected and consolidated from site to EU sectors level (NEPSI, 2017).

27.7 Data sources

27.7.1 Data sources used in the factsheet

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. Silica Sand profile, p87-91.

Eurostat (2016)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

IMA-Europe (2013). Recycling Industrial Minerals. p.19-22

IMA-Europe. (2016a). Communication during the workshop held in Brussels on 28/10/2016

IMA-Europe (2016b) Silica. [online]. Available at : http://www.ima-europe.eu/sites/ima-europe.eu/files/minerals/Silica_An-WEB-2011.pdf [Accessed December 2016]

Minerals4EU (2014). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

NEPSI. European Network for Silica (NEPSI). (2017) [online] Available at: http://www.nepsi.eu/agreement [Accessed January 2017]

Research and Markets (2016) Global silica minerals mining market 2016-2020

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

USGS (2016) Mineral Commodity Summaries: Sand and Gravel (Industrial). [online] Available at: http://minerals.usgs.gov/minerals/pubs/mcs/2016/mcs2016.pdf

27.7.2 Data sources used in the criticality assessment

European Commission (2014) Report on critical raw materials for the EU - Non Critical raw materials profiles. Silica Sand profile, p87-91.

European Commission, (2016). Free trade agreements. [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/[Accessed September 2016]

Eurostat (2016)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

IMA-Europe (2016). Communication during the workshop held in Brussels on 28/10/2016

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

USGS (2016) Mineral Commodity Summaries: Sand and Gravel (Industrial). [online] Available at: http://minerals.usgs.gov/minerals/pubs/mcs/2016/mcs2016.pdf

USGS (2013) Minerals Yearbook: Silica (Includes Industrial Sand and Gravel, Quartz Crystal, and Tripoli and Special Silica). [online] Available at: http://minerals.usgs.gov/minerals/pubs/commodity/silica/myb1-2013-silic.pdf

27.8 Acknowledgments

This Factsheet was prepared by Deloitte. The authors would like to thank IMA-Europe and the members of the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this Factsheet.

28. SILVER

Key facts and figures

Material name and Element symbol	Silver, Ag	World/EU production (tonnes)[1]	25,069/1,725
Parent group	NA	EU import reliance[1]	59%
Life cycle stage assessed	Extraction	Substitution index for supply risk [SI(SR)][1]	0.98
Economic importance (EI)(2017)	3.8	Substitution Index for economic importance [SI(EI)][1]	0.96
Supply risk (SR)(2017)	0.5	End of life recycling input rate	55%
Abiotic or biotic	Abiotic	Major end uses in the EU[1]	Jewellery: 31% Pigments: 18% Electronics: 8%
Main product, co-product or by-product	All of the options	Major world producers[1]	Mexico: 21% Peru: 14% China: 14%
Criticality results	2011	2014	2017 (current)
	Not critical	Not critical	Not critical

[1] average for 2010-2014, unless otherwise stated

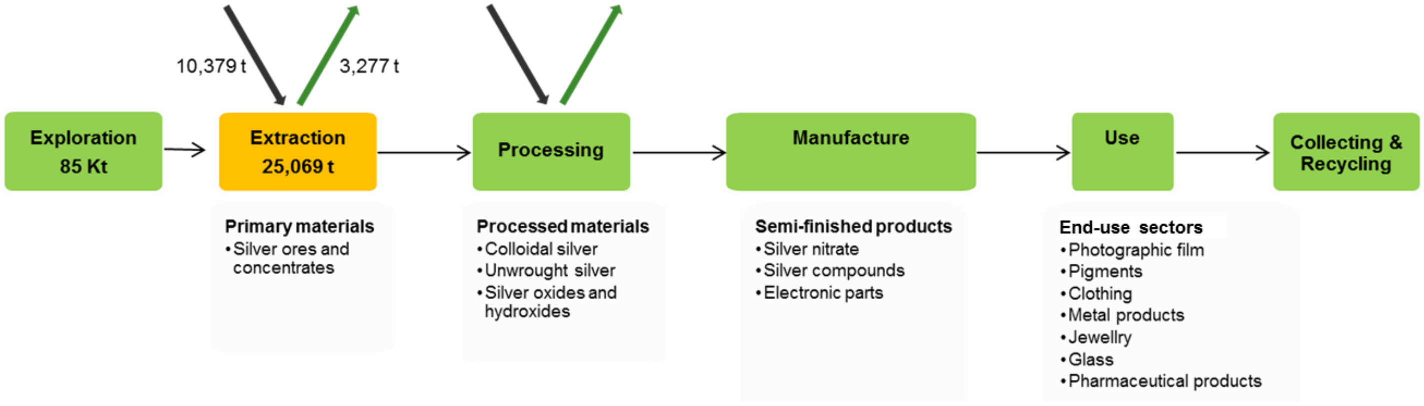


Figure 217: Simplified value chain for silver

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU. A quantitative figure on recycling is not included as the EOL-RIR is below 70%.

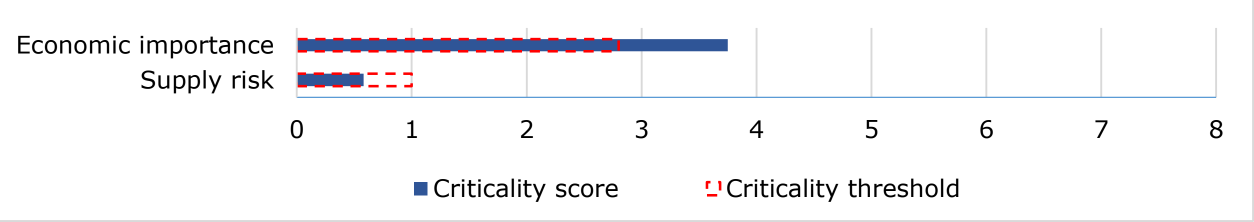


Figure 218: Economic importance and supply risk scores for silver

28.1 Introduction

Silver is a chemical element with symbol Ag and atomic number 47. Silver is one of eight precious, or noble metals which are resistant to corrosion. Silver 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.

In the EU, it is used for jewellery and several specific electronic and chemical applications. It has high photosensitivity to visible, x-ray, and gamma-ray wavelengths in the electromagnetic spectrum. Its use, however, is restricted by its relatively high cost.

28.2 Supply

28.2.1 Supply from primary materials

28.2.1.1 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 (Ag2S), proustite (Ag3AsS3) and pyragyrite (Ag3SbS3). Silver minerals can be sulphides, tellurides, halides, sulphates, sulphonates, silicates, borates, chlorates, iodates, bromates, carbonates, nitrates, oxides, and hydroxides.

As natural Ag-alloy, silver is for the most part combined with gold. The term 'electrum' is used for minerals in which the Ag/Au 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 Ag-minerals.

28.2.1.2 Exploration

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, 2014).

28.2.1.3 Processing and refining

According to the Silver Institute (2015), 31% of the global silver production derived from silver ores, 35% from lead and zinc ores, 20% from copper, 13% from gold ores, and 1% from other types of mining operations.

Native silver is usually extracted in underground mines, where the operations follow the Ag-veins and cavities. Other Ag-bearing ores are mined depending on their original deposit type.

Sulphide ores (Cu, Pb, Zn) go through various stages of comminution followed by froth flotation. Then, copper and lead concentrates are usually sent to smelters in order to recover metals under crude forms. Zinc concentrates are roasted and the Ag-rich residue follows further pyrometallurgical process in order to recover the metallic element.

Gold-silver ores undergo hydrometallurgical treatment. The leaching product (silver doré) is then further refined by electrolysis, to obtain metallic silver up to 99.9% purity (BGS, 2012).

28.2.1.4 Resources and reserves

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[26], 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.

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, 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, 2015).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 USGS does not provide any figure for global silver resources. It only states that "The polymetallic ore deposits from which silver was recovered account for more than two-thirds of U.S. and world resources of silver". Data on silver resources in some countries in Europe are available in the Minerals4EU website (Minerals4EU, 2014).

World silver reserves contained within both primary silver deposits, as well as polymetallic base metals ores are estimated at over half a million tonnes (Table 136). The largest of these are located within Peru, Australia, Poland and Chile, which between them account for approximately two thirds of world reserves. Data on silver reserves in some countries in

---

[26] www.crirsco.com

Europe are available are available in the Minerals 4EU website (Minerals4EU, 2014), see Table 137, but cannot be summed as they are partial and they do not use the same reporting code.

Table 136: Global reserves of silver in year 2016 (Data from USGS, 2016).

Country	Silver Reserves (tonnes)	Percentage of total (%)
Peru	120,000	21
Australia	85,000	15
Poland	85,000	15
Chili	77,000	14
China	42,000	7
Mexico	37,000	6
United States	25,000	4
Bolivia	22,000	4
Russia	20,000	4
Canada	7,000	1
Other countries	50,000	9
World total (rounded)	*570,000*	*100*

Table 137: Reserve data for Europe compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Value	Unit	Grade	Code Reserve Type
Sweden	FRB-standard NI43-101	517.1 12.3	Mt Mt	5.22 g/t 69 g/t	Proven Proven
Finland	NI43-101 JORC	7.4 1.8	Mt Mt	14 g/t 98 g/t	Proven Proved
Portugal	NI43-101	16.521	Mt	62.37 g/t	Proven
Poland	Nat. Rep. Code	70.74	kt	-	Total
Slovakia	None	7.335	Mt	12.04 g/t	Z1
Ukraine	Russian Classification	158.35	t	-	C1
Kosovo	Nat. Rep. Code	13,247	kt	0.00788%	(RUS)A
Greece	CIM	2,206.8	t	-	Proved
Turkey	NI43-101 JORC	4.49 20.51	Mt Mt	27 g/t 1.3 g/t	Proven Proved

28.2.1.5 World mine production

The global production of silver between 2010 and 2014 was 25,069 tonnes on average (BGS, 2016). Mine production for silver is distributed between at least 50 different countries worldwide, and from a diverse range of sources. The three largest silver producing countries are Mexico, China and Peru, which between them account for almost half of the world's production. This represents nearly one half of world silver mine production, which stood just over 25,000 tonnes on average between 2010 and 2014 (Figure 219).

The EU represents a minor source of world silver mine production, at just under 7% of the world total. Poland is the largest producer, accounting for approximately 5% of world silver mine production. There are a further eight silver producing countries within the EU, most notably including Sweden (1.3% of global production), Bulgaria (0.2%) and Greece (0.14%) (BGS, 2016).

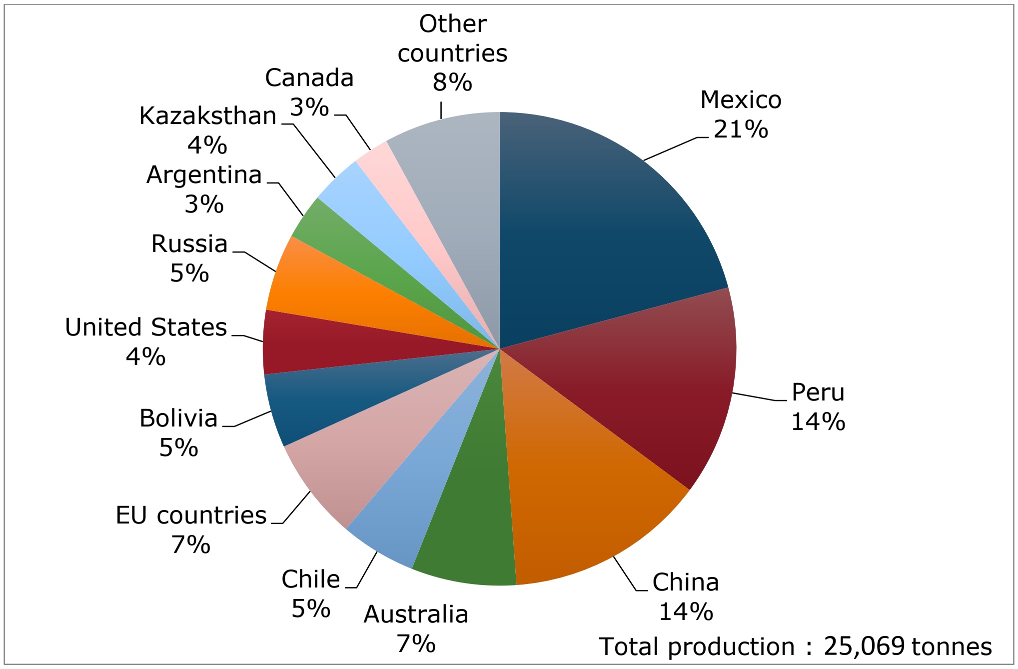


Figure 219: Global mine production of silver, average 2010–2014 (Data from BGS World Mineral Statistics database, 2016)

28.2.2 Supply from secondary materials

The end-of-life recycling input rate for silver is estimated to be 55% (UNEP, 2011). It must be said that several other percentages of the End-of-life recycling input rate are reported, ranging between 20% (GFMS, 2015) and 80% (UNEP, 2011).

A significant proportion of silver is recycled during the manufacturing process. An estimated 5.2 Kt of silver scrap was recycled in 2014 (GFMS, 2015), 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%.

However, the EOL-RR varies considerably by application (UNEP, 2011):

- Vehicles: 0%-5%
- Electronics: 10%-15%
- Industrial Applications: 40%-60%
- Others: 40%-60%

For applications where silver use is more dissipative, such as 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 recycling rate.

28.2.3 EU trade

The volume of imports and exports of silver to and from the EU have been fluctuating in recent years. The changes of silver ores and concentrates in absolute volume might not appear significant, but they are compared to the EU consumption. The total net imports have been reduced in 2014 to around 2,000 tonnes from 12,000 tonnes in 2012, see Figure 220.

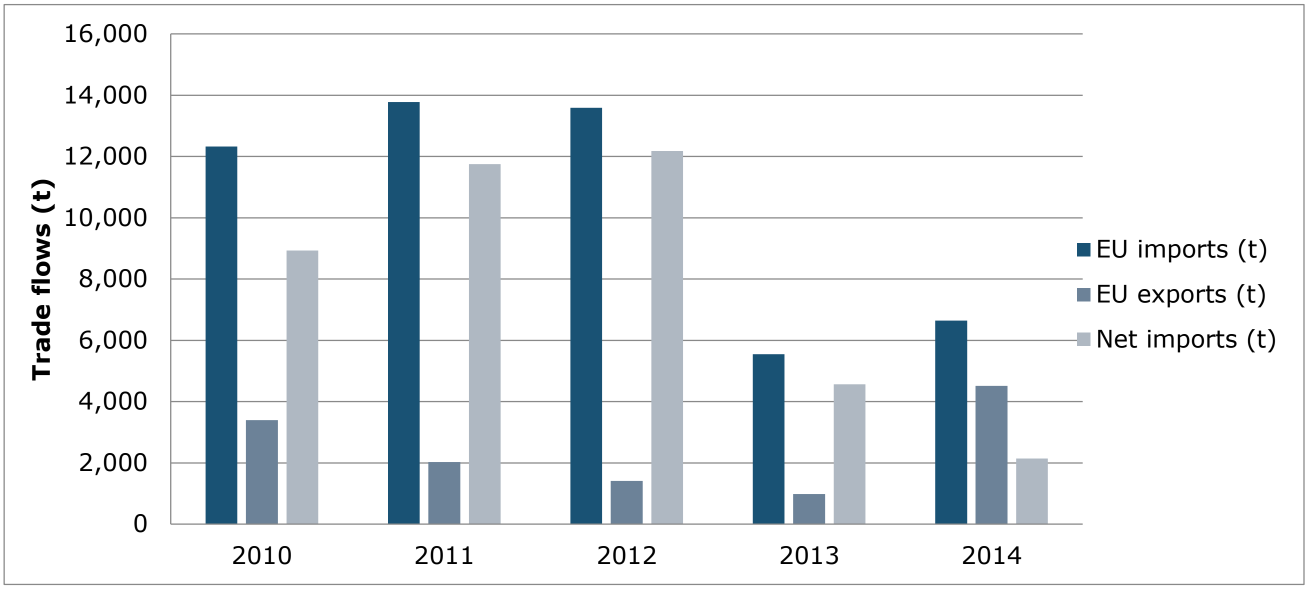


Figure 220: EU trade flows for silver (Data from Eurostat Comext 2016)

The origins of silver ores and concentrates trade to the EU are found in Latin America. Peru, Mexico and Argentina together ship over 90% of the traded volume to the EU, see Figure 221.

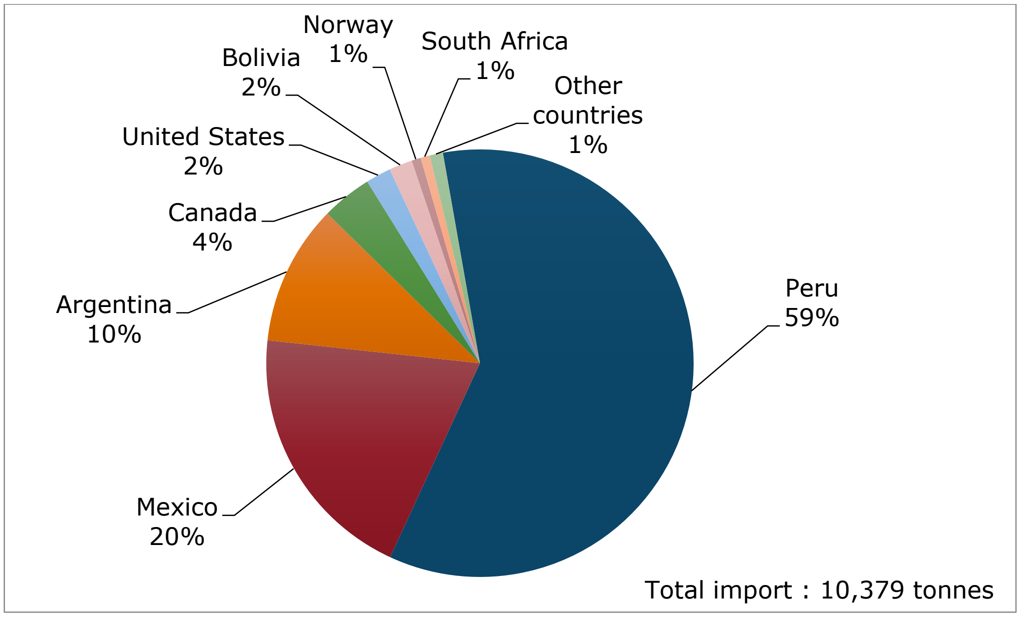


Figure 221: EU imports of silver, average 2010-2014 (Data from Eurostat Comext 2016)

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.

28.2.4 EU 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 59% on 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, 2016). Indonesia issues an export prohibition in for silver ores and concentrates. China and Morocco issued an export tax for silver ores and concentrates of 10%, 7.5% respectively. Russia has a licensing requirement for the export of silver ores.

The Figure 222 shows the EU sourcing (domestic production + imports) for silver.

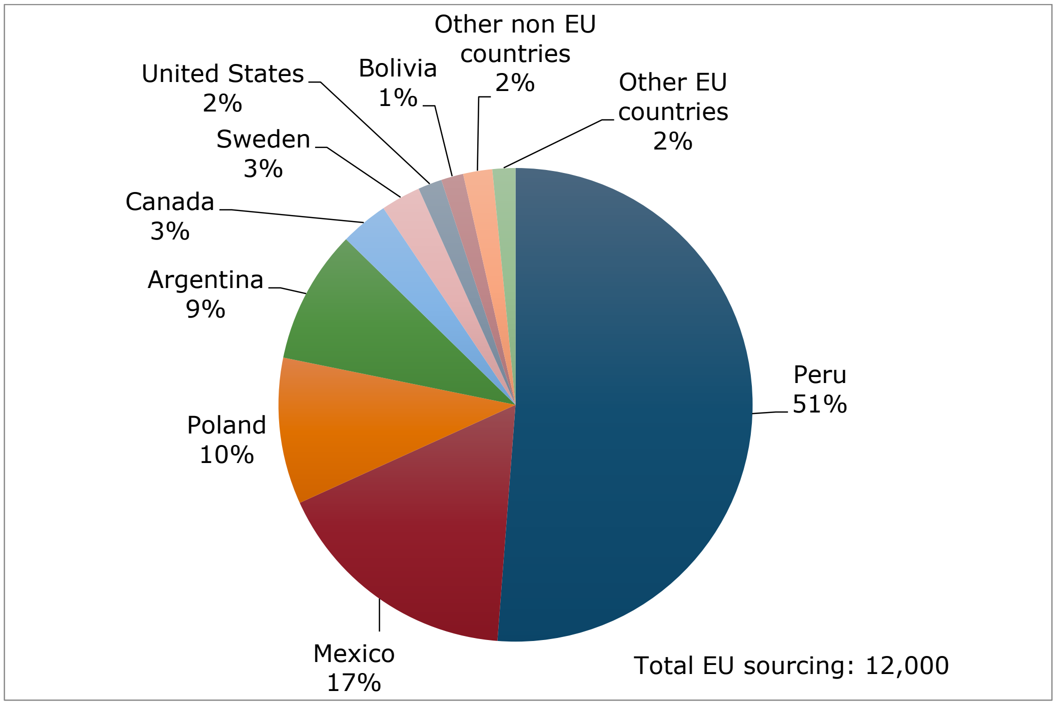


Figure 222: EU sourcing (domestic production + imports) of silver, average 2010-2014 (Eurostat, 2016)

28.3 Demand

28.3.1 EU consumption

The EU consumption of silver ores and concentrates is on average 12,105 tonnes. The total consumption of ores and concentrates is just under half the world's production. This share can also be observed in silver metal based on 2010 data (GFMS, 2011).

28.3.2 Applications / End uses

Silver is used for a variety of industrial and aesthetic applications such as electronics and jewellery. Figure 223 provides a breakdown of silver demand by application. Approximately half of world silver demand is in industrial applications, with around one fifth used for silverware or jewellery.

However, as a precious metal, it is worth noting that silver is also used for investment purposes, whether that is for silver coins or as bullion. This has a significant impact upon the year-to-year market balance for silver and market prices. Just over one quarter of world silver demand was for investment, a use that is ignored in this criticality analysis.

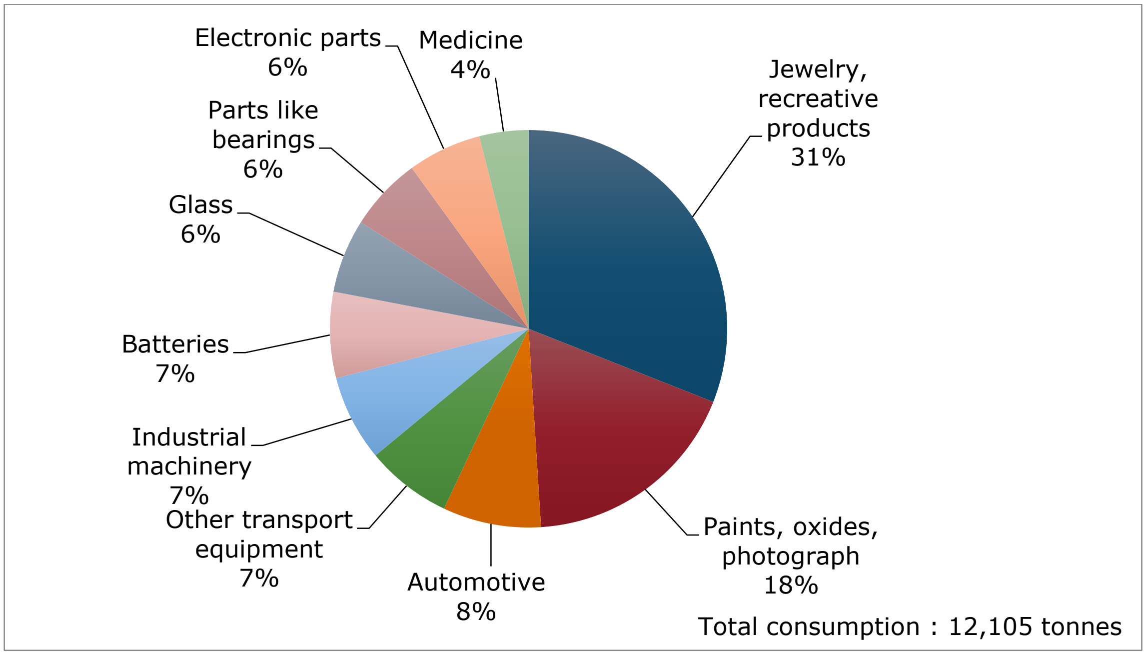


Figure 223: Global end uses of silver, average 2010-2014 (GFMS, 2011)

Descriptions of the major fabrication applications are as follows (GFMS, 2011):

- Coins, silverware and jewellery: silver's aesthetic properties, as well as its store of value make it an attractive material for these markets. These include use both as solid silver and silver plate.
- 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: silver is used as one element in these alloys, which are used to join together two different metals of different (higher) melting points.
- Ethylene oxide industry: silver oxide is used as a catalyst in this petro-chemical industry for the production of polyester intermediates.
- Photography: silver's high optical reflectivity has given it historical usage for film photography within light sensitive silver halide crystals; however this market has been in decline with the advent of digital photography since the late 1990s.
- Other industrial applications: these include coating materials for compact disks and digital video disks, mirrors, glass coatings and cellophane and batteries. 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.

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 138). The value added data correspond to 2013 figures.

Table 138: Silver applications, 2-digit NACE associated 4-digit NACE sectors and value added per sector (Data from the Eurostat database, Eurostat, 2016).

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (millions €)
Paints, oxides, photograph	C20 - Manufacture of chemicals and chemical products	C20.13 - Manufacture of other inorganic basic chemicals	110,000.0
Medicine	C21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations	C21.20 - Manufacture of pharmaceutical preparations	79,545.0
Glass	C23 - Manufacture of other non-metallic mineral products	C23.19 - Manufacture and processing of other glass, including technical glassware	59,166.0
Specific parts, like bearings	C25 - Manufacture of fabricated metal products, except machinery and equipment	C25.61 - Treatment and coating of metals	159,513.4
Electronic parts	C26 - Manufacture of computer, electronic and optical products	C26.11 - Manufacture of electronic components	75,260.3
Batteries	C27 - Manufacture of electrical equipment	C27.20 - Manufacture of batteries and accumulators	84,608.9
Industrial machinery	C28 - Manufacture of machinery and equipment n.e.c.	C28.12 - Manufacture of fluid power equipment	191,000.0
Automotive	C29 - Manufacture of motor vehicles, trailers and semi-trailers	C29.31 - Manufacture of electrical and electronic equipment for motor vehicles	158,081.4
Other transport equipment	C30 - Manufacture of other transport equipment	C30.30 - Manufacture of air and spacecraft and related machinery	53,644.5
Jewellery, recreative products	C32 - Other manufacturing	C32.12 - Manufacture of jewellery and related articles	41,612.6

28.3.3 Prices

The price development of silver is shown in Figure 224. The left y-axis expresses the price in EUR/kg. The metal price surge around 2011. Although the application of silver as monetary used is not considered in the 2017 criticality assessment, the effect of monetary policy on the price of silver (in wake of the gold price) is undeniable. Industrial demand has proven to be less of a driver of silver prices than the demand of investment currency. 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. The average price of silver (>99.5%) between 2011 and 2015 was 24.97 US$/troy ounce (31.10 gram) (DERA, 2016).

Figure 224: Global developments in price of silver. Average figures for 1998-2016. (Data from silverprice, 2016)

28.4 Substitution

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.
- Electrical and electronics: copper, aluminium and other precious metals can replace silver completely or partially in many electrical and electronic uses. However, this is based upon both cost and performance, where silver offers the highest electrical conductivity at a relatively lower cost.
- 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, batteries and jewellery.

28.5 Discussion of the criticality assessment

28.5.1 Data 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.

28.5.2 Calculation of Economic Importance and Supply Risk indicators

The decision was taken to assess silver in the extraction stage of the chain. However, only approximately 30% of mine production comes from so-called primary silver mines, where silver is the main source of revenue. The majority of the metal is therefore obtained as a by-product of refining other ores, notably lead and zinc (37%), copper (21%) and gold (13%). (GFMS, 2015). World mine production for silver is therefore correlated with the production of these other metals. In spite of this, the concentration of countries is larger when looking at the supply of relevant product groups (Eurostat Comext, 2016).

The supply risk was assessed on silver ore using both the global HHI and the EU-28 HHI as prescribed in the revised methodology.

28.5.3 Comparison with previous EU assessments

The results of the economic importance of silver in this assessment are smaller than found in previous assessments. 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.

Table 139: Economic importance and supply risk results for silver in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Silver	5.07	0.27		4.77	0.73		3.8	0.5

28.6 Other considerations

28.6.1 Forward look for supply and demand

The demand for silver for emerging technologies is estimated to be just above 3 tonnes in 2035 (Marscheider-Weidemann et al., 2016). The outlook of silver in PV products in the coming years is "extremely bullish" (GFMS, 2011).

Table 140: Qualitative forecast of supply and demand of silver

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
Silver		x	+	+	+	++	++	+

28.6.2 Environmental and regulatory 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 health regulators. It is currently used in silver ion filtration canisters for pools, tubes and spas. The use of silver based water treatment is more dominant in Europe than elsewhere (GFMS, 2011).

28.6.3 Supply market organisation

Significant investor stocks of silver exist which influences the market. The supply of silver metal to the world market can therefore change abruptly per year (GFMS, 2015).

28.7 Data sources

28.7.1 Data sources used in the factsheet

BGR (2016). Expert consultation with A. Wittenberg.

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

Eurostat (2016)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

Lenntech (2016). Silver. [online] Available at: http://www.lenntech.com/periodic/elements/ag.htm

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

Minerals4EU (2014). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

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.

Silver Institute, The, 2015, World silver survey 2015: Washington, DC, The Silver Institute, May, 100 p

Silverprice (2016). History of silver price. [online] Available at: http://silverprice.org/silver-price-history.html

USGS (2016) George, M.W. Silver USGS Minerals Yearbook 2014. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/silver/myb1-2014-silve.pdf

28.7.2 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

BGS (2012). Gold, silver and bronze: where do these metals come from? Available at: http://www.bgs.ac.uk/research/highlights/2012/goldSilverBronze.html#silver

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

GFMS (2011). The future of silver industrial demand. GFMS at ThomsonReuters. Commissioned by the silver institute. Available at: http://www.silverinstitute.org/site/wp-content/uploads/2011/07/futuresilverindustrialdemand.pdf

GFMS (2015). World silver survey 2015. GFMS at ThomsonReuters. Commissioned by the silver institute. https://www.silverinstitute.org/site/wp-content/uploads/2011/06/WSS2015Summary.pdf

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

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. 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

28.8 Acknowledgments

This Factsheet was prepared by the Netherlands Organisation for Applied Scientific Research (TNO). The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this Factsheet. Specific experts that have contributed their input and feedback to the factsheet and criticality assessments are listed in the data sources section.

29. SULPHUR

Key facts and figures

Material name and Element symbol	Sulphur S	World/EU production (million tonnes)[1]	Refining: 69.8/ 6.86
Parent group (where applicable)	N/A	EU import reliance[1]	0%
Life cycle stage assessed	Processing	Substitution index for supply risk [SI(SR)][1]	0.99
Economic importance score (EI)(2017)	4.6	Substitution Index for economic importance [SI(EI)][1]	0.97
Supply risk (SR) (2017)	0.6	End of life recycling input rate	5%
Abiotic or biotic	Abiotic	Major end uses in the EU[1]	Chemical industry (92%)
Main product, co-product or by-product	By-product	Major world producers[1]	Refining: China (15%), United States (14%), Russia (10%)
Criticality results	2011	2014	2017
	Not assessed	Not assessed	Not critical

[1] Average for 2010-2014, unless otherwise stated.

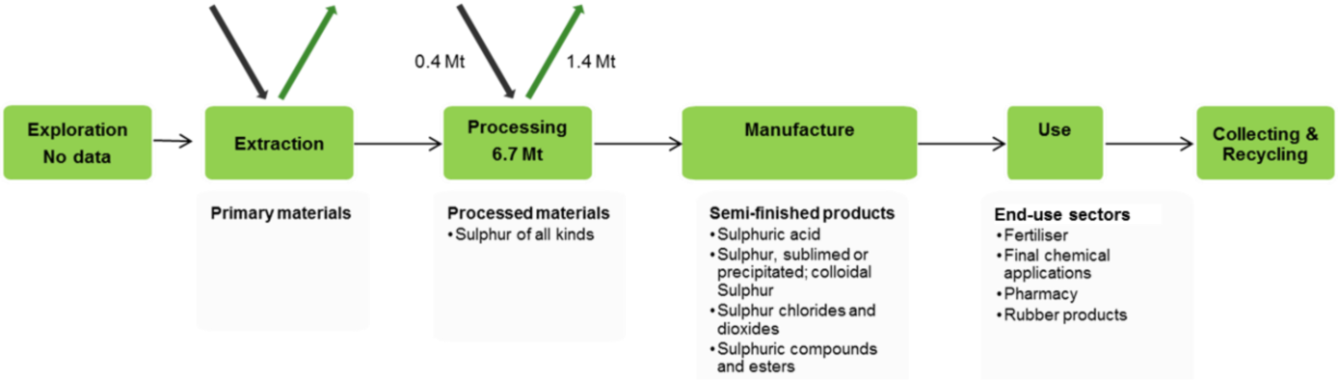


Figure 225: Simplified value chain for sulphur

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU. EU reserves are displayed in the exploration box.

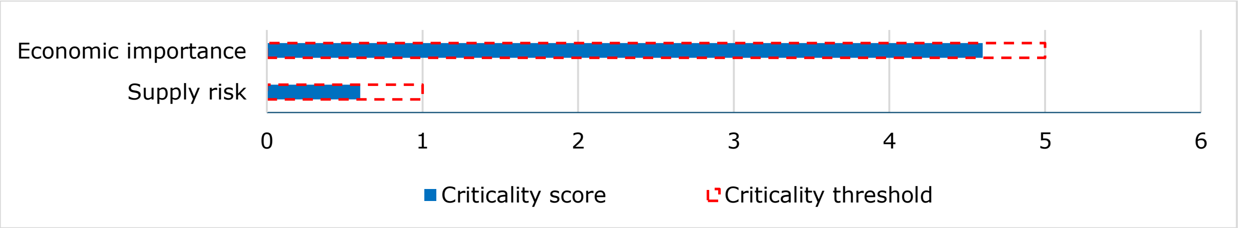


Figure 226: Economic importance and supply risk scores for sulphur

29.1 Introduction

Sulphur is a chemical element with symbol S and atomic number 16.

Sulphur 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. Although sulphur is infamous for its smell, frequently compare to rotten eggs, that odour is actually characteristic of hydrogen sulphide (H_2S). The crystallography of sulphur is complex. Depending on the specific conditions, sulphur allotropes form several distinct crystal structures (Lenntech, 2016).

The major derivative of sulphur is sulphuric acid (H_2SO_4), one of the most important materials used in the base industries (Lenntech, 2016). Sulphur can therefore be considered one of the most important industrial elements in terms of volume.

Sulphur is one of the so-called materials for life, next to hydrogen, carbon, phosphorous, oxygen and nitrogen.

29.2 Supply

29.2.1 Supply from primary materials

29.2.1.1 Geological occurrence/exploration

The presence of sulphur in the earth's crust is quite common, with 621 parts per million upper crustal abundance (Rudnick & Gao, 2003).

Sulphur is mostly associated with volcanic activity. Most of the native sulphur occurs naturally as massive deposits. Many sulphide minerals are known: pyrite and marcasite are iron sulphide; stibnite is antimony sulphide; galena is lead sulphide; cinnabar is mercury sulphide and sphalerite is zinc sulphide. Other, more important, sulphide ores are chalcopyrite, bornite, pentlandite, milarite and molybdenite (Lenntech, 2016).

29.2.1.2 Processing

Sulphur is a by-product in most cases, and a co-product in virtually the other cases. It is estimated that recovered elemental sulphur or by-product sulphuric acid, increasing the percentage of by-product sulphur production to about 90% annually (USGS, 2016a). Sulphur production is for 50% of the annually produced volumes a result of processing of fossil fuels, especially natural gas. This had an severe effect on discretionary mining operations, i.e. operation with the goal to extract ores that would enable voluntarily production of 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 mined ores are beneficiated using the conventional mining method for pyrites or the Frasch process.

Conventional mining methods for pyrites refer to sulphide containing ores. Sulphur emerges as by-product of several metal refining processes. For instance, nickel concentrations of sulphide ores are the most important source of nickel. Sulphide containing ores are also relevant for lead, silver, tin and copper. By far the largest use of manganese (more than 90%) in steel production is as reduction and desulphurization agent (European Commission, 2014), indicating the separation of sulphur as well. This means that sulphur, next to the 50% coming from fossil fuel processing, is also obtained in various forms is obtained in metallurgical processes (close to 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).

29.2.1.3 Resources and reserves

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[27], 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.

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, 2015).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.

Given the abundance of Sulphur in several material flows, the reserves of sulphur and sulphide ores are large (USGS, 2016a).

29.2.1.4 World production

The global production of sulphur between 2010 and 2014 was annually 69.8Mt on average. Figure 227 illustrates the widely dispersed industrial activities that lead to the production of sulphur. More than half of the world production takes place in “other” countries, mostly following involuntarily production of sulphur from in the metal and fossil fuel industries.

---

[27] www.crirsco.com

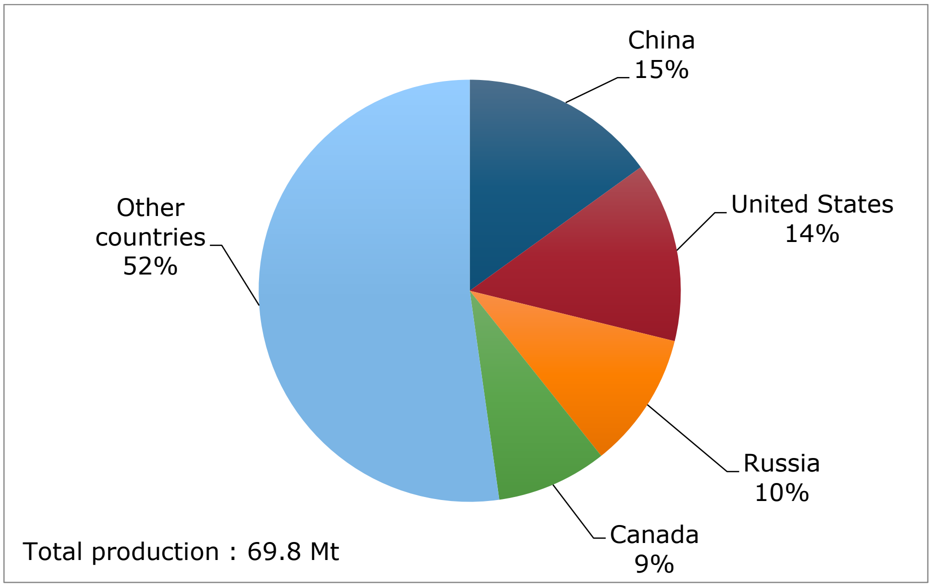


Figure 227: Global production of sulphur, average 2010–2014 (Data from BMWFW, 2016)

29.2.2 Supply from secondary materials

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 (USGS, 2016a).

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.

29.2.3 EU trade

The volumes of internationally traded sulphur are small compared to the annual production. The volumes of traded sulphur are relatively constant, as shown in Figure 228. The EU is a net exporter of sulphur.

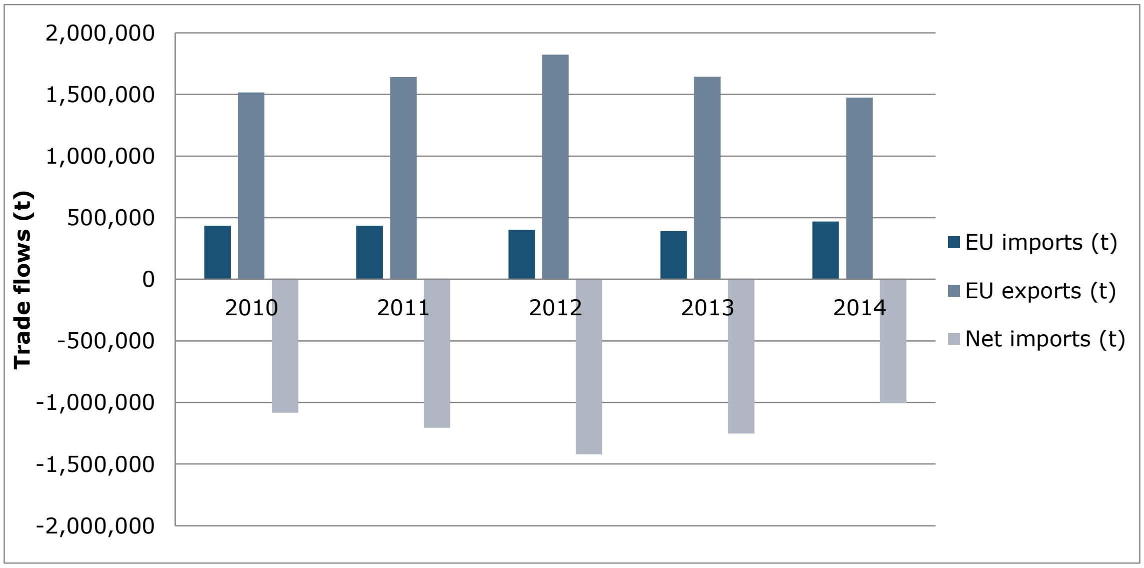


Figure 228: EU trade flows for sulphur (Data from Eurostat Comext 2016)

The trade of sulphur is associated with flows of material related to countries importing natural gas to the EU. The total volume of EU imports was 425Kt on average, a small fraction of the EU consumption. The majority of EU-28 imports originates from Kazakhstan (52%), followed by Russia (34%).

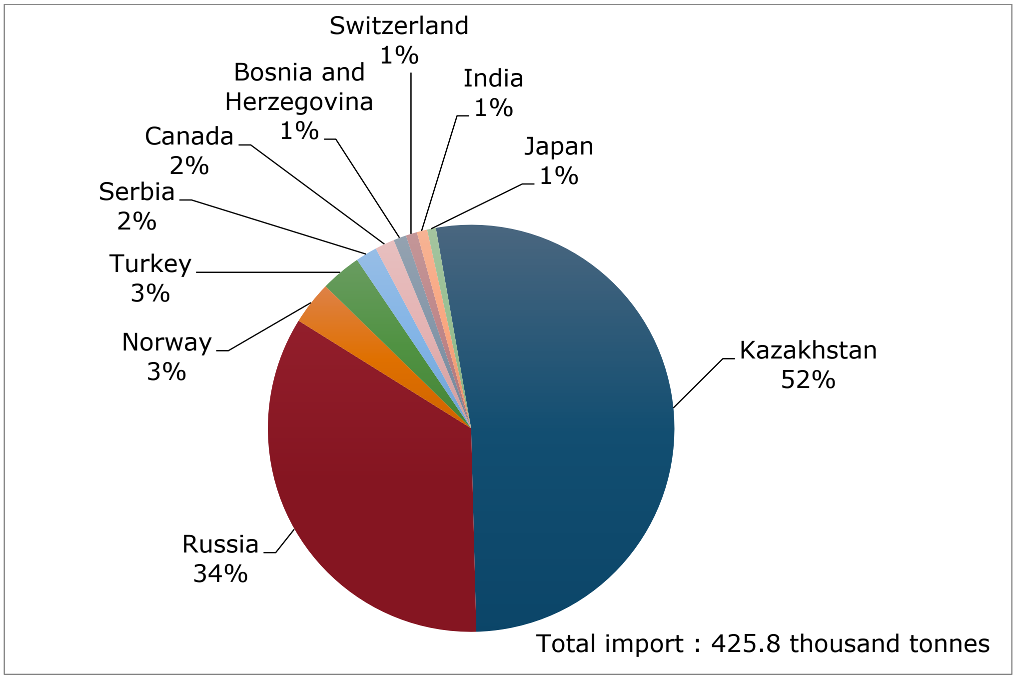


Figure 229: EU imports of sulphur, average 2010-2014 (Data from Eurostat Comext, 2016)

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.

No trade restrictions were reported over the 2010-2014 period (OECD, 2016). Some EU free trade agreements are in place with suppliers such as Turkey, Norway, Serbia, Bosnia and Switzerland (European Commission, 2016).

29.2.4 EU supply chain

The EU relies for the supply of sulphur for 0% on its imports. Given the sizeable petrochemical and metallurgical industries in the EU, there is an abundance of sulphur in European manufacturing processes.

There is no trade restriction associated with the product groups that contain high concentrations of sulphur (OECD, 2016).

Figure 230 shows the EU sourcing (domestic production + imports) for sulphur.

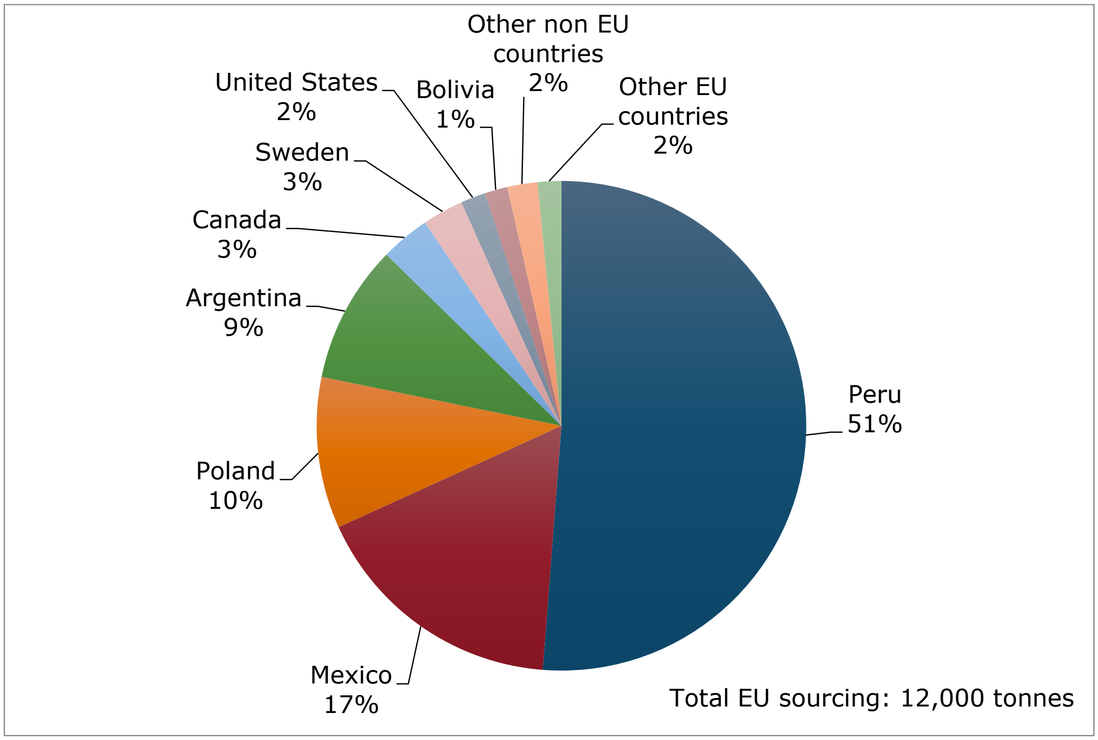


Figure 230: EU sourcing (domestic production + imports) of sulphur, average 2010-2014 (Eurostat, 2016; USGS, 2016a)

29.3 Demand

29.3.1 EU consumption

The EU consumption of sulphur was on average 7.2 Mt between 2010 and 2014. As mentioned in the trade section, the sizeable EU industries mostly provide the volumes rather than importing industries.

29.3.2 Applications / End uses

Most sulphur is used in the shape of acids. Sulphuric acid is an essential intermediate in many processes in the chemical and manufacturing industries. Sulphuric acid also is used by the fertilizer industry to manufacture primarily phosphates, nitrogen, potassium, and sulphate fertilizers. It is also used in manufacturing other products, including non-ferrous metals, pigments, fibres, hydrofluoric acid, carbon disulphide, pharmaceuticals, agricultural pesticides, personal care products, cosmetics, synthetic rubber vulcanization, water treatment, and steel pickling (Sulphur institute 2016).

Sulphuric acids ire also used in detergents, fungicides, manufacture of fertilizers, gun power, matches and fireworks. Other applications are making corrosion-resistant concrete which has great strength and is frost resistant, for solvents and in a host of other products of the chemical and pharmaceutical industries (Lenntech, 2016).The dominance of applications for the chemical industry for sulphur is illustrated in Figure 231.

The reason sulphur is chiefly allocated to chemical applications as NACE2 digit sector is that the applications metal products manufacturing normally take place on the production site without the materials entering the supply chain (Vandenbroucke, 2016).

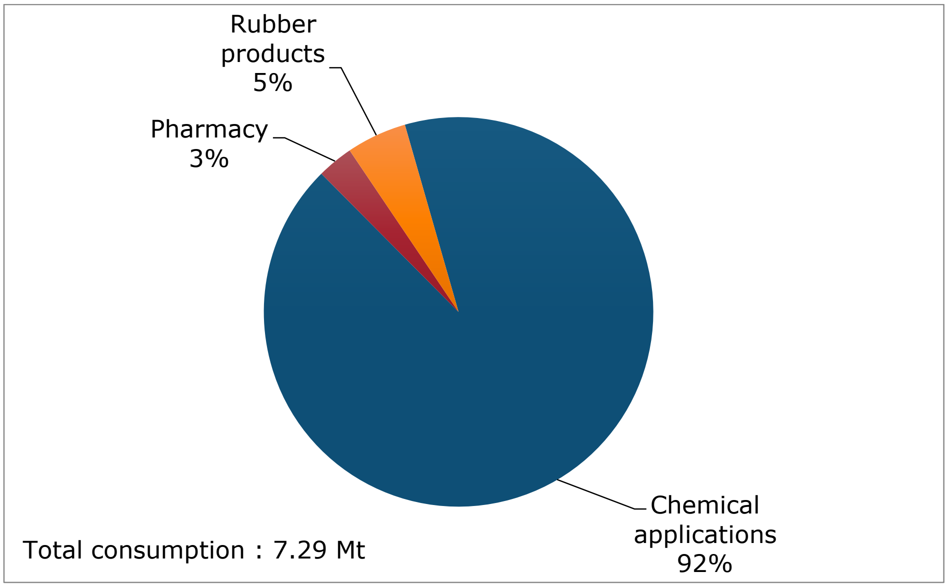


Figure 231: Global/EU end uses of sulphur, average 2010-2014 (Data from Sulphur institute 2016)

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 141). The value added data correspond to 2013 figures.

Table 141: Sulphur applications, 2-digit NACE sectors associated 4-digit NACE sectors and value added per sector (Data from the Eurostat database, Eurostat, 2016)

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (millions €)
Chemical applications	C20 - Manufacture of chemicals and chemical products	C20.13 - Manufacture of other inorganic basic chemicals	110,000
Pharmacy	C21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations	C21.10 - Manufacture of basic pharmaceutical products	79,545
Rubber products	C22 - Manufacture of rubber and plastic products	C22.19 - Manufacture of other rubber products	82,000

29.3.3 Prices

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, which has reduced in 2013 and 2014.

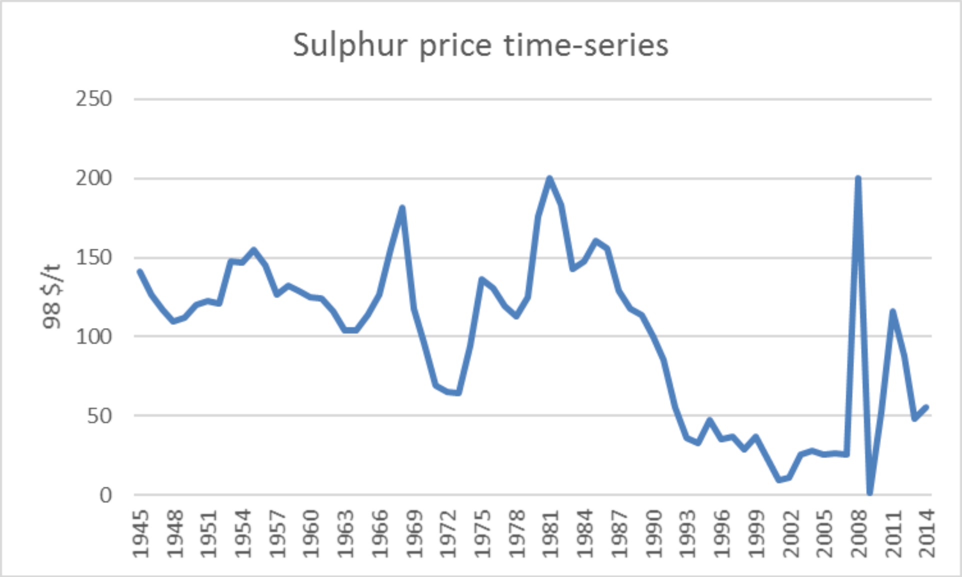


Figure 232: Global developments in price of sulphur, average 1945-2014 (USGSb, 2016)

29.4 Substitution

There are no known substitutes for sulphur as "materials for life", being essential for agriculture.

The use of sulphuric acids can be substituted by various acids, although the total size of this substitution is set at 15% in the criticality assessment. The applications of sulphuric acids in industrial processes are numerous and it is difficult to ascertain to what extent these can be instantly changed by substituting H_2SO_4 (Vandenbroucke, 2016).

In reverse, 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 (European Commission, 2014).

29.5 Discussion of the criticality assessment

29.5.1 Data sources

The CN codes used for the criticality assessment are 2503 0010 and 2503 0090. They are respectively labelled "Sulphur of all kinds (excl. crude or unrefined, and sublimed sulphur, precipitated sulphur and colloidal sulphur)" and "Sulphur, sublimed or precipitated; colloidal Sulphur". The fact that elemental sulphur is present in several other product groups (acids, fuels, liquids, minerals) is discarded since it is unclear when elemental sulphur, if at all, will be separated in the supply chain.

The data sources have a very strong coverage. Data is available on EU level, is available for time series and updated at regular intervals and is publicly available.

29.5.2 Calculation of Economic Importance and Supply Risk indicators

Sulphur clearly needs to be assessed at the processing stage, given the dominant role of sulphur as a by-product.

The economic importance of sulphur originates from the dominance of its applications in the chemical industry. The supply risk is relatively modest given the many suppliers and substation options.

The supply risk was assessed for sulphur using both the global HHI and the EU-28 HHI as prescribed in the revised methodology.

29.5.3 Comparison with previous EU assessments

Sulphur is being assessed for the first time in 2017 with the EI and SR results presented in the following table. Sulphur was not assessed in 2011 or in 2014, therefore, it is not possible to make any comparisons with the previous assessments.

Table 142: Economic importance and supply risk results for sulphur in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Sulphur	Not assessed			Not assessed			4.6	0.6

29.6 Other considerations

29.6.1 Forward look for supply and demand

Demand of sulphur will be dominated by developments in other agriculture and base metal (TSI, 2012).

Uncertainty in the global fossil fuel production may affect the supply. The supply of sulphur can be adjusted i.e. increased by changing volumes from other processes, but it remains to be seen how the market response will be to such a change. See Table 143.

Table 143: Qualitative forecast of supply and demand of of sulphur

Materials	**Criticality of the material**		**Demand forecast**			**Supply forecast**		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Sulphur		x	+	+	+	+	+/0	+/0

29.6.2 Environmental and regulatory issues

Sulphur is present in many economically relevant flows in the soil, water and air. This is illustrated by the fact that elemental sulphur (and by-product sulphuric acid), produced as a result of efforts to meet environmental requirement, contribute to world supply (USGS, 2016a). Atmospheric sulphur oxides, SO_2 in particular, are emission that need to be reduced to increase health standards in parts of the EU (EEA, 2016). The level of sulphur in several environments is thus closely 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 (European commission, 2014).

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 fertilizers, and c) reduction of sulphur dioxide emissions, particularly in developed regions, reduces atmospheric sulphur deposition, a "natural" sulphur source (Sulphur institute, 2016).

29.7 Data sources

29.7.1 Data sources used in the factsheet

BGS (2016). World Mineral Production 2010-2014 [online]. Keyworth, Nottingham British Geological Survey, Available at: http://www.bgs.ac.uk/mineralsuk/statistics/home.html

BMWFW (2016). World Mining Data. Sulfur. Pp. 81-82 of the PDF file. http://www.en.bmwfw.gv.at/Energy/Documents/WMD2016.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 – 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 (2016)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

USGS (2016a). Apodaca, L.E. 2014 Minerals yearbook USGS. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/sulfur/myb1-2014-sulfu.pdf

29.7.2 Data sources used in the criticality assessment

EEA (2016). Sulphur dioxide (SO2) emissions. [online] Available at: http://www.eea.europa.eu/data-and-maps/indicators/eea-32-sulphur-dioxide-so2-emissions-1/assessment-3

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

Lenntech (2016) Sulphur. [online] http://www.lenntech.com/periodic/elements/s.htm

Minerals4EU (2014). 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]. http://qdd.oecd.org/table.aspx?Subject=ExportRestrictions_IndustrialRawMaterials

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.

Sulphur institute (2016). Learn more about Sulphur. [online] Available at: http://www.sulphurinstitute.org/learnmore/faq.cfm#used

TSI (2012). World sulphur outlook, Donald L. Messick. Available at: http://www.firt.org/sites/default/files/DonMessick_Sulphur_Outlook.pdf

USGS (2016b) Historical Statistics for Mineral and Material Commodities in the United States. [online] Available at: https://minerals.usgs.gov/minerals/pubs/historical-statistics

Vandenbroucke, J. (2016). Expert consultation.

29.8 Acknowledgments

This Factsheet was prepared by the Netherlands Organisation for Applied Scientific Research (TNO). The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this Factsheet. Specific experts that have contributed their input and feedback to the factsheet and criticality assessments are listed in the data sources section.

30. TALC

Key facts and figures

Material name and Formula	Talc, $Mg_3Si_4O_{10}(OH)_2$	World/EU production (tonnes)[1]	7,828,191/1,091,503
Parent group (where applicable)	-	EU import reliance[1]	11%
Life cycle stage assessed	Extraction	Substitution index for supply risk [SI (SR)][1]	0.97
Economic importance (EI)(2017)	3.0	Substitution Index for economic importance [SI(EI)][1]	0.95
Supply risk (SR) (2017)	0.4	End of life recycling input rate	5%
Abiotic or biotic	Abiotic	Major end uses in the EU[1]	Paper (28%), Plastics (26%), Paints (17%)
Main product, co-product or by-product	Co-product	Major world producers[1]	China (27%), India (15%), Korean rep (7%)
Criticality results	2011	2014	2017 (current)
	Not critical	Not critical	Not critical

[1] average for 2010-2014, unless otherwise stated;

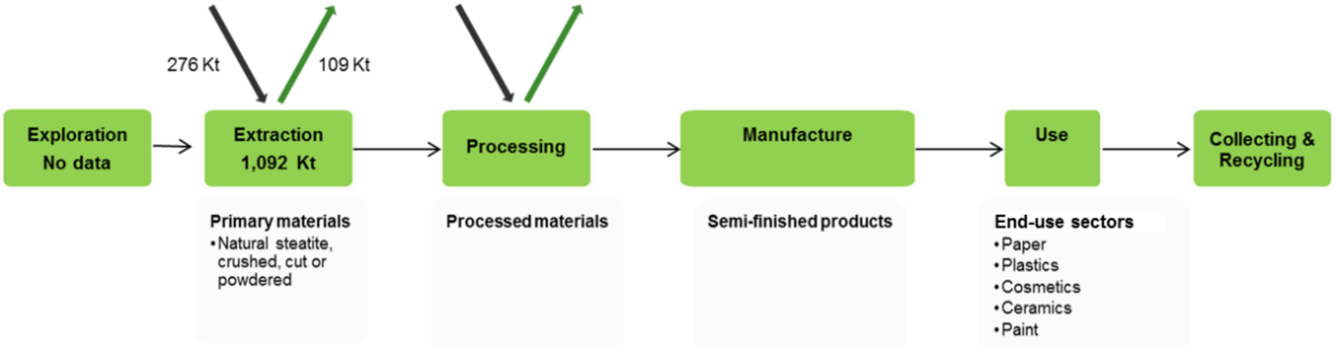


Figure 233: Simplified value chain for talc

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU. A quantitative figure on recycling is not included as the EOL-RIR is below 70%. EU reserves are displayed in the exploration box.

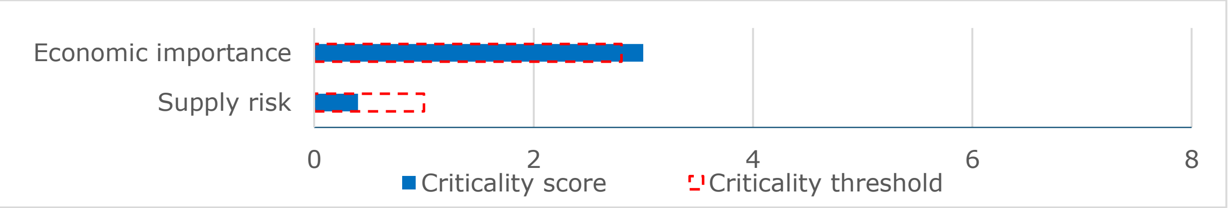


Figure 234: Economic importance and supply risk scores for talc

30.1 Introduction

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, 2011). 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.

Talc is the world's softest mineral. Although all talc ores are soft, platy, water repellent and chemically inert, talc ores are almost never similar (IMA, 2011).

30.2 Supply

30.2.1 Supply from primary materials

30.2.1.1 Geological occurrence/exploration

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, 2011)

30.2.1.2 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 process to select low grade ores and can do comprehensive recovery of beneficial associated minerals (Zenith, 2016).

30.2.1.3 Resources and reserves

Talc deposits are widespread and mined worldwide (Tufar, 2000). It is not likely that more accurate reserve estimations will be available in the coming years.

Table 144: Global reserves of talc in year 2014 (Data from USGS, 2014)

Country	Talc Reserves (tonnes)
United States	140,000,000
Japan	100,000,000
India	75,000,000
Brazil	45,000,000
Korean republic	11,000,000
China	Large
Finland	Large
France	Large
Other countries	Large
World total (rounded)	*Large*

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[28], 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.

For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for talc. The Minerals4EU 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 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 (Minerals4EU, 2015).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.

30.2.1.4 World production

The global production of talc between 2010 and 2014 was annually 7.8 Mt on average. In 2011, China was the largest talc producer with 27 % of the total output (see Figure 235). 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 1.09 million tonnes which represent over 14 % of the global talc production. Talc is within the EU mainly produced in Finland (29 % of EU sourcing), France (27% of EU sourcing), Austria and Italy.

---

[28] www.crirsco.com

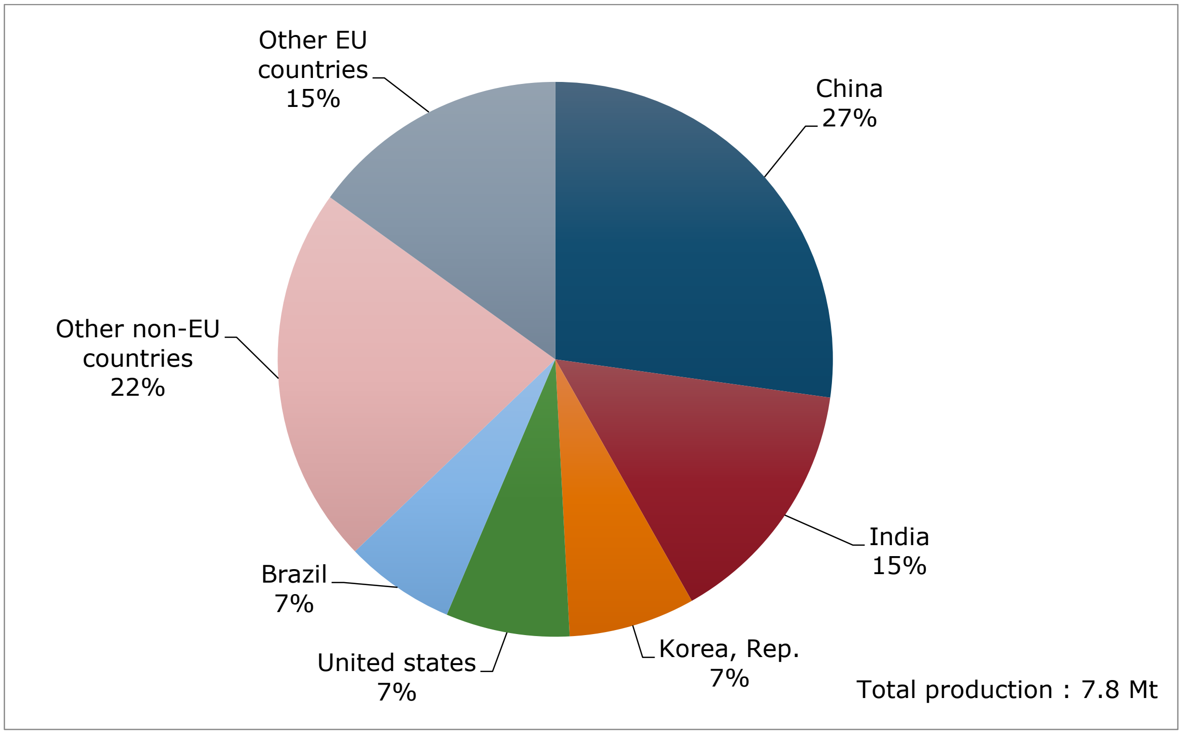


Figure 235: Global mine production of talc, average 2010–2014 (Data from BGS World Mineral Statistics database, 2016)

30.2.2 Supply from secondary materials

End of life recycling input rate for talc is estimated to be 5%.

The end-of-life recycling input rate of talc is modest still. Like industrial minerals such as kaolin the recycling of talc is significant, around 60% (IMA, 2013). However, this talc is not replacing primary talc, and is therefore not taken as value in the criticality assessment.

30.2.3 EU trade

Figure 236 shows the data for talc imports to the EU between 2010 and 2014. The supply of talc is quite stable, amounting to 276 Kt per year on average in those years. The total share of imports in the EU consumption is also more or less constant over the years. The size of EU trade compared to EU production is small, ranging around 15%.

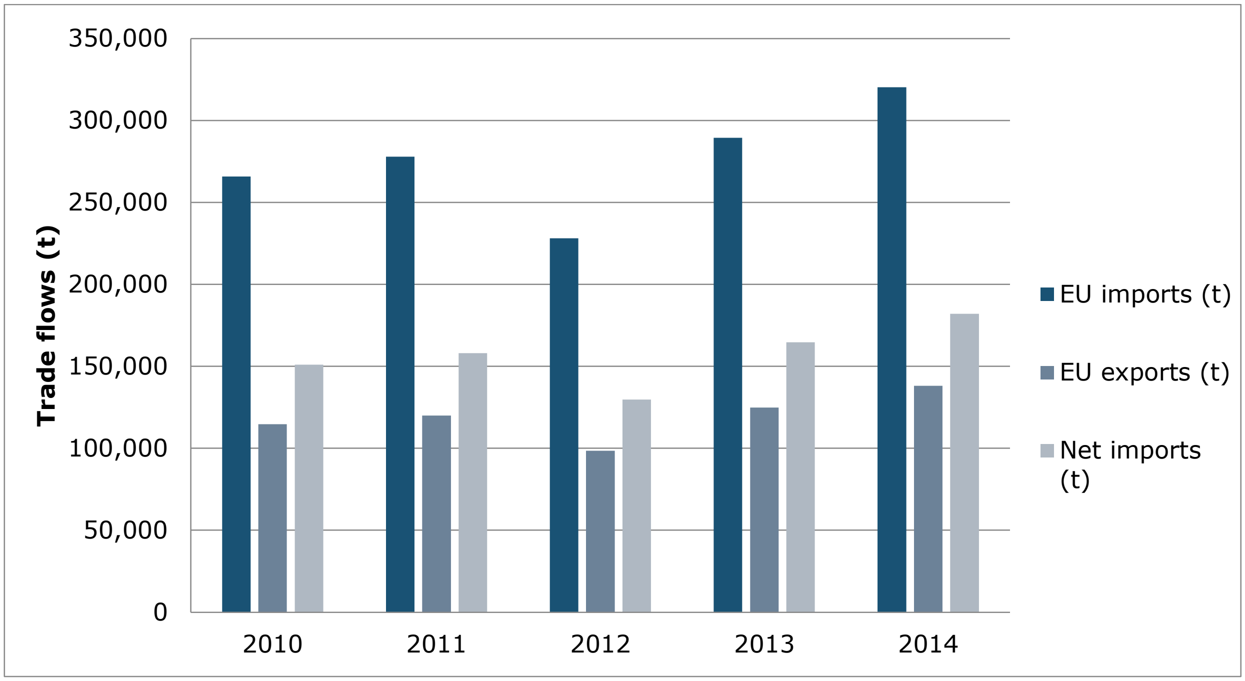


Figure 236: EU trade flows for talc (Data from Eurostat 2016)

According to the Eurostat data, the biggest amount of talc was exported by Pakistan (46%), China (21%) and Australia (17%) to the European Union (see Figure 237).

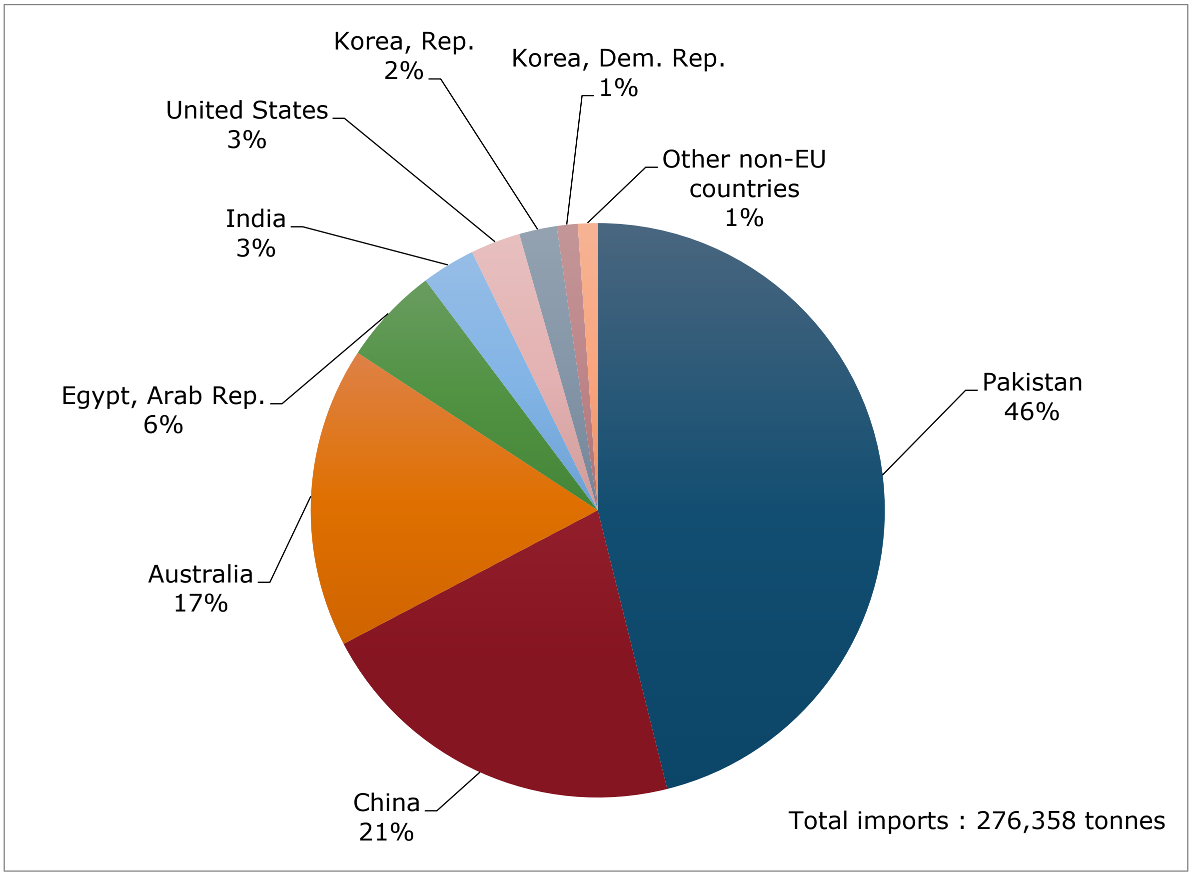


Figure 237: EU imports of talc, average 2010-2014 (Data from Eurostat 2016)

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.

30.2.4 EU supply chain

As with many industrial minerals, the base industry (mineral products, construction materials, chemical productions, paper manufacturing) in the EU takes the raw materials inputs directly from extraction and wholesale businesses. Figure 238 shows the EU sourcing (domestic production + imports) for talc.

The EU relies for the supply of talc for 11% on its imports. 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 500kt and 700kt between 2010 and 2014, an export tax of 10% and a licensing requirement (OECD, 2016).

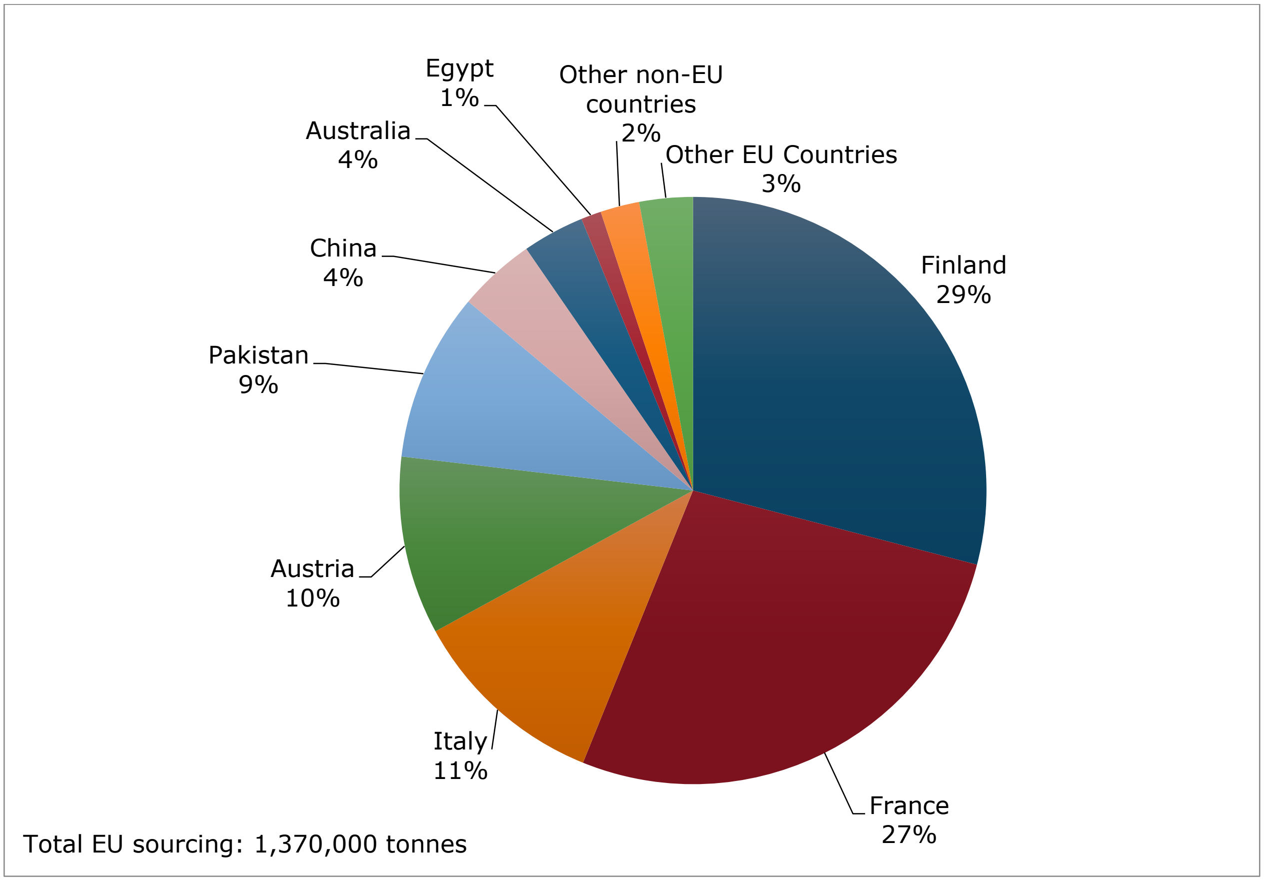


Figure 238: EU sourcing (domestic production + imports) of talc, average 2010-2014. (Eurostat, 2016; BGS, 2016)

30.3 Demand

30.3.1 EU consumption

The annual EU consumption was around 1.37 Mt between 2010 and 2014.

30.3.2 Applications / End uses

Applications of talc are amongst others the production of paper, ceramics, plastics, paints, roofing, sealants, cosmetics, pharmaceuticals, and agricultural chemicals (IMA, 2011). Talc is a smooth, opaque, porous mineral with high sheet retention, low abrasion, and low yellow index score. These properties allow its extensive use as a filler (Tufar, 2000).

The most important uses of talc (European Commission, 2014; IMA, 2011) are:

- Paper: As bulking agent, for deposit control, and for coating.
- Plastics: Thermoplastics strengthened by the addition of talc are extensively used as construction materials e.g. for the automobile production for dashboards and bumpers and to produce thermoplastic resins. Moreover talc is used as an anti-blocking agent for plastic films, e.g. to make the opening of plastic bags easier.
- Paint: As a bulking agent in pigment industry, where up to 30 wt% of paint can consist of talc. The mineral leads to a better pseudo-plasticity and corrosion resistance, to an ease of re-dispersion of sediments, to an improvement of the adhesion to substrates, to a reduced diffusion through coating films, and to good dielectric properties.
- Ceramics: Talc is utilised in traditional and technical ceramics to enhance pressing and permeability properties. Steatite ceramics are used for electrical isolating applications. Furthermore talc is used as a filler and glazing agent. Talc is mainly used in the Cordierite ceramic for the Mg intake.
- Cosmetics: Talc is used for face powder and body talc, as an additive for soaps, and as filler in solid antiperspirant sticks. In cosmetics, talc grants stability, texture, skin adhesion, and water resistance.
- Agriculture: Talc is used as a dry carrier for pesticides, fertilizers, herbicides, fungicides, and insecticides.
- Roofing: Talc stabilizes the asphalt of tar paper and shingles. By improving its fire resistance and weatherability.
- Rubber: As filler, talc is used in carpet backings, valves, and cable insulation. As coating, talc serves to lubricate dies and to avoid sticking together of surfaces.
- Pharmaceuticals: The quantity of high-purity talc consumed by the pharmaceutical industry is rather small. Moreover, it needs complicated processes to remove all contamination (for example accompanying minerals, carbon, iron oxide, and base metal traces)
- Food: For processing foods, mostly polishing of foodstuffs (e.g. rice) or coating of chewing gum to prevent sheets sticking together.
- Animal feed: As an anti-caking agent and to improve ability to process.

Some minor applications are the sealant industry, sculpturing, and polishing (e.g. shoe, floor, and car polishing).

For Europe, the largest applications of talc are paper, plastics and paints consuming respectively 28%, 26 % and 17% of the total talc consumption. (IMA, 2013) These applications are easily allocated to the NACE sectors that entail the manufacturing of these products. Further end-uses are represented by agricultural applications, and the manufacturing of ceramics, rubber, food, cosmetics and pharmaceuticals (Figure 239).

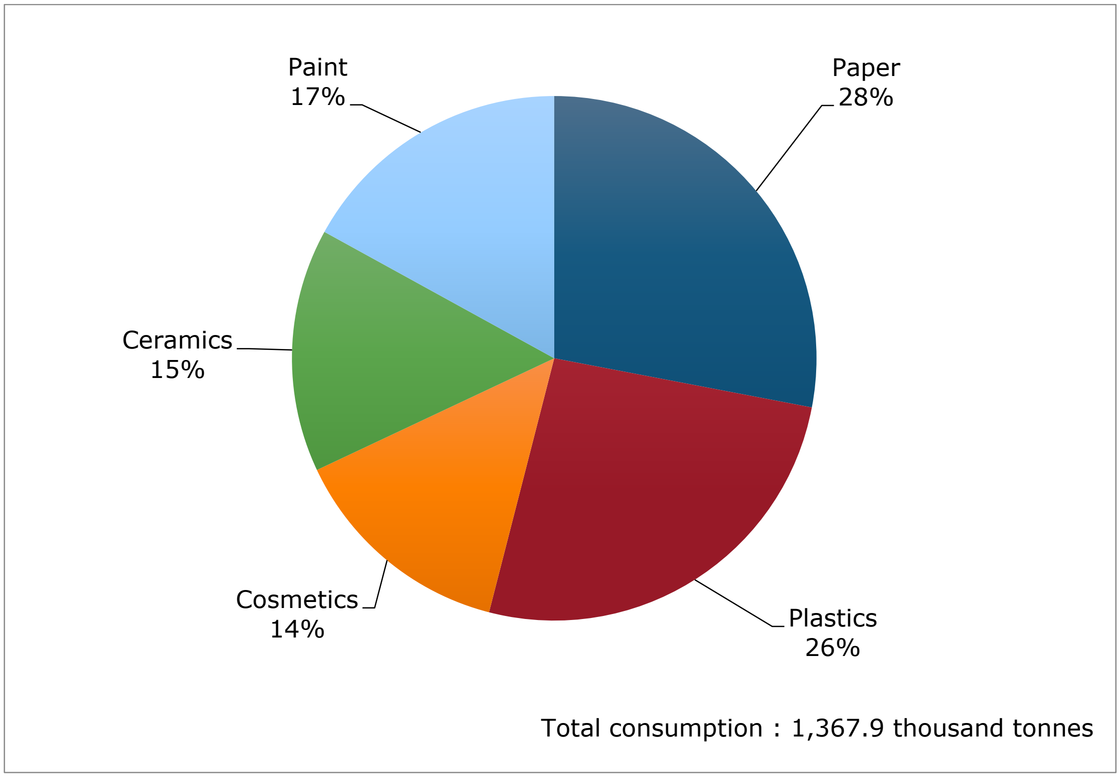


Figure 239: EU end uses of talc, average 2010-2014 (IMA, 2013)

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 145). The value added data correspond to 2013 figures.

Table 145: Talc applications, 2-digit NACE sectors associated 4-digit NACE sectors and value added per sector (Data from the Eurostat database, Eurostat, 2016)

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (millions €)
Paper	C17 - Manufacture of paper and paper products	C17.23 -Manufacture of paper stationery	41,281.5
Paint	C20 - Manufacture of chemicals and chemical products	C20.30 - Manufacture of paints, varnishes and similar coatings, printing ink and mastics	110,000.0
Cosmetics	C21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations	C21.20 -Manufacture of pharmaceutical preparations	79,545.0
Plastics	C22 - Manufacture of rubber and plastic products	C22.21 -Manufacture of plastic plates, sheets, tubes and profiles	82,000.0
Ceramics	C23 - Manufacture of other non-metallic mineral products	C23.42 - Manufacture of ceramic sanitary fixtures	59,166.0

30.3.3 Prices

The price of talc has been constant through the years. The price increased after 1974 given the changes in oil-price and the corresponding use of talc for plastic products (see Figure 240).

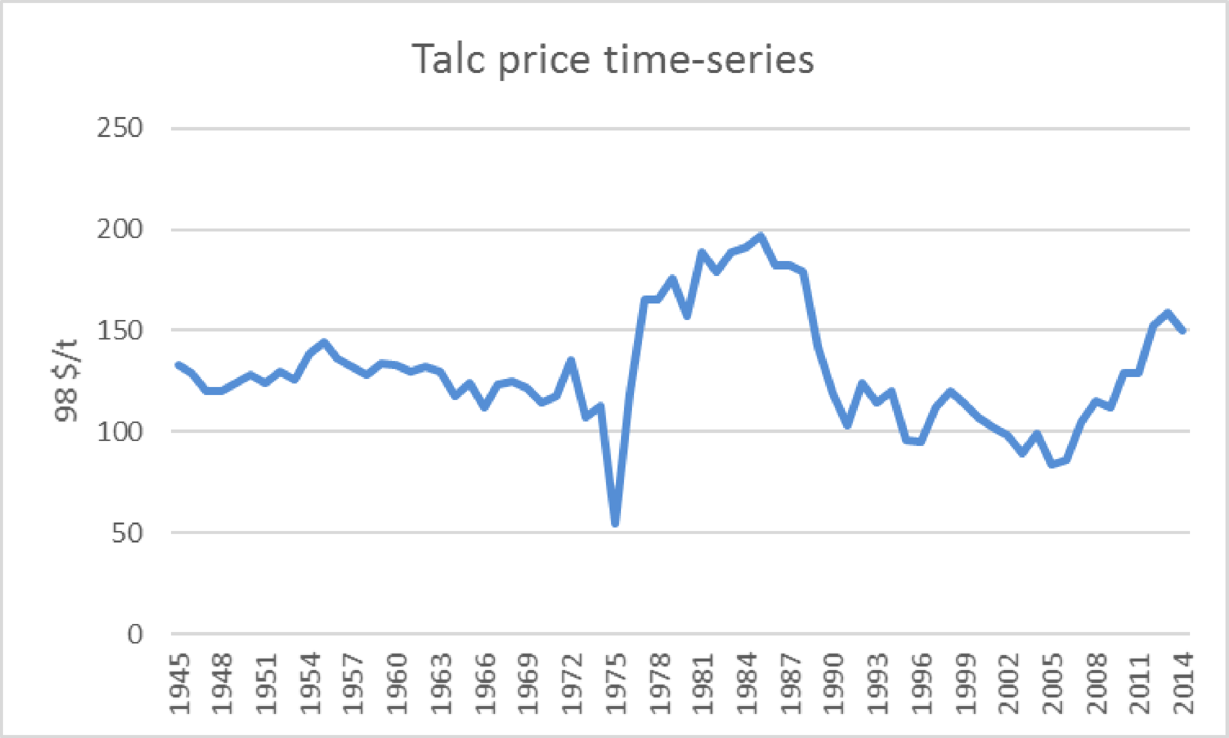


Figure 240: Global developments in price of talc, average 1945-2014 (USGS, 2014).

30.4 Substitution

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.

Calcium carbonate and kaolin are substitutes for talc in paper as filler. Talc being the most expensive between the three minerals, all papermakers try to replace talc if it is technically possible. If substitution is feasible based on the technical requirements, the performance of kaolin and carbonate for the user is quite similar. 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, 2016).

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 (Tufar, 2000).

30.5 Discussion of the criticality assessment

30.5.1 Data 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 are mainly coming from (BGS, 2016; Eurostat, 2016). They are available on EU level, is available for time series relevant to the assessment 2010-2014) and updated at regular intervals and are freely available.

30.5.2 Calculation of Economic Importance and Supply Risk indicators

Given the usual proximity of refining and extraction, the criticality assessment was conducted at the extraction phase of the supply chain.

The supply risk was assessed on talc using both the global HHI and the EU-28 HHI as prescribed in the revised methodology.

30.5.3 Comparison with previous EU assessments

The resulting values of the criticality assessment of talc show a similar pattern as can be seen for other industrial minerals.

The economic importance is reduced given the modest size (compared to the mega sector size of over 140 billion in the previous analysis) of value added in the mineral products manufacturing sector (e.g. ceramics), plastic products and paper products.

The increase in supply risk is due to the weight that the new methodology places in very low end-of-life recycling input rates. Therefore, this assessment has a same stance as recycling opportunities as the previous assessments. The input values relate to substitution are also similar to the previous assessments, which indicates that the change in supply risk is due to the new methodology. See Table 146.

Table 146: Economic importance and supply risk results for talc in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

Assessment year	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Talc	4.02	0.3		5.10	0.26		3.0	0.4

30.6 Other considerations

30.6.1 Forward look for supply and demand

Growth in these industry sectors suggests that sales of talc may increase in the next five years (USGS, 2014). The changes in supply and demand on a longer term are expected to be rather stable and balanced compared to each other, see Table 147.

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).

Table 147: Qualitative forecast of supply and demand of talc

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
Talc		x	+	0/+	0/+	+	0/+	0/+

30.7 Data sources

30.7.1 Data sources used in the factsheet

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

Eurostat (2016)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

Minerals4EU (2014). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

Tufar, W. (2000). Talc. Ullmann's Encyclopedia of Industrial Chemistry. Available at: http://onlinelibrary.wiley.com/doi/10.1002/14356007.a26_047/abstract

USGS (2014). Virta, R. L., Flanagan, D. M. USGS Minerals Yearbook 2014. Talc and pyrophyllite. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/talc/myb1-2014-talc.pdf

USGS (2016). Historical statistics. Available at: https://minerals.usgs.gov/minerals/pubs/historical-statistics/

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

30.7.2 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). Factsheet talc. Available at: http://www.ima-europe.eu/about-industrial-minerals/industrial-minerals-ima-europe/talc

IMA (2013). Factsheet recycling. Available at; http://www.ima-europe.eu/sites/ima-europe.eu/files/publications/IMA%20Recycling%20Sheets%20FULL%20published%20on%2024.10.2013_0.pdf

IMA (2016). Expert consultation.

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

30.8 Acknowledgments

This Factsheet was prepared by the Netherlands Organisation for Applied Scientific Research (TNO). The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this Factsheet.

31. TELLURIUM

Key facts and figures

Material name and Element symbol	Tellurium, Te	World/EU production (tonnes)[1]	Refining: 142 / 12
Parent group (where applicable)	N/A	EU import reliance[1]	112%
Life cycle stage/material assessed	Refined material	Substitution index for supply risk [SI (SR)]	0.93
Economic importance (EI)(2017)	3.4	Substitution Index for economic importance [SI(EI)]	0.85
Supply risk (SR) (2017)	0.7	End of life recycling input rate (EOL-RIR)	1%
Abiotic or biotic	Abiotic	Major end uses in the EU	Solar power (40%); Thermo-electric devices (30%); Metallurgy (15%)
Main product, co-product or by-product	Almost always a by-product	Major world producers[1]	Refining: US (35%), Japan (28%), Russia (21%)
Criticality results	2011	2014	2017 (current)
	Not critical	Not critical	Not critical

[1] average for 2010-2014

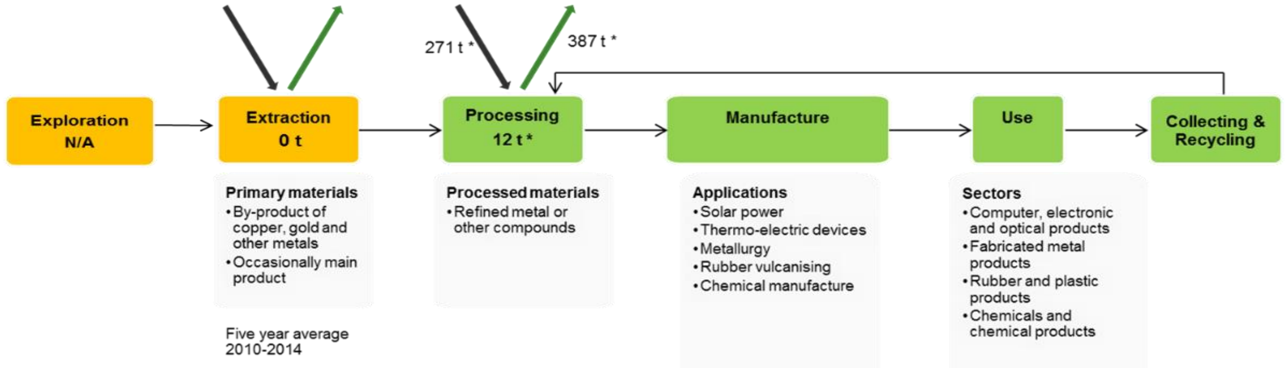


Figure 241: Simplified value chain for tellurium

The green box of the processing stage in the above figure suggests that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU. A quantitative figure on recycling is included as the EOL-RIR is above 70%. EU reserves are displayed in the exploration box.

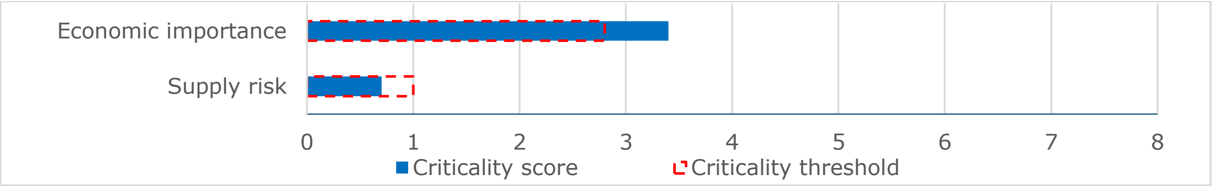


Figure 242: Economic importance and supply risk scores for tellurium

31.1 Introduction

Tellurium (chemical symbol Te) is a metalloid or semi-metal that is a silvery-grey in appearance, has a hardness of 2.25 on Mohs scale and a melting point of 449.51°C (722.66 K). It is one of the rarest elements in the Earth's crust with an abundance of only 1 part per billion, which is less than that for platinum. Tellurium rarely occurs in native form, but is more commonly found in compounds that also contain base or precious metals. It is mainly produced as a by-product, predominantly from the anode muds resulting from the electrolytic refining of copper. Tellurium is mainly used in cadmium-telluride solar cells, in thermo-electric devices (which are a semi-conducting electronic component), as an additive in steel or other metals to improve machinability, as an accelerator for the vulcanising of rubber and other minor applications (e.g. a catalyst in the production of synthetic fibres, a pigment in glass and ceramics). Tellurium has no known biological role and in certain forms is both toxic and teratogenic (disrupts the development of an embryo).

Within the EU, tellurium is mined as a by-product of gold in Sweden and may occur elsewhere as a by-product of copper. A number of copper refineries in the EU are reported to have tellurium present within anode muds and in some cases this is recovered.

31.2 Supply

31.2.1 Supply from primary materials

31.2.1.1 Geological occurrence

Tellurium is one of the rarest elements in the Earth's crust with an abundance of only 1 part per billion (ppb), which means it is less abundant than platinum or gold. It is also widely distributed meaning that concentrations which are sufficient in size to allow economic extraction in their own right are rare. Although tellurium does rarely occur as a native metal, it is more commonly found in compounds with precious or base metals, primarily as tellurides but other compounds also exist. Tellurium 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.

31.2.1.2 Exploration

During the Minerals4EU project it was identified that in 2013 there were no exploration activities ongoing which specifically included tellurium as one of the target metals. However, exploration may have taken place in countries where no information was provided during the survey (Minerals4EU, 2015).

31.2.1.3 Mining, processing and extractive metallurgy

Although there are reports of two mines in China that may have been extracting tellurium as the main product at some point in the past, industry sources believe this is no longer the case (personal communication, industry sources). 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-28, 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.

To reach the refining stage, copper, and its associated by-products including tellurium, will have undergone a number of processing stages. These will 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 will have been lost in tailings or residues (Kavlak & Graedel, 2013).

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 (Willis et al, 2012).

Kavlak & Graedel (2013) reported that 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 will be 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 will be optimised to ensure the highest possible recovery rate of tellurium as this has become the focus.

31.2.1.4 Resources and reserves

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[29], 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.

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

---

[29] www.crirsco.com

Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for tellurium at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU, 2015).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 United States Geological Survey (USGS) does not report figures for global tellurium resources (USGS, 2016a). More than 90% of tellurium has been produced from anode slimes collected from electrolytic copper refining, and the remainder was derived from skimmings at lead refineries and from flue dusts and gases generated during the smelting of bismuth, copper, and lead-zinc ores. Other potential sources of tellurium include bismuth telluride and gold telluride ores (USGS, 2016a).

During the Minerals4EU project only Sweden reported resources of tellurium (measured resources of 0.11 Mt at 149 g/t) and these statistics were reported in accordance with the Fennoscandian Review Board standard, not the United Nations Framework Classification (UNFC) system of reporting. 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, 2015).

Global tellurium reserves reported by the USGS are shown in Table 148 (USGS, 2016a). Statistics for tellurium are notoriously difficult to obtain. For example, Table 148 does not mention China at all and yet it is known that country has two mines which are extracting tellurium as a main product and reserves must therefore exist. Sweden also reported reserves of tellurium, again in accordance with the Fennoscandian Review Board standard (0.88 Mt of proven reserves at 172 g/t). As with resources, it is possible that tellurium reserves exist in countries that did not respond to the survey (Minerals4EU, 2015).

Table 148: Global reserves of tellurium in 2015, data does not sum due to rounding (Data from USGS, 2016a)

Country	**Tellurium Reserves (tonnes)**	**Percentage of total (%)**
Peru	3,600	14
U.S.A.	3,500	14
Canada	800	3
Sweden	700	3
Russia	n/a	n/a
Other countries	16,000	64
World Total (rounded)	*25,000*	*100*

According to USGS (USGS, 2016a), in addition to the countries listed, Australia, Belgium, Chile, China, Colombia, Germany, India, Kazakhstan, Mexico, the Philippines, and Poland produce refined tellurium, but output was not reported, and available information was inadequate for formulation of reliable production and detailed reserve estimates.

31.2.1.5 World refinery production

Statistics for tellurium production are easily confused because it is 'produced' in different forms and some crude compounds are subsequently further refined. For this criticality assessment, data from the British Geological Survey were used for tellurium metal production (BGS, 2016) and the six producing countries are shown in Figure 243. The global average production over the 2010–2014 period used in the 2017 criticality assessment amounts to approximately 140 tonnes per year, of which an average of 12 tonnes per year originated in Sweden.

The most recently available Yearbook from the USGS lists production by year for just three countries (Canada, Japan and Russia), with the figure for the U.S.A. withheld to avoid disclosing company proprietary data. The figures shown sum to between 86 and 74 tonnes per year in 2010 to 2014. The footnotes to the table indicate firstly that the data relate only to refinery output and tellurium produced in other forms are not included to avoid double-counting. Secondly, the USGS list 11 countries as "known to produce refined tellurium" but with inadequate information available to enable an estimate to be formulated, these are: Australia, Belgium, Chile, China, Columbia, Germany, Kazakhstan, Mexico, the Philippines, Poland and Sweden (USGS, 2016b).

Willis et al. (2012) included a table headed "estimated world tellurium refinery production by company" for the year 2011, based on industry sources. However, these figures include both "refined tellurium metal" and "crude tellurium dioxide or copper telluride" and it is not appropriate to sum these two things together because one could be used to produce the other and therefore double-counting could occur. The companies shown in the table as producing refined tellurium metal are operating in Japan (x 2), Kazakhstan, the Philippines, Russia (x 2) and Uzbekistan, with a combined output of 110 tonnes. The less refined crude tellurium dioxide and copper telluride was produced in Chile, India, Indonesia, Japan, Spain and Sweden/Finland, with a combined output of 73 tonnes. The last entry in that list refers to Boliden, which built its tellurium refining plant in Sweden in 2012 (i.e. after Willis et al [2012] compiled their table). A number of other companies are shown without indication of the form of the output, operating in Canada, China (x 5), Germany, Japan, Mexico, Peru, Poland, South Korea, the U.S.A and unspecified 'others', with a combined output of 230 tonnes.

Tellurium is known to occur in the anode slimes of a number of electrolytic copper refineries not included in the above lists (Moats et al, 2007), but it is unclear whether this material is actually recovered.

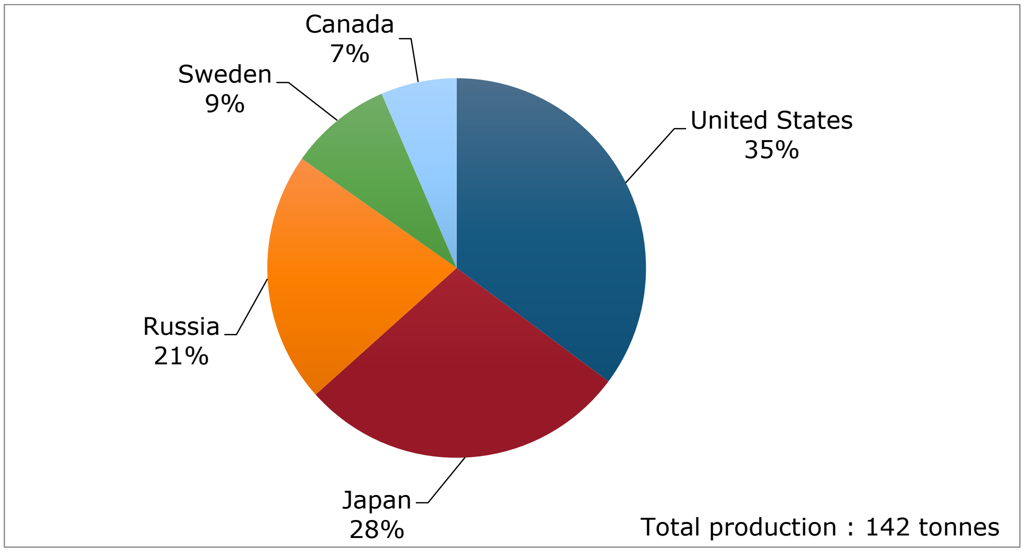


Figure 243: Global refined production of tellurium, average 2010–2014 (Data from BGS World Mineral Statistics database)

Because of the difficulties in compiling accurate and complete datasets, the figures quoted are likely to be an under-estimation of the actual global production total.

31.2.2 Supply from secondary materials

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 as yet these are a relatively new technology and few have so far reached the end-of-life stage (USGS, 2016a).

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.

31.2.3 EU 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.

The quantities of tellurium recorded against this code as imported to or exported from the EU-28 during 2010–2014 are shown in Figure 244. For the years 2010, 2011 and 2012 exports of tellurium were larger than imports but in 2013 and 2014 the EU-28 was a net importer. The leading EU-28 exporting countries, on an average-basis across the period, are Belgium, Sweden, the United Kingdom, Spain and Germany, with small quantities exported in some years from a further 4 countries. However, Belgium's exports have dropped significantly between 2012 and 2013, while Sweden's have risen notably in 2014.

The largest importing countries are Germany, the Netherlands, Belgium and the United Kingdom, with smaller quantities imported in some years from 4 further EU-28 countries. The main originating countries for these imports are shown in Figure 245. Ukraine is shown as the largest originating country for EU-28 imports but this is distorted by a large import figure in a single year, 2014. The EU-28 imports originated in 17 named countries but the largest import in three of the five years was labelled as "Countries and territories not specified for commercial or military reasons in the framework of trade with third countries".

Figure 245 is based on average figures across the 2010–2014 period. "Other non-EU countries" regroups Malaysia, Uzbekistan, India, Kazakhstan, Switzerland, Chile and Brazil.

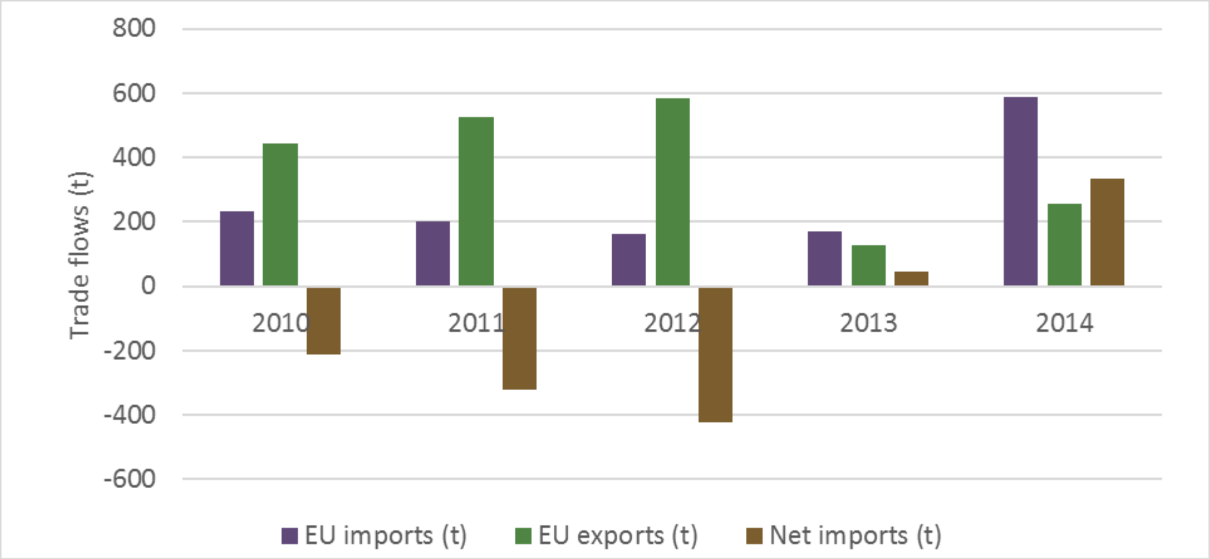


Figure 244: EU trade flows for tellurium. (Data from Eurostat, 2016)

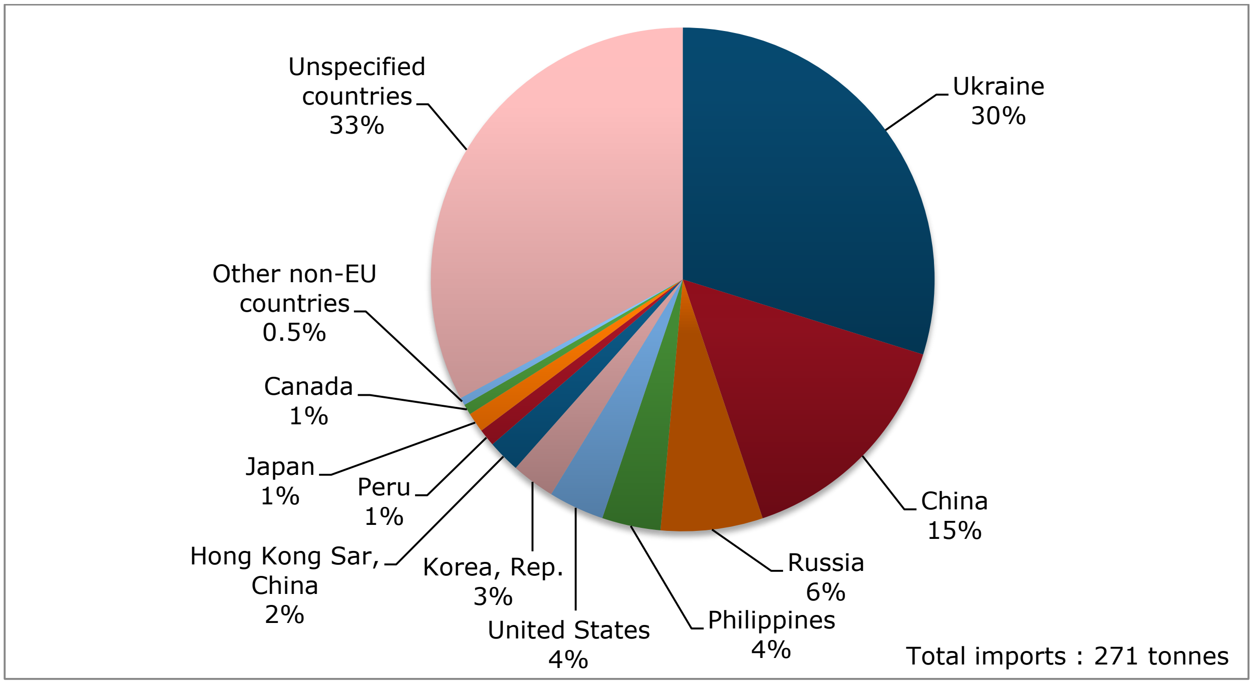


Figure 245: EU imports of tellurium, average 2010-2014. (Data from Eurostat, 2016). *Unspecified countries: "Countries and territories not specified for commercial or military reasons in the framework of trade with third countries"*

No trade restrictions were reported over the 2010-2014 period (OECD, 2016). Some EU free trade agreements are in place with suppliers such as South Korea, Peru, Switzerland and Chile (European Commission, 2016).

31.2.4 EU supply chain

As mentioned earlier, tellurium is mined in one location with the EU-28, at the Krankberg Mine in the Boliden Area of Sweden where it is a by-product of gold mining. The same company, Boliden, also operate a smelter/refinery at Rönnskär in Sweden, which recovers tellurium in addition to other metals.

Reported production of refined tellurium within the EU-28 (i.e. from Sweden) amounted to an average of 12 tonnes per year (averaged over the 2010–2014 period). Imports to the EU-28 from the rest of the world were 271 tonnes per year, while total exports (i.e. from both producing and non-producing countries) were 387 tonnes per year (again both averaged over the 2010–2014 period). Based on these figures the calculated import reliance is 112%. The Figure 100 shows the EU sourcing (domestic production + imports).

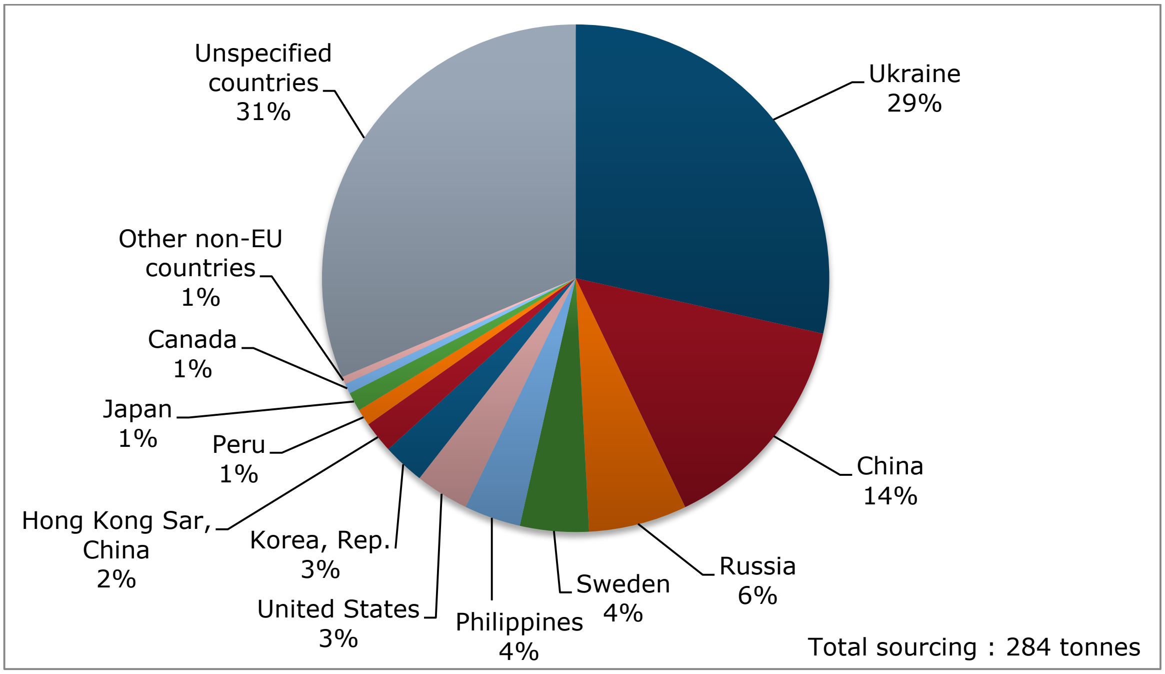


Figure 246: EU sourcing (domestic production + imports) of tellurium, average 2010-2014. (Data from Eurostat, 2016). *Unspecified countries: "Countries and territories not specified for commercial or military reasons in the framework of trade with third countries"*

Aurubis operates copper refineries in Germany and Bulgaria and tellurium is known to occur in the anode slimes at these refineries. Although the company website does mention that tellurium is a recovered by-product no details are provided as to what form it takes nor 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 organisations for treatment and recovery of those metals. One organisation that processes these kinds of anode slimes is Umicore, located in Hoboken, Belgium, which has an annual capacity of 150 tonnes of refined tellurium but details of actual production are confidential.

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-28. Similarly not all copper that is mined in the EU-28 is refined within Europe.

Copper mines are known to exist in Bulgaria, Cyprus, Finland, Poland, Portugal, Romania, Slovakia, Spain and Sweden but it is not known whether these deposits contain any tellurium. Similarly gold is mined in Bulgaria, Finland, Greece, Poland, Romania, Slovakia, Spain, Sweden and the United Kingdom but, other than Sweden, it is not known whether any of these other mines contain by-product tellurium.

The EU-28 countries both import and export tellurium but the trade code system is not detailed enough to determine from the available statistics what form this traded material takes.

31.3 Demand

31.3.1 EU consumption

During the criticality assessment, EU-28 apparent consumption (calculated using the formula: 'production' + 'imports' – 'exports') of tellurium was calculated as -103 tonnes per year. This negative number occurs because exports from the EU-28 are higher than both production within the EU-28 and imports to the EU-28.

Clearly there are some problems with the statistical data because apparent consumption calculates to a negative number, which is counter-intuitive. It is possible that additional tellurium is imported to the EU-28 but 'hidden' within another material, for example a copper intermediate product may be imported for further refining in the EU-28 and tellurium may be contained within the resulting anode slimes. Alternatively the import and export statistics may not be 100% tellurium content.

31.3.2 Applications / end uses

The main categories of end uses for tellurium are shown in Figure 247.

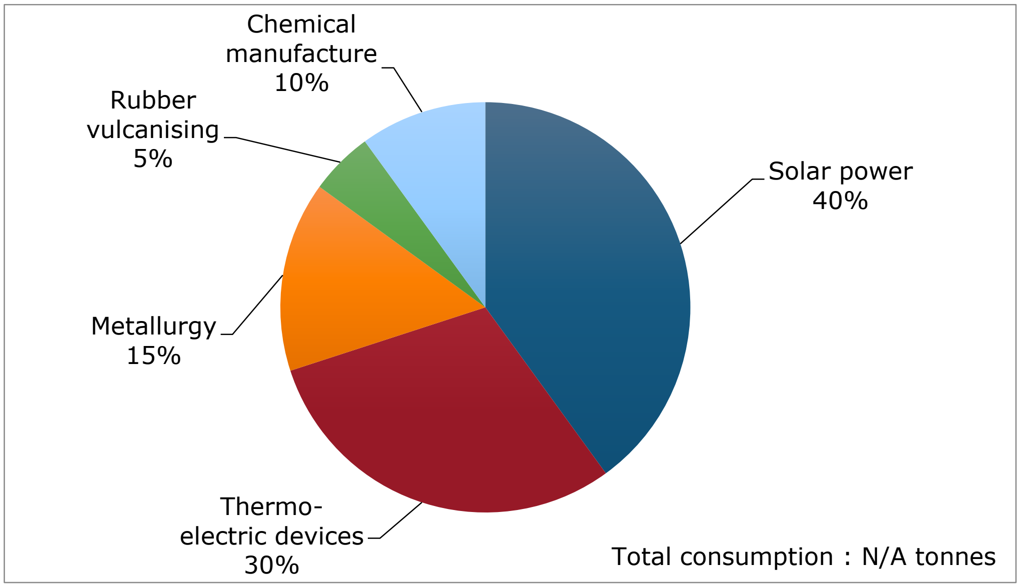


Figure 247: Global end uses of tellurium. (Data from Selenium Tellurium Development Association and United States Geological Survey).

Relevant industry sectors are described using the NACE sector codes in Table 149.

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-tellurium used in infrared detectors.

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 vulcanizing 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.

Table 149: Tellurium applications, 2 digit and examples of associated 4-digit NACE sectors, and value added per sector (Eurostat, 2016c)

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	75,260.3	C2611 – Manufacture of electronic components
Thermo-electric devices	C26 – Manufacture of computer, electronic and optical products	75,260.3	C2611 – Manufacture of electronic components
Metallurgy	C25 – Manufacture of fabricated metal products, except machinery and equipment	159,513.4	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	82,000.0	C2219 – Manufacture of other rubber products
Chemical Manufacture	C20 – Manufacture of chemicals and chemical products	110,000.0	C2059 – Manufacture of other rubber products; C2012 – Manufacture of dues and pigments; C2059 – Manufacture of other chemical products n.e.c.

31.3.3 Prices

Tellurium prices are published by relevant trade journals, but a subscription is normally required to access the information. USGS (2016a) reported prices for refined tellurium (99.95% minimum content) averaged US$89 per kilogram in 2015, which is down from a yearly average of US$119 per kilogram in 2014 and much lower than the US$349 per kilogram reported for 2011 (see Figure 248).

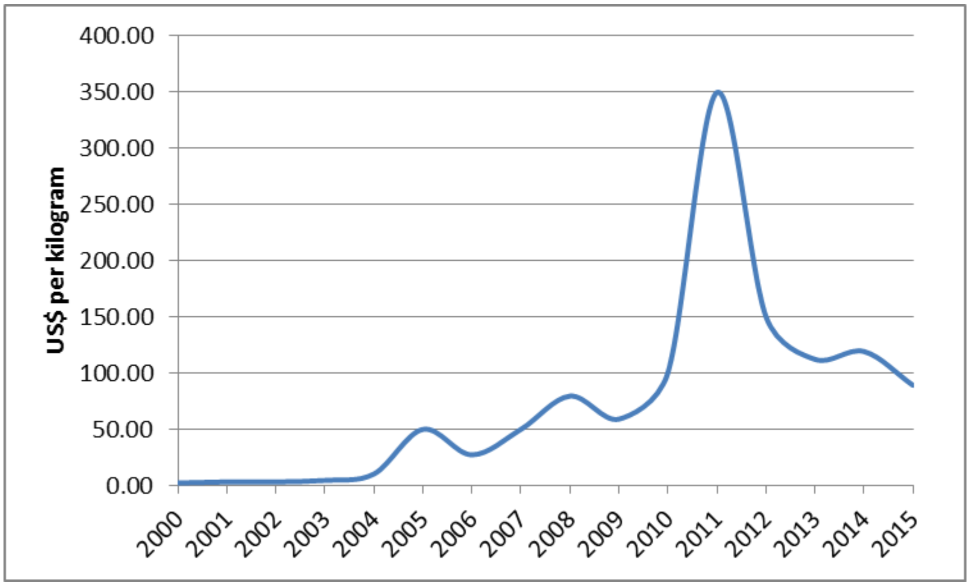


Figure 248 : Tellurium price trend based on yearly averages, US$ per kilogram, 99.95% minimum (data sourced from United States Geological Survey)

31.4 Substitution

Substitution has been included in this review of the criticality assessment in a completely new way. Each application has been considered in turn with both product to product and material to material substitute included in the assessment. Consideration has been given to the cost and performance of each potential substitute in each application, relative to that of the material in question, together with the level of production, whether or not the substitute was previously considered to be 'critical' and whether the potential substitute is produced as a by-, co- or main product.

Specific data relating to all of these criteria are often difficult to find and a number of assumptions have had to be made to complete the calculations. Consequently a significant degree of uncertainty is associated with the results. The level of precision shown for the Substitution Indices does not fully reflect this uncertainty.

Not all of the materials listed can be substitutes in each of the detailed applications within a category or sector.

Within the solar power sector, the most significant material in use currently is silicon. There are various sub-types of silicon-based solar cells and currently the efficiencies achieved with these cells are slightly higher than with cadmium-telluride solar cells, although cadmium-telluride has improved significantly over time and continues to do so. Although the silicon materials are similar in cost to cadmium-telluride, the cost of producing the completed solar cells is larger with silicon because greater quantities of materials are required. Another alternative type of solar cells is the copper-indium-gallium-selenide (CIGS) type. The cost of the materials to produce a CIGS solar cell is currently higher but performance is similar to cadmium-telluride. Silicon, indium and gallium were all assessed as being 'critical' in the previous EU criticality assessment (EC, 2014). Indium, gallium and selenium are similar to tellurium in that they are by-product metals.

For thermo-electric devices, only silicon-germanium was considered a potential substitute for materials containing tellurium (bismuth-telluride and lead-telluride) but this would incur greater cost and result in reduced performance. There are a number of different materials that are currently undergoing research for their thermo-electric properties but none of these are currently in use commercially and therefore none are included for the purposes of the 2017 criticality assessment. Both silicon and germanium were assessed by the previous EU criticality assessment as being 'critical' (EC, 2014).

In metallurgy, bismuth, calcium, lead, phosphorus, selenium and sulphur can all be used instead of tellurium to improve machinability of steels (USGS, 2016a) and it was concluded that this would be at similar or lower cost and similar performance. No substitutes were considered for the rubber vulcanising or chemical applications because less than 10% of tellurium production is used in these categories.

31.5 Discussion of the criticality assessment

31.5.1 Data sources

Production data were taken from the British Geological Survey's World Mineral Statistics dataset (as published in BGS, 2016). Trade data was extracted from the Eurostat COMEXT online database (Eurostat, 2016) and used the Combined Nomenclature (CN) code 2804 5090 'Tellurium'. These data were averaged over the five-year period 2010 to 2014 inclusive. Other data sources are listed in section 31.7.

31.5.2 Calculation of economic importance and supply risk indicators

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 149). For information relating to the application share of each category, see section on applications and end-uses. The figures for value added were the most recently available at the time of the assessment, i.e. 2013, and are expressed in thousands of Euros.

The calculation of the Supply Risk (SR) was carried out for tellurium at the 'refined material' stage of the life cycle and used both the global HHI and EU-28 HHI calculation as prescribed in the methodology.

31.5.3 Comparison with previous EU criticality 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 are not directly comparable.

The results of this review and earlier assessments are shown in Table 150.

Table 150: Economic importance and supply risk results for tellurium in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

Assessment	2011		2014		2017	
Indicator	EI	SR	EI	SR	EI	SR
Tellurium	7.90	0.56	5.98	0.19	3.4	0.7

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 in Table 150. 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.

31.6 Other considerations

The supply and demand of tellurium is expected to grow in the future (see Table 151).

Table 151: Qualitative forecast of supply and demand of tellurium

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
Tellurium		x	+	+	+	+	+	?

A total of 9 substances containing tellurium have been registered with the European Chemicals Agency under the REACH Regulations as shown in Table 152.

Table 152: Substances containing selenium registered under the REACH regulations (Source: ECHA, 2016)

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

31.7 Data sources

31.7.1 Data sources used in the factsheet

USGS. (2016a). Tellurium Mineral Commodity Summary. January 2016. United States Geological Survey. https://minerals.usgs.gov/minerals/pubs/commodity/selenium/mcs-2016-tellu.pdf

USGS. (2016b). Selenium and Tellurium in 2014 Minerals Yearbook. November 2016. United States Geological Survey. https://minerals.usgs.gov/minerals/pubs/commodity/selenium/myb1-2014-selen.pdf

BGS (2016) World Mineral Production 2010–2014. Keyworth, Nottingham: British Geological Survey, p. 81. Available at: http://www.bgs.ac.uk/mineralsuk/statistics/worldStatistics.html

European Chemicals Agency. (2016) Registered Substances. https://echa.europa.eu/information-on-chemicals/registered-substances

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) International trade in goods database (COMEXT) [online]. http://ec.europa.eu/eurostat/data/database

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 (2016)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

Kavlak, G. and Graedel, T.E. (2013) Global anthropogenic tellurium cycles for 1940–2010. Resources Conservation and Recycling 76, 21–26.

Minerals4EU (2015) European Mineral Yearbook – Data for bauxite, alumina and aluminium [online]. http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

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 Willis, P., Chapman, A. and Fryer, A. (2012) Study of by-products of copper, lead, zinc and nickel. Table 62, p. 107. Oakdene Hollins for International Lead and Zinc Study Group, International Nickel Study Group and International Copper Study Group.

Selenium Tellurium Development Association (2010) Sources and applications for selenium and tellurium. http://www.stda.org/se_te.html

United Nations Environment Programme. (2011) Recycling Rates of Metals A Status Report. p.44. http://www.unep.org/resourcepanel/Portals/50244/publications/UNEP_report2_Recycling_130920.pdf

Willis, P., Chapman, A. and Fryer, A. (2012) Study of by-products of copper, lead, zinc and nickel. Table 62, p. 107. Oakdene Hollins for International Lead and Zinc Study Group, International Nickel Study Group and International Copper Study Group.

31.7.2 Data sources used in the criticality assessment

USGS. (2016a). Tellurium Mineral Commodity Summary. January 2016. United States Geological Survey. https://minerals.usgs.gov/minerals/pubs/commodity/selenium/mcs-2016-tellu.pdf

USGS. (2016b). Selenium and Tellurium in 2014 Minerals Yearbook. November 2016. United States Geological Survey. https://minerals.usgs.gov/minerals/pubs/commodity/selenium/myb1-2014-selen.pdf

BGS (2016) World Mineral Production 2010–2014. Keyworth, Nottingham: British Geological Survey, p. 81. Available at: http://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

European Commission. (2016) EU trade agreements webpage [online]. Directorate General for Trade. http://ec.europa.eu/trade/policy/countries-and-regions/agreements/index_en.htm

Eurostat. (2016) International trade in goods database (COMEXT) [online]. http://ec.europa.eu/eurostat/data/database

Fraunhofer Institute for Solar Energy Systems, ISE. (2016) Photovolaics Report. https://www.ise.fraunhofer.de/de/downloads/pdf-files/aktuelles/photovoltaics-report-in-englischer-sprache.pdf

Nassar, N.T., Graedel, T.E. and Harper, E.M. (2015) By-product metals are technologically essential but have problematic supply. Industrial Ecology. 3 April 2015

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

Selenium Tellurium Development Association (2010) Sources and applications for selenium and tellurium. http://www.stda.org/se_te.html

United Nations Environment Programme. (2011) Recycling Rates of Metals A Status Report. p.44. http://www.unep.org/resourcepanel/Portals/50244/publications/UNEP_report2_Recycling_130920.pdf

Zhang, X. and Zhao, L-D. (2015) Thermoelectric materials: Energy conversion between heat and electricity. Journal of Materiomics 1, 92-105

31.8 Acknowledgments

This Factsheet was prepared by the British Geological Survey (BGS). The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this Factsheet.

32.TIN

Key facts and figures

Material name and Element symbol	Tin, Sn	World/EU production (tonnes)[1]	Refining : 358,400 / 11,500
Parent group (where applicable)	-	EU import reliance[1]	78%
Life cycle stage/ material assessed	Processing / refined tin (99.9 %)	Substitute index for supply risk [SI(SR)]	0.90
Economic importance score EI (2017)	4.4	Substitute Index for economic importance [SI(EI)]	0.87
Supply risk SR (2017)	0.8	End of life recycling input rate (EOL-RIR)	32%
Abiotic or biotic	Abiotic	Major end uses (EU)	Food packaging (28%), Industrial solders (20%), Chemicals (18%)
Main product, co-product or by-product	Main product in majority	Major world producers	Refining: China (45%), Indonesia (19%), Malaysia (10%)
Criticality results	2010	2014	2017
	Not assessed	Not critical	Not critical

[1] average for 2010-2014, unless otherwise stated

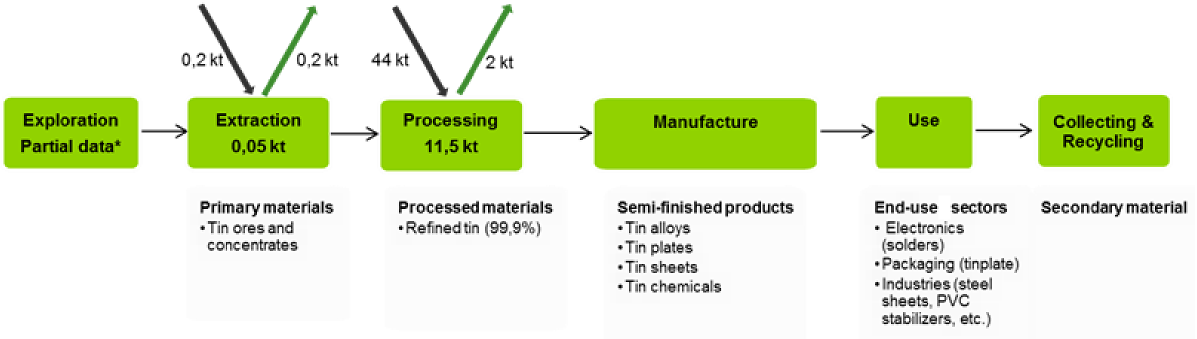


Figure 249: Simplified EU value chain for tin.

Numbers are derived from Eurostat and only indicative. The green boxes in the above figure indicate activities that are undertaken within the EU. The black arrows represent imports of material to the EU and the green arrows represent exports of materials from the EU. A quantitative figure on recycling is not included as the EOL-RIR is below 70%. EU reserves are displayed in the exploration box.

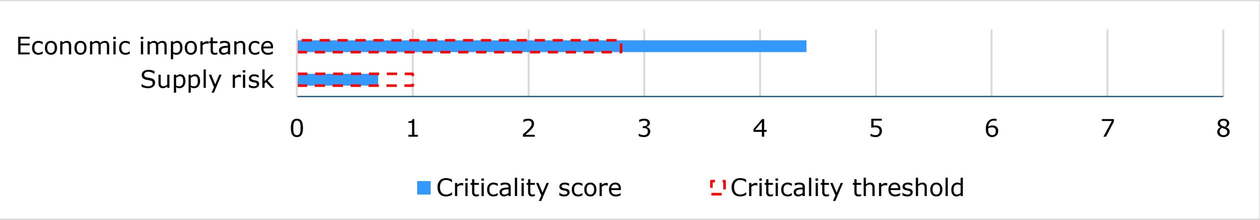


Figure 250 : Economic importance and supply risk scores for tin

32.1 Introduction

Tin (chemical symbol Sn, from the Latin ‘stannum’) is a silvery-white metal, malleable, and with 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 soon alloyed with copper to make bronze, notably by the Romans in the first century AD. Despite this fact, its estimated abundance in the upper continental crust is 2.1 ppm (Rudnick, 2003) which is quite low in comparison to other usual industrial metals (Al, Cu, Pb).

Tin is non-toxic, resistant to corrosion, and a good electrical conductor. Thanks to those properties, it is primarily used today as a coating for steel sheet in tinplate (food containers, etc.) and for industrial solders in electronics. In the EU in particular, others 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 chemicals.

In the EU, modest mining producers of tin are Spain and Portugal and refined tin production occurs in Poland and Belgium.

32.2 Supply

32.2.1 Supply from primary materials

32.2.1.1 Geological occurrence

Tin is invariably found in association with granitic rocks for it is concentrated preferentially in magmatic differentiation processes. It is mainly contained in the mineral cassiterite (SnO_2), its purest form, which is the only commercially important mineral source of tin. Small quantities of tin have also been recovered from complex sulphide ores such as stannite. Its recovery can occur either in-situ or as alluvial or eluvial deposits resulting from the weathering of the original tin-bearing rock (Geoscience Australia, 2016).

Primary deposits can occur within the granite or within pegmatites or aplites associated with the granite. They occur also in rocks surrounding the margins of the intrusive rocks as veins, disseminations, skarns or carbonate replacements generated by tin bearing fluids derived from the granite magmas. It is the case in Bolivia, Peru, or China for instance (Pohl, 2011).

Secondary deposits (placers) derive from the weathering and erosion of primary tin deposits, for 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 is from deposits such as these, mainly in Malaysia, Indonesia and Thailand (Geoscience Australia, 2016).

32.2.1.2 Mining, smelting and refining of tin

Methods used to mine vein and disseminated tin deposits are the same than for hard-rock mining. The ore is broken by drilling and blasting, transported to a concentrator where it is crushed and ground and then concentrated by gravity methods. The concentrate is usually of a lower grade (about 50% tin) than placer concentrate because of the fine grain size of the cassiterite and the difficulty of removing all the associated sulphide minerals. Flotation can be used to improve the amount of tin recovered and to recover tin from the residues of earlier treatment (Geoscience Australia, 2016).

The main method for mining large placer tin deposits is by bucket-line dredging. The alluvium containing the tin is excavated and transported by a continuous chain of buckets to the interior of the dredge where it is washed and roughly concentrated. In South-East Asia particularly, smaller deposits, or those unsuitable for dredging are worked by gravel pumping. The alluvium is broken up by a high pressure jet of water and the resulting slurry is pumped to the concentrating plant. Other methods for secondary deposits include artisanal and small scale mining, particularly in Central Africa, potentially associated with tantalum and tungsten mining.

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).

The next step is smelting. The objective is to reduce cassiterite into tin by heating it with carbon at 1,200°C to 1,300°C in reverberatory furnaces together with a carbon-reducing agent, limestone and silica fluxes. Smelting takes 10 to 12 hours. 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 to 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% to 99.9 %) pyrometallurgical techniques are the more 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% Sn 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.

32.2.1.3 Tin resources and reserves

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[30], 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.

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

---

[30] www.crirsco.com

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 at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU, 2015).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 Minerals4EU project includes estimates based on a variety of reporting codes used by different countries (Table 153). These quantities cannot be summed. Tin resources were identified in Czech Republic, Finland, France, Germany, Spain, Sweden, and United Kingdom (Minerals4EU, 2014).

Table 153: Resource data for tin compiled in the European Minerals Yearbook (Minerals4EU, 2014)

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
UK	JORC	39.9	Mt	0.02%	Measured

Globally, only estimates exist on tin reserve figures, varying on the inclusion of CRIRSCO compliance (Mineral Reserves International Reporting Standards). Two references are respectively the International Tin Research Institute (ITRI), giving an estimate of 2.1 million tonnes in 2016, and USGS giving 4.7 million tonnes (Mt) of tin reserves globally (USGS, 2016), see Table 154. It can be stressed that these numbers represent between 7 and 16 years of yearly production (350,000 tonnes) which is quite small for an industrial metal. However, known resources and reserves are likely to increase as many exploration projects are ongoing and could come into production by 2024 (Roskill, 2015).

Table 154: Global reserves of tin by country (USGS, 2016)

Country	Tin reserves (tonnes)
China	1,100,000
Indonesia	800,000
Brazil	700,000
Bolivia	400,000
Australia	370,000
Russia	350,000
Malaysia	250,000
Thailand	170,000
Burma	110,000
Congo D.R.	110,000
Peru	100,000
Vietnam	11,000
Other countries	180,000
World total	*4,700,000*

The Minerals4EU website only provides data for UK tin reserves, with 27.9 million tonnes at 0.03% of proved reserves (JORC) (Minerals4EU, 2014).

32.2.1.4 World refined tin production

World production was considered only at the refining step, based on the fact that it was judged as the main bottleneck at the EU level for criticality assessment. Except for Belgium, most of the main tin refining countries are also important tin mine producers (see BGS, 2016). Another exception is Myanmar, which has become an important mining producer only since 2010 and exports the majority of its production to China for refining.

Total production of refined tin is of the order of 358,400 tonnes (average 2010-2014). China is the single largest producer with 45% of total output, followed by Indonesia and Malaysia (see Figure 251). Peru is also an important producer (8%), together with Thailand, Bolivia, Brazil and Belgium completing the top 10 (BGS, 2016). In the EU, a tin mining and smelting operation in Spain is due to come into production in Q1 2017 (Strategic Minerals Spain, 2016).

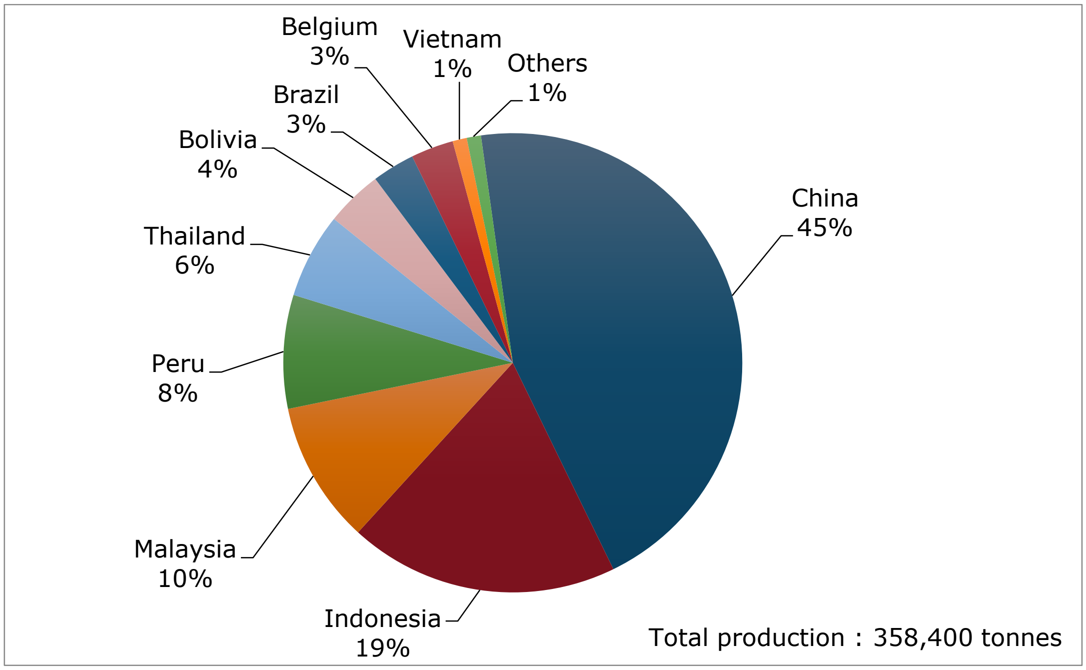


Figure 251: Global production of refined tin. Average 2010-2014 (BGS, 2016)

32.2.2 Supply from secondary materials

The recovery of tin is quite easy due to its intrinsic properties. End-of-life recycling rates depend on the applications and their respective lifespans, with great values for tinplate in food and beverages cans (around 65%), lower for solders in electronics (40%) to negligible in the case of chemical applications. The share of secondary materials in total tin use in all forms is estimated to be 30-35% globally (ITRI, 2016).

32.2.3 EU trade

EU Import reliance for refined tin is 78%. More than 40,000 tonnes per year of refined tin are imported to the EU-28, almost the two-third coming from Indonesia and Peru (Figure 253).

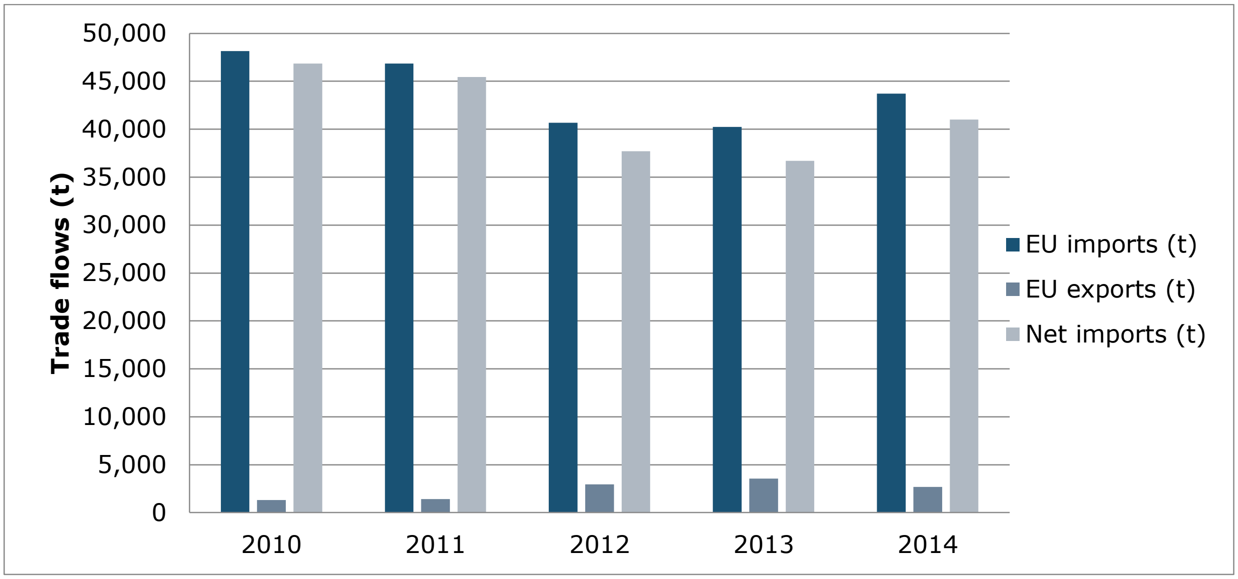


Figure 252: EU trade flows for refined tin (Data from Comext, CN8 code 80011000 (Eurostat, 2016a))

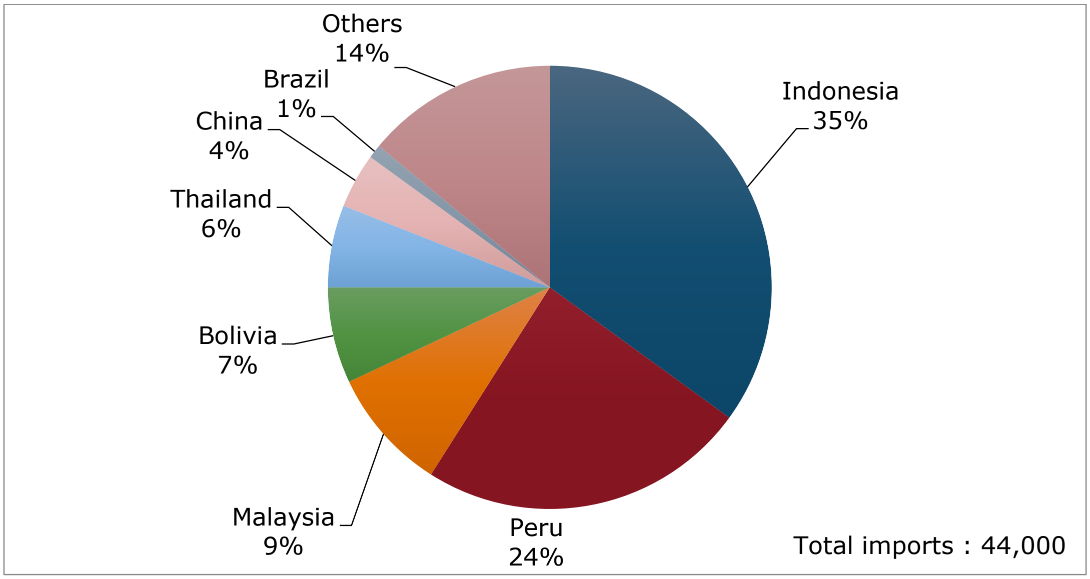


Figure 253: EU imports of tin from extra-EU countries, average 2010-2014 (Data from Comext (Eurostat, 2016a))

Export restrictions on tin are the following: China imposes an export tax of 10% on unwrought tin, plus an export quota of 17,261 tonnes by year. Vietnam, Rwanda and the Democratic Republic of Congo also apply export taxes of respectively 10%, 4% and 1% (OECD, 2016).

In Indonesia, in January 2014, a new legislation came into effect that banned the export of raw mineral ores and concentrates and required such material to be processed into crude or refined tin metal prior to export. Nevertheless, this measure had a lesser impact on the tin market than for bauxite and nickel ores, as Indonesia already beneficiated most of the tin into refined material prior to the ban coming into effect (Roskill, 2015).

There are several official market places for tin: the London Metal Exchange (LME), the Kuala Lumpur Tin Market (KLTM), the Shanghai Futures Exchange (SHFE) and the Indonesia Commodities and Derivatives Exchange (ICDX).

32.2.4 EU supply chain

During the period of study (2010-2014), tin was mined in two EU countries in very low quantities: Spain, which production stopped in 2012 and Portugal, with 52.4 tonnes on average according to BGS 2010–2014 World Mineral Statistics database (BGS, 2016). These figures are anecdotic when compared to the global total production (of the order of 350,000 tonnes).

Tin is mostly used in its refined form. There are two relatively important tin smelters in the EU: Belgium (10,000 tonnes per year on average) and Poland (1,500 t/y) contributing directly to EU supply, however insufficient to fulfill total demand. In addition to this production, more than 40,000 tonnes per year of refined tin are imported to the EU-28. The Figure 254 shows the EU sourcing (domestic production + imports) for tin.

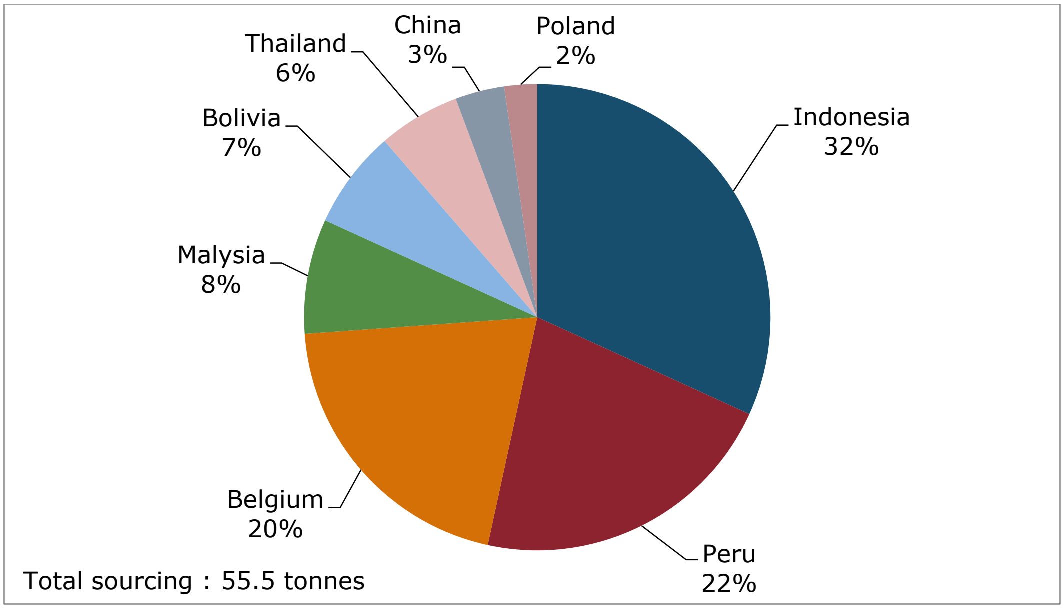


Figure 254: EU sourcing (domestic production + imports) of tin, average 2010-2014 (Data from Comext (Eurostat, 2016a; BGS, 2016))

Great quantities of refined tin are imported to the EU to fulfill total demand from many industries such as tinplate and food packaging with companies like Crown Packaging, electronic and industrial solders (the company MBO Solder for instance) or more generally tin-plated steel sheets (e.g. ArcelorMittal).

32.3 Demand

32.3.1 EU consumption

According to ITRI statistics, the EU would consume close to 60,000 tonnes of refined tin each year on average, which represents 16% of world total uses of tin (ITRI, 2016a).

32.3.2 Applications / end uses

At the world level, tin demand is dominated by its use in solders, both in electronics (solders found in the electric circuits of the majority of electronic appliances) and industrials (automotive radiators, joining lead pipes, etc.). Tin-lead alloys are widely used mostly due to their low melting range. However, most new solders are lead-free due to environmental concerns but still rely heavily on tin with additives.

Chemicals sector has seen the strongest growth in the tin market over the last years. New applications such as organo-tin chemicals for PVC stabilisers have had a great success and now represent a major commercial use of tin. In the absence of stabilisers PVC degrades to give a brittle plastic in the presence of light, heat or atmospheric oxygen.

Tinplate for packaging remains an important sector of consumption. It is produced by coating steel in a thin layer of tin. Because of its non-toxicity, light weight and resistance to corrosion, tinplated steel containers are commonly used as food containers. Wine and spirits capsules play the same role, which is an important market in the EU (ITRI, 2016).

Alloys such as brass and bronze include many industrial applications (in the automotive sector, springs valves for instance). Brass is an alloy of copper, zinc and tin. Bronze is an alloy of copper and tin. For both brass and bronze, varying the amount of copper in the composition will change the properties of the alloy.

Float glass: Tin is used in the Pilkington process for making window glass, whereby molten glass is floated on top of molten tin at 1,100°C. This process produces glass sheets with perfectly smooth surfaces and a uniform thickness. Other applications of tin include pewter items, tin powders and batteries.

Figure 255 and Figure 256 show the differences in repartition of tin uses at the world and EU levels.

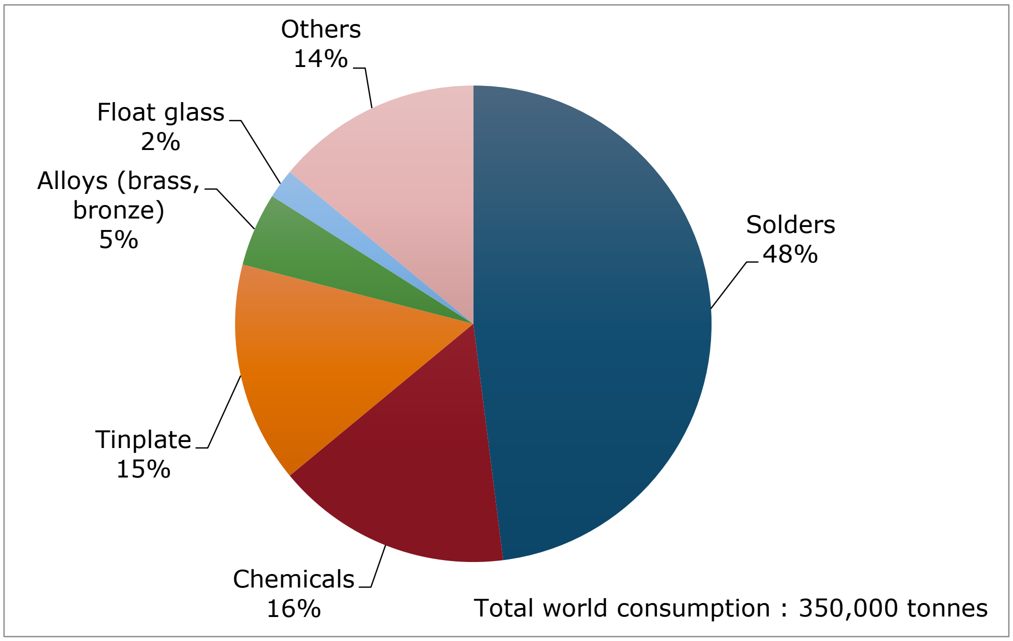


Figure 255: Main uses of tin globally. Average 2010-2014 (ITRI,2016)

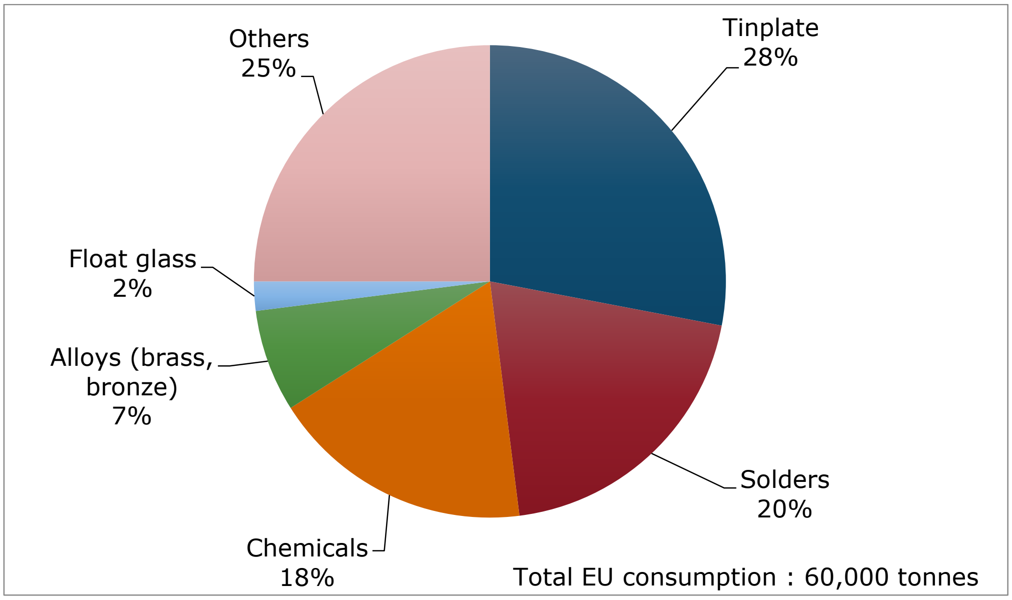


Figure 256: EU end-uses of tin. Average 2010-2014 (ITRI, 2016)

The calculation of economic importance of tin is based on the use of the NACE 2-digit codes. Relevant industry sectors used in the criticality assessment are the following:

Table 155 : Tin applications, 2-digit NACE sectors and associated 4-digit NACE sectors, and added values [Data from the Eurostat database, (Eurostat, 2016)]

Applications	2-digit NACE sector	Value added of sector (millions €)	4-digit NACE sectors
Tinplate	C25 - Manufacture of fabricated metal products, except machinery and equipment	159,513	C2599- Manufacture of light metal packaging
Solders	C27 - Manufacture of electrical equipment	75,260	C2610- Manufacture of electronic components
Chemicals	C20 - Manufacture of chemicals and chemical products	110,000	C2029- Manufacture of other chemical products n.e.c.

32.3.3 Prices and markets

From 2003 to 2011, tin prices have seen a 6-fold increase, until reaching the historical level of 32,000 $US/t. Since then, the range of prices has been 15,000 to 25,000 $US/t (see Figure 257). Tin prices show relative volatility and high sensitivity to external parameters (Indonesian ban, Chinese oversupply, etc.). There are several official market places for tin: the London Metal Exchange (LME), the Kuala Lumpur Tin Market (KLTM), the Shanghai Futures Exchange (SHFE) and the Indonesia Commodities and Derivatives Exchange (ICDX). Recently, stocks in those markets have gone low, which can partly explain the latest evolution of prices.

Figure 257: Tin prices, min. 99.85 %, cash, in LME warehouse (Data from DERA, 2016)

32.4 Substitution

Substitutes exist for many applications of tin. The main one is food and beverage containers, where tinplate can be replaced by glass, plastic, or aluminium depending on price, quality, or toxicity and merely depends on the choice of the manufacturers. It can be noted that since the 1970s, there has been a decline in tin use in packaging due to tough competition with aluminium and others.

For solders in electronics, the main potential substitute is epoxy resin although currently marginal. Health and safety concerns over the toxicity of lead has restricted the use of tin-lead solders in many of those applications and boosted the development of lead-free solders based on silver-copper and other alloys with higher tin content. However, another trend of all the industries and electronics in particular is to decrease quantities of tin on a per-product basis.

32.5 Discussion of the criticality assessment

Criticality assessment was performed at the refining step based on the fact that it was judged as the main bottleneck at the EU level, in particular because of dependence on imports at this stage. This decision was confirmed by industry experts (ITRI).

32.5.1 Data sources

Production data for are from BGS (BGS, 2016). Trade data were extracted from the Eurostat Easy Comext database for the Combined Nomenclature CN8 code '80011000: Unwrought tin not alloyed' has been used (Eurostat, 2016a). 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 derived from the OECD Export restrictions on the Industrial Raw Materials database (OECD, 2016).

32.5.2 Economic Importance and Supply Risk calculation

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 155). The value added data correspond to 2013 figures. The supply risk was assessed using the global HHI and the EU-28 HHI as prescribed in the revised methodology.

32.5.3 Comparison with previous EU assessments

Both Economic Importance (EI) and Supply Risk (SR) scores are lower than in the 2014 criticality assessment (Table 156). Most of the explanation comes from the change in the methodology. To evaluate EI, 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. The way the supply risk is calculated in the new methodology (taking into account global HHI and the EU-28 HHI, for instance) also explains why SR score is slightly lower than in the previous years, together with the fact that the bottleneck chosen for the criticality assessment has been moved to the refining stage rather that the extraction stage.

Table 156: Economic importance and supply risk results for tin in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Tin	-	-		6.7	0.9		4.4	0.8

32.6 Other considerations

32.6.1 Forward look for supply and demand

The rapid rise of consumer electronics industry has spurred growth in demand for tin solders which is now the largest single application, led by China (67% of tin use in this country) together with industrial solders used in the construction and transport sectors (Roskill, 2015). The outlook for tin consumption is positive according to Roskill, growing at a moderate pace of 2.2% per year (see Table 5). The fastest markets will remain in Asia, but a recovery could be expected in North America and potentially in Europe. The use of tin in energy applications could be a potential driver for demand.

Table 5: Qualitative forecast of supply and demand of tin

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
Tin		x	+	+	?	+	+	?

On the supply side, while there has been substantial oversupply in China's tin market in recent years, other important producing countries have seen their production decrease, mostly in Peru as ore grades fell in the San Rafael mine which is approaching depletion and in Indonesia because of a lack of resource development. However, extension of reserves in these regions could still be possible should the increase in prices give a sufficient incentive. Furthermore, also current known reserves appear low in comparison to yearly consumption (see Resources&Reserves paragraph) many projects have the potential of reaching first production by 2024 if global conditions allow (Roskill, 2015).

Some factors weighing on the future of the tin market include regulations on conflict minerals and their impact on production from Central Africa, but also the status of export duties in China which seems to have been removed in January 2017 and other trade regulations in Indonesia and Malaysia (ITRI, 2017).

32.6.2 Environmental and regulatory issues

No environmental restriction is known for tin. Regulatory issues are linked with Conflict minerals legislation issues (European Parliament, 2016).

The Regulation of the European Parliament and of the Council (EU) 2017/821 sets up a Union system for supply chain due diligence self-certification in order to curtail opportunities for armed groups and unlawful security forces to trade in tin, tantalum and tungsten, their ores, and gold. It will take effect on 1 January 2021. It is designed to provide transparency and certainty as regards the supply practices of importers, (notably smelters and refiners) sourcing from conflict-affected and high-risk areas. The EU regulation covers tin, tantalum, tungsten, and gold because these are the four metals that are most mined in areas affected by conflict or in mines that rely on forced labour.

The regulation also draws on well-established rules drawn up by the Organisation for Economic Co-operation and Development (OECD) in a document called 'Due Diligence Guidance for Responsible Supply Chains from Conflict-Affected and High-Risk Areas.'

The regulation only applies directly to EU-based importers of tin, tantalum, tungsten and gold, whether these are in the form of mineral ores, concentrates or processed metals.

The US also has legislation on conflict minerals: Section 1502 of the Dodd-Frank Wall Street Reform and Consumer Act of 2010, which covers the same four products.

32.7 Data sources

32.7.1 Data sources used in the factsheet

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

European Commission (2014)b. 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/

Eurostat (2016)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

European Parliament (2016). Conflict minerals: MEPs secure mandatory due diligence for importers. Press release - External/international trade – November 2016 [online] Available at: http://www.europarl.europa.eu/news/en/news-room/20161122IPR52536/conflict-minerals-meps-secure-mandatory-due-diligence-for-importers

Geoscience Australia (2016) Tin factsheet. [online] Available at: http://www.australianminesatlas.gov.au/education/fact_sheets/tin.html

ITRI (2016) Tin usage patterns by region, tin production and recycling www.itri.co.uk

ITRI (2017) 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

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

Pohl W. L. (2011) Tin In *Economic Geology, Principles and Practices*, Part I Metalliferous ore deposits, Chapter 2.2.3, publisher Wiley&Sons, pp. 202-207

Roskill (2015) The World Market for Tin to 2024. 9th Edition. Roskill Information Services Ltd., London, UK. pp.286

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.

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 (2016) Anderson C.S. Tin - Mineral Commodity Summaries. United States Geological Survey. Ed., Washington DC, pp.2

World Mining Data (2016) Bundesministerium für Wissenschaft, Forschung und Wirtschaft. Austrian Ministry of Science, Research and Economy. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx

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

European Commission (2014)b. 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/

Eurostat (2016)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

Roskill (2015) The World Market for Tin to 2024. 9th Edition. Roskill Information Services Ltd., London, UK. pp.286

River Cap (2016) Tin capsule [online] Available at: www.rivercap.com/en/tin-capsule/the-tin-capsule-by-rivercap

USGS (2016) Anderson C.S. Tin - Mineral Commodity Summaries. United States Geological Survey. Ed., Washington DC, pp.2

32.8 Acknowledgments

This factsheet was prepared by the French Geological Survey (BRGM). The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this Factsheet.

33. TITANIUM

Key facts and figures

Material name and Element symbol	Titanium, Ti	World/EU production (tonnes)1	12,265,593/0
Parent group (where applicable)	-	EU import reliance[1]	100%
Life cycle stage assessed	Extraction	Substitution index for supply risk [SI (SR)][1]	0.94
Economic importance (EI)(2017)	4.3	Substitution Index for economic importance [SI(EI)][1]	0.94
Supply risk (SR)(2017)	0.3	End of life recycling input rate	19%
Abiotic or biotic	Abiotic	Major end uses in the EU[1]	Chemical industry (54%), Plastic products (24%), Other transport (aviation) (8%)
Main product, co-product or by-product	Main product	Major world producers[1]	Canada (21%), Australia (16%), South Africa (12%)
Criticality results	2011	2014	2017 (current)
	Not critical	Not critical	Not critical

[1] average for 2010-2014, unless otherwise stated;

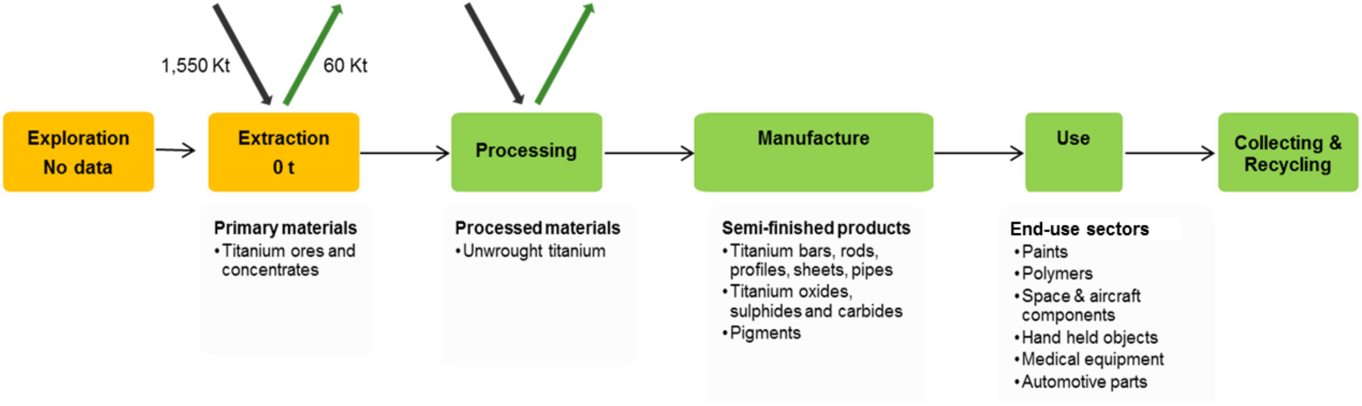


Figure 258: Simplified value chain for titanium.

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU. EU reserves are displayed in the exploration box.

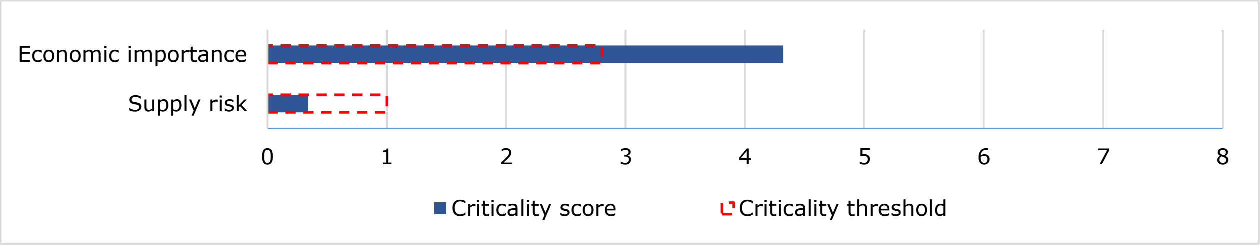


Figure 259: Economic importance and supply risk scores for titanium

33.1 Introduction

Titanium is a chemical element with symbol Ti and atomic number 22. Titanium is a lustrous-white metal of low density (4.51 g/cm^3) with high mechanical strength. The light metal has a high melting point (1,668°C). Its boiling point is 3,500°C. Despite its high melting point, titanium is not suitable for high temperature applications, since its mechanical strength drops sharply when the temperature exceeds 426°C. Titanium is affected by hydrofluoric acid and hot acids, but it is resistant to diluted, cold hydrochloric acid and sulphuric acid, and to nitric acid up to 100°C in every concentration. At room temperature it is resistant even to aqua regia (the infamous mixture of nitric acid and hydrochloric acid able to dissolve noble metals). Pulverized titanium, formed by various cutting processes, is pyrophorus meaning that it ignites spontaneously in air at or below 55 °C. The range of applications using titanium widened as a result of transport equipment inventions during the 20th century, although the current common most compound of titanium is used for pigments.

33.2 Supply

33.2.1 Supply from primary materials

33.2.1.1 Geological occurrence / exploration

The presence of titanium in the earth's crust is abundant, with TiO_2 being one of the 10 most common materials in the upper crust, resulting in crustal abundance being expressed in mass fraction (wt %), namely 0.64% in case of TiO_2 (Rudnick & Gao, 2003).

The economically important sources for titanium metal and dioxide are ilmenite, titanite, anatase, leucoxene, rutile, and synthetic rutile. Since the ionic radius of titanium is similar to some other common elements, titanium is present in most minerals, rocks, and soils. However, there are few titanium minerals with more than 1% titanium content. Another relevant source of titanium is titaniferous slag, which can contain up to 95% titanium dioxide.

Heavy-mineral exploration and mining projects were underway in Australia, Madagascar, Mozambique, Tanzania, and Sri Lanka (USGS, 2016). According to the Minerals4EU website, some exploration is done for titanium in Spain, Sweden, Poland, Ukraine and Romania but with no further details (Minerals4EU, 2014).

33.2.1.2 Processing

Titanium ores are mostly obtained by surface methods. After mining, the sulphate process or the chloride process are the main techniques to produce titanium dioxide from raw materials. The choice for a process at this stage depends on for instance on the titanium material content of the ore, the desired resulting pigments and the allowable amount of waste (ECI, 2016).

Titanium dioxide is extracted by pyro metallurgical processing of ilmenite-containing iron ores, titano-magnetites and titano-haematites (USGS, 2016). Titanium was first isolated as a pure metal in 1910, but it was not until 1948 that metal was produced commercially using the Kroll process (named after its developer, William Kroll) to reduce titanium tetrachloride with magnesium to produce titanium metal.

33.2.1.3 Resources and reserves

There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of titanium 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[31], 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.

For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for titanium. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for titanium, 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 titanium at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU, 2015).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.

Estimated world resources of ilmenite, rutile, and anatase might even add up to more than 2 billion tons (USGS, 2016). Resource data for some countries in Europe are available (see Table 157) in the Minerals4EU website (Minerals4EU, 2014) but cannot be summed as they are partial and they do not use the same reporting code.

Table 157: Resource data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Quantity	Unit	Grade	Code Resource Type
Portugal	None	690,000	m^3	21.12%	Historic Resource Estimates
France	None	840,000	t	-	Historic Resource Estimates
Finland	JORC	39	Mt	4.9%	Indicated
Sweden	JORC	88.8	Mt	0.06%	Indicated
Norway	None	31.7 635	Mt Mt	3.77% rutile 18% ilmenite	Indicated Total
Slovakia	None	0.068	Mt	16% economic	Verified (Z1)
Albania	Nat. rep. code	99	Mt	5 -6.4%	A

According to USGS, the world known reserves of titanium are about 796 million tonnes (USGS, 2016). The largest titanium ore deposits are situated in China, Australia, India, and South Africa, see Table 158. The world's consumption of titanium minerals consists of about 92% ilmenite, which is reflected in the reserves in Table 158 that for around 93% relates to

---

[31] www.crirsco.com

ilmenite as well. Reserve data for some countries in Europe are available in the Minerals4EU website (see Table 159) but cannot be summed as they are partial and they do not use the same reporting code.

Table 158: Global reserves of titanium (ilmenite and rutile) in year 2015 (Data from USGS, 2016)

Country	Titanium Reserves (tonnes)	Percentage of total (%)
China	200,000,000	25%
Australia	162,000,000	20%
India	92,400,000	12%
South Africa	71,300,000	9%
Kenya	67,000,000	8%
Brazil	43,000,000	5%
Madagascar	40,000,000	5%
Norway	37,000,000	5%
Canada	31,000,000	4%
Other countries	26,000,000	3%
Mozambique	14,000,000	2%
Ukraine	8,400,000	1%
United States	2,000,000	0%
Vietnam	2,000,000	0%
Russia	N/A	-
Senegal	N/A	-
World total (rounded)	*796,000,000*	*100%*

Table 159: Reserve data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Quantity	Unit	Grade	Code Reserve Type
Norway	None	200	Mt	18%	Known reserves
Slovakia	None	0.068	Mt	16%	Verified (Z1)

33.2.1.4 World mine production

The global production of titanium minerals between 2010 and 2014 was annually 12.3Mt on average. The leading titanium producing countries are Canada, Australia, South Africa, and China (Figure 260).

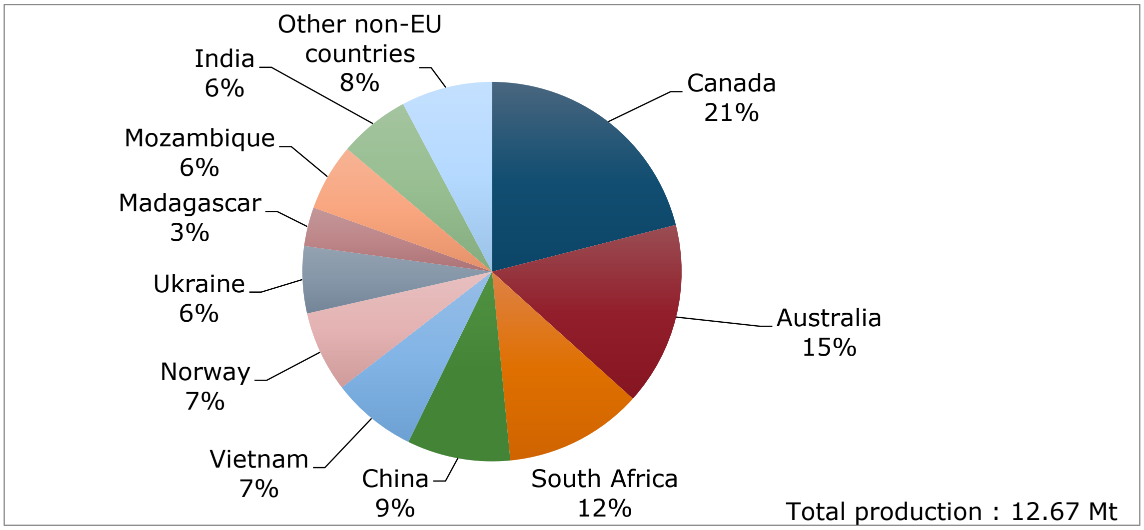


Figure 260: Global mine production of titanium, average 2010–2014 (Data from BGS World Mineral Statistics database)

Together they produce almost 50 % of the global titanium minerals production, which amounted to 12.2 Mt on average between 2010 and 2014. The only recorded production of titanium in Europe on a regular basis takes place in Norway and Ukraine (respectively 7% and 6% of the global titanium production respectively) BGS, 2016). There is no production of titanium minerals in the EU-28.

33.2.2 Supply from secondary materials

In 2012, about 35,000 tons of new scrap and 1,000 tons of old scrap were recycled. Whereas the steel industry used about 10,000 tons of recycled titanium and ferrotitanium, 1,000 tons were used by the super-alloy industry and further 1,000 tons by other industries. Today, recycled content from old scrap accounts for 6% of the entire use. In the future, recycled titanium will only cover a small share of the demand, due to a fast rising consumption (UNEP, 2011).

Processing and consequently using titanium scrap is a longstanding practice with patens dating back to the 1950s. The cold hearth melting process contributed to a greater input of secondary titanium starting from the 1980s. (Newman, 2015)

The end of life recycling input rate for titanium is estimated to be 19%, using the UNEP methodology. For the primary material input we take the amount found in the study from (BGS, 2016) of 12,265 kt. The (UNEP, 2011) report offers amounts of scrap of titanium that are uses a worldwide. a recycled end-of-life material input (old scrap) of 2715.9 kt, an amount of scrap used in fabrication (new and old scrap) 1629.5 kt and scrap used in production (new and old scrap)of 244.4 kt.

33.2.3 EU trade

The volumes of imports and exports of titanium to and from the EU have been stable in recent years, generally following macroeconomic trends. Figure 261 shows the data for average annual total titanium ore imports (expressed in titanium material content) to the EU between 2010 and 2014.

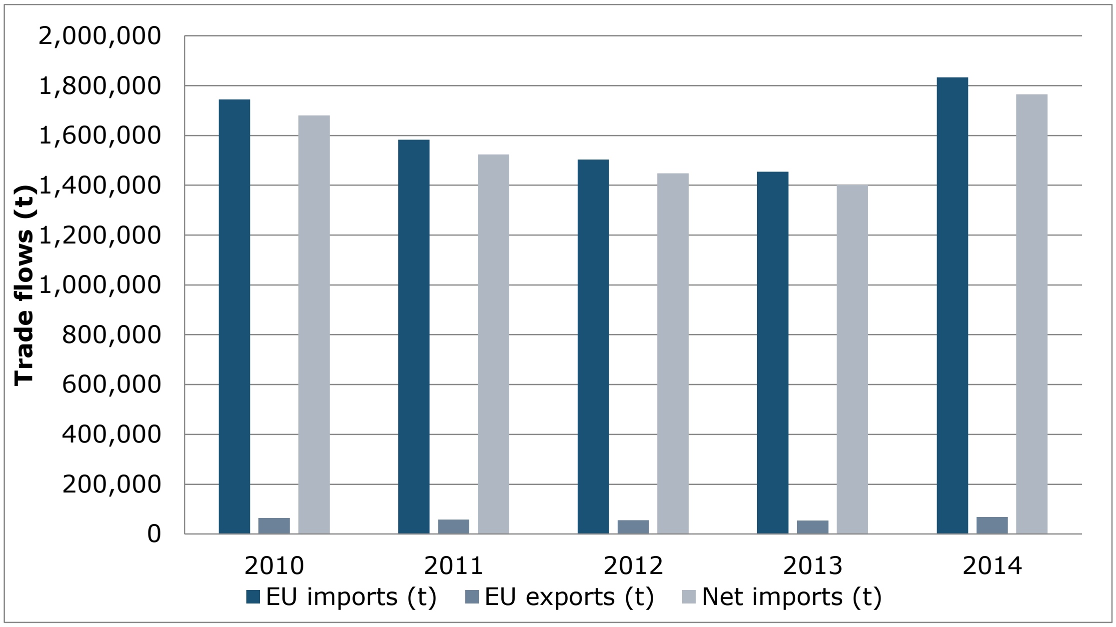


Figure 261: EU trade flows for titanium ore. (Data from Eurostat Comext, 2016)

According to Comtrade data, the largest quantity of titanium imported by the EU was exported by Canada, Norway, South Africa, Mozambique and India. Figure 262 shows the data for the originating countries, importing to the EU between 2010 and 2014.

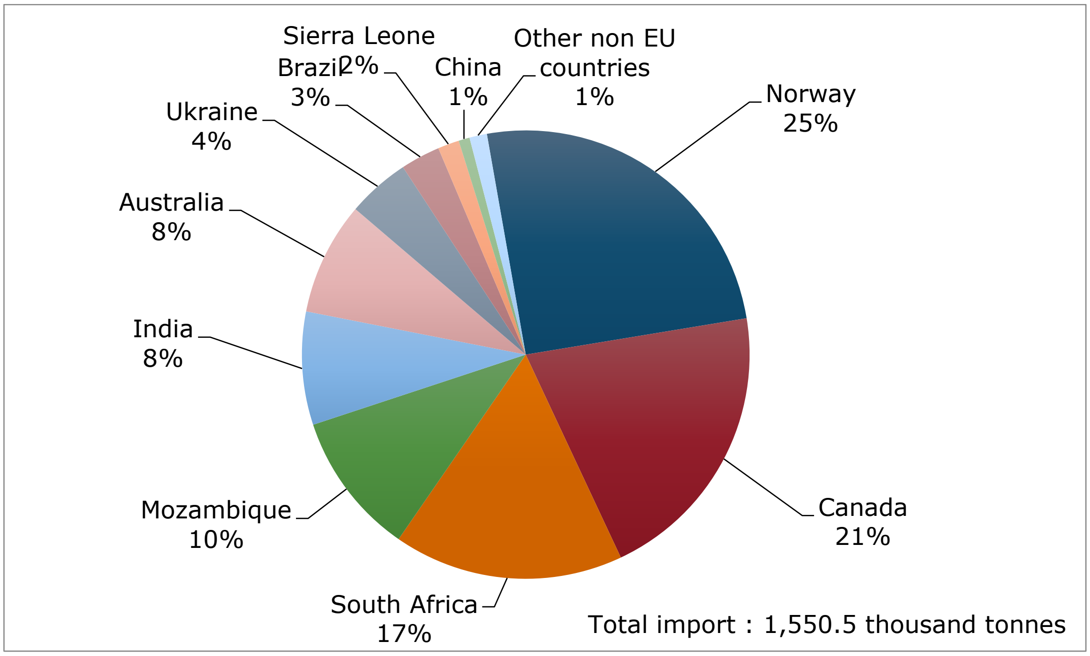


Figure 262: EU imports of titanium, average 2010-2014 (Eurostat, 2016)

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.

33.2.4 EU supply chain

The aero structures market, the metal product manufacturing and the chemical industry are EU based “destinations” of earlier links of the supply chain. There are specialized producers in the EU that prepare powders for enabling technologies such as additive manufacturing. There are several major EU companies specialized in producing secondary titanium, several thousands of employees.

The EU relies for the supply of titanium for 100% on its imports. Since there is no domestic production of titanium in the EU, the EU sourcing (domestic production + imports) is displayed in the previous section in Figure 262.

A limited number of countries have restrictions concerning trade of titanium ores and concentrates. According to the OECD´s inventory on export restrictions, China and Vietnam use export taxes on titanium ores, concentrates and articles thereof ranging between 5% and 45%. A few instances of a license requirement are in place as well (Brazil, Madagascar, and Malaysia).

The broader range of titanium products, titanium scrap and unwrought titanium is subject to export restrictions, by countries such as Argentina, Burundi, India, Jamaica, Morocco, Kenya, Mozambique, Russia and the Ukraine.

33.3 Demand

33.3.1 EU consumption

The EU consumption of primary titanium is on average around 1.5Mt. This volume refers to actual titanium content in the ores and concentrates. Global trading activities are only to a limited part undertaken within the EU, given a small export volume of around 60 kt. This is in line with the large numbers of countries supplying titanium ores and concentrates, making complex and/or long supply chains less likely to be less competitive.

33.3.2 Applications / End uses

Its remarkable properties, like its low weight, high mechanical strength, high melting point, and small thermal expansion, make titanium and titanium alloys important for many applications, e.g. for aircraft industries or medical use.

The main end-uses of titanium are paints, plastics, paper, metal and chemical applications (Figure 263). The major markets for titanium dioxide are inorganic pigments, so-called ‘titanium white’. These non-toxic pigments are used for paints, plastics and papers, and also for opaquely white porcelain glazes. Approximately 54% of all titanium is used as TiO_2 pigment. Since the TiO_2 demand exceeds the natural available amount, an artificial substitute had to be found. Nowadays, synthetic TiO_2 is produced from titanium slag, which is extracted by a metallurgical process in which iron is extracted from ilmenite or titano-magnetites. Titanium oxide is also used for rutile welding electrodes. (Enghag, 2004)

Titanium metal has a distinct tendency to build a passive film of TiO2, which leads to a high corrosion resistance for the metal. Hence titanium and its alloys are used in chemical plants and in seawater. This passive layer also leads to a good toleration of titanium by human tissue, and titanium is used for implants, pins for fixing broken bones and heart pacemaker capsules. (Enghag, 2004).

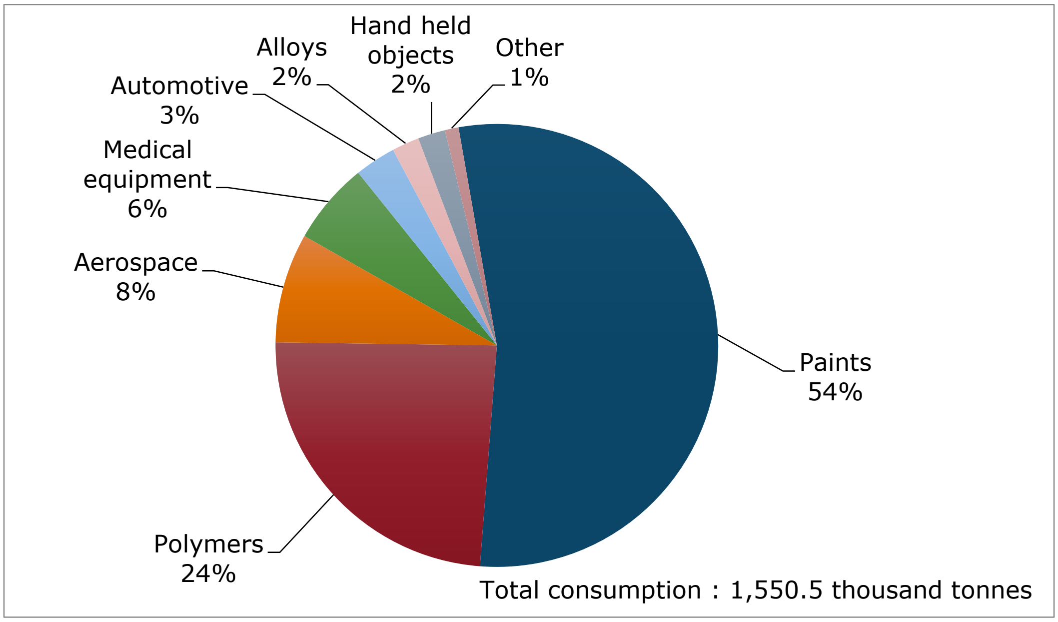


Figure 263: Global/EU end uses of titanium, average 2010-2014. (TNO, 2015)

Table 160: titanium applications, 2-digit NACE sectors and value added per sector (Data from the Eurostat database, Eurostat, 2016)

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (millions €)
Paints	C20 - Manufacture of chemicals and chemical products	C20.30 - Manufacture of paints, varnishes and similar coatings, printing ink and mastics	110,000.0
Pharmaceutical additives	C21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations	C21.10 -Manufacture of basic pharmaceutical products	79,545.0
Polymers	C22 - Manufacture of rubber and plastic products	C22.22 - Manufacture of plastic packing goods	82,000.0
Alloys	C24 - Manufacture of basic metals	C24.45 - Other non-ferrous metal production	57,000.0
Hand held objects	C25 - Manufacture of fabricated metal products, except machinery and equipment	C25.73 - Manufacture of tools	159,513.4
Specialized equipment	C28 - Manufacture of machinery and equipment n.e.c.	C28.99 - Manufacture of other special-purpose machinery n.e.c.	191,000.0
Automotive parts	C29 - Manufacture of motor vehicles, trailers and semi-trailers	C29.32 - Manufacture of other parts and accessories for motor vehicles	158,081.4
Components for aerospace	C30 - Manufacture of other transport equipment	C3030 - Manufacture of air and spacecraft and related machinery	53,644.5

Some titanium alloys can be used at working temperatures up to 600°C. Titanium is lighter than steel, and titanium alloys are stronger than aluminium alloys at elevated temperatures. This specific combination of low weight and high-temperature strength makes titanium valued for the aerospace applications. A civil aircraft can contain up to 1,100 kg titanium (Enghag, 2004), and the aircraft industry is the largest consumer (72%) of titanium alloys. Cemented carbides are usually manufactured from tungsten and a binding element (e.g. cobalt). Modern hard metals have significant contents of titanium carbide or titanium nitride (TNO 2015).

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 160). The value added data correspond to 2013 figures.

33.3.3 Prices

Figure 264 shows that real titanium prices rose steadily between the late 1970s and the late 1980s. From 1971 to 1981, titanium price rose by 80 % due to a growing demand from military and civil aviation industries. Titanium prices stayed at a high level with minor fluctuations until early 2000s, before decreasing with the global economic crisis. The average price of ilmenite concentrate (> 54% TiO_2) on the Northern European markets between 2011 and 2015 was 210 US$/tonne (DERA, 2016). According to the DERA raw materials price monitor and the LMB Bulletin, titanium material prices have decreased drastically since 2015 as :

- Ilmenite concentrates cost 210 US$/t in average on the period 2011-2015 but only 105 US$/t in average on the period December 2015 - November 2016, i.e. a price drop of 50%.
- Rutile concentrates cost 1,421 US$/t in average on the period 2011-2015 but only 711 US$/t in average on the period December 2015 - November 2016, i.e. a price drop of 50%.
- Titanium oxide cost 2,882 €/t in average on the period 2011-2015 but only 2,045 €/t in average on the period December 2015 - November 2016, i.e. a price drop of 29%.

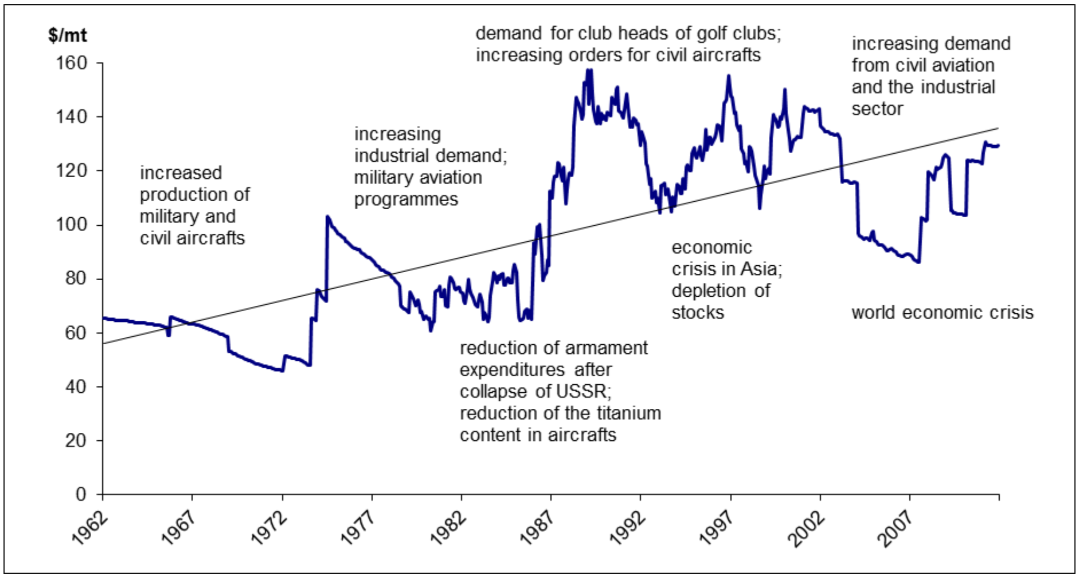


Figure 264: Global developments in price of titanium (Data from DERA 2013)

The Figure 265 shows ferro-titanium pri evolition over the 2005-2017 period.

Figure 265: Ferro Titanium prices (US $/kg), (Infomine, 2017)

33.4 Substitution

Due to outstanding properties of titanium, only few materials can compete with its strength-to-weight ratio and corrosion resistance. When a good corrosion resistance is necessary, titanium can be substituted by aluminium, nickel, specialty steels or zirconium alloys (Terceiro et al. 2013). For applications where high strength is required, titanium competes with superalloys, steel, composites, and aluminium. (USGS, 2016)

As a white pigment, titanium dioxide can in some cases be replaced by calcium carbonate, kaolin or talc. Studies have been undertaken to replace TiO_2 pigment by various percentages of calcined clays in two latex paint formulations. Properties such as thixotropy ("becoming liquid when being put under stress, being shaken), film brightness, scrub resistance, and weather resistance are important to be substituted (Narayan & Raju, 1999).

33.5 Discussion of the criticality assessment

33.5.1 Data sources

The CN code 2614 00 00, labelled "Titanium ores and concentrates" is used for the trade analysis.

The data has a very strong coverage. The data is available on EU level, is available for time series and updated at regular intervals and is publicly available.

33.5.2 Calculation of Economic Importance and Supply Risk indicators

The bottleneck for the supply of titanium to the EU was chosen to be the supply of extracted raw material instead of refined materials. This was done given the larger geographic spread of refining activities

The evidence to link titanium to final products is ample. This allows titanium to be allocated to for instance transport equipment, flight and aerospace in particular, instead of merely metal products or even base metal.

The supply risk was assessed on titanium ore using both the global HHI and the EU-28 HHI as prescribed in the revised methodology.

33.5.3 Comparison with previous EU assessments

The assessment of titanium using the JRC method has resulted in shifts in criticality scores both for economic importance and supply risk. The decrease in economic importance is caused, as for many other materials, by the use of NACE 2 digit sectors opposed to megasectors. The increase in supply risk is expected to be caused by the new methodology to factor in substitution options. See Table 161.

Table 161: Economic importance and supply risk results for titanium in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

Assessment	2011			2014			2017	
Indicator	EI	SR		EI	SR		EI	SR
Titanium	5.38	0.13		5.54	0.13		4.3	0.3

33.6 Other considerations

33.6.1 Forward look for supply and demand

In the future, recycled titanium will only cover a small share of the demand, due to a fast rising consumption. (Marscheider-Weidemann, 2016) Furthermore, buy-back systems and better collection and capturing of materials could make competitive business models possible. (Newman, 2015) Some important technologies that are expected to increase the demand for titanium metal are micro-capacitors, sea water desalination, orthopaedic implants and dye-sensitised solar cells. See Table 162.

Table 162: Qualitative forecast of supply and demand of titanium

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
Titanium		x	+	+	+	+	+	+

33.6.2 Environmental and regulatory issues

Two titanium products are present on the REACH SVHC list: lead titanium zirconium oxide and lead titanium trioxide.

33.6.3 Supply market organisation

The international titanium organization has around fifteen hundred members that together are a comprehensive representation of important titanium market players around the world.

33.7 Data sources

33.7.1 Data sources used in the factsheet

DERA (2013). Rohstoffinformationen. Ursachen von Preispeaks, -einbrüchen und -trends bei mineralischen Rohstoffen. Available at : http://www.deutsche-rohstoffagentur.de/DE/Gemeinsames/Produkte/Downloads/DERA_Rohstoffinformationen/rohstoffinformationen-17.pdf?__blob=publicationFile&v=2

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

ECI (2016). Titanium dioxide. [online] Available at: http://www.essentialchemicalindustry.org/chemicals/titanium-dioxide.html

Enghag, P. (2004). Titanium, in Encyclopedia of the Elements: Technical Data - History - Processing - Applications. With a Foreword by Bengt Nordén, Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, Germany. doi: 10.1002/9783527612338.ch18

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 (2016)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2016)b. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2). [online] Available at: http://ec.europa.eu/eurostat/data/database

Eurostat (2016)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

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

Minerals4EU (2014). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

Narayan, R, Raju, K.V.S.N. (1999). Use of calcined clay as part replacement of titanium dioxide in latex paint formulations. Journal of Applied Polymer Science 77(5):1029 – 1036.

Newman, E. (2015). Recycling trends. Titanium Europe from the International Titanium Organization. [online]. Available at: http://c.ymcdn.com/sites/www.titanium.org/resource/resmgr/NewmanEdTiEU2015Recycling.pdf

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.

TDMA (2016). Titanium Dioxide Manufacturers Association. [online] Available at: http://www.tdma.info/

USGS (2016). Bedinger, G. M. Titanium Minerals Yearbook. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/titanium/myb1-2014-titan.pdf

33.7.2 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

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

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.

TNO (2015). Materialen in de Nederlandse Economie. Bastein, T., Rietveld, E., Keijzer, E. Available at: https://www.rijksoverheid.nl/documenten/rapporten/2015/12/11/materialen-in-de-nederlandse-economie

UNEP (2011). Recycling rate of metals. Available at: http://www.unep.org/resourcepanel/portals/24102/pdfs/metals_recycling_rates_110412-1.pdf

33.8 Acknowledgments

This Factsheet was prepared by the Netherlands Organisation for Applied Scientific Research (TNO). The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials and all other relevant stakeholders for their contributions to the preparation of this Factsheet.

34. ZINC

Key facts and figures

Material name and Element symbol	Zinc, Zn	World/EU mine production (tonnes)1	13,137,570/ 742,006
Parent group (where applicable)	-	EU import reliance[1]	50%
Life cycle stage assessed	Extraction	Substitution index for supply risk [SI (SR)][1]	0.94
Economic importance (EI)(2017)	4.5	Substitution Index for economic importance [SI(EI)][1]	0.89
Supply risk (SR) (2017)	0.3	End of life recycling input rate	31%
Abiotic or biotic	Abiotic	Major end uses in the EU[1]	Steel products (51%), Zinc alloys (34%), Electrical appliances (10%)
Main product, co-product or by-product	Main product	Major world producers[1]	China (35%), Australia: (12%), Peru (10%)
Criticality results	2011	2014	2017 (current)
	Not critical	Not critical	Not critical

[1] average for 2010-2014, unless otherwise stated;

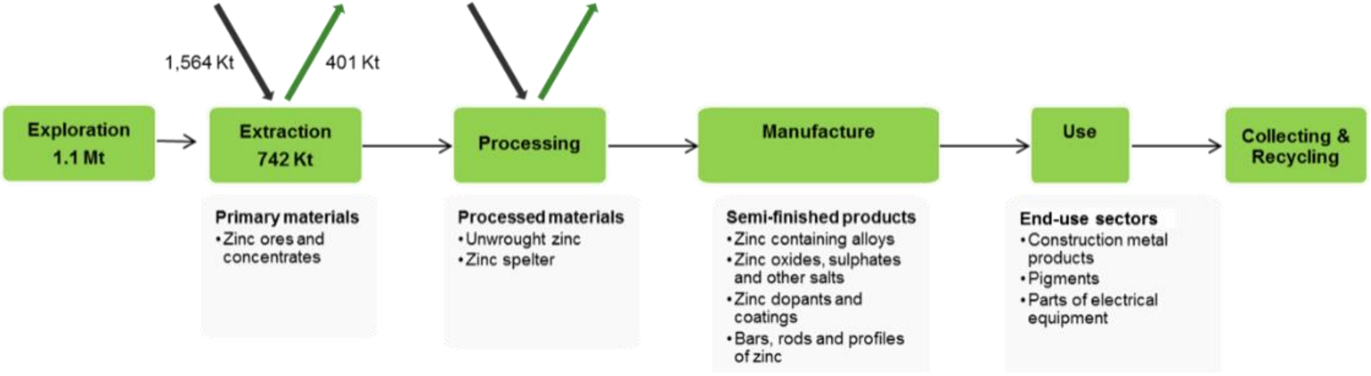


Figure 266: Simplified value chain for zinc

The green boxes of the production and processing stages in the above figure suggest that activities are undertaken within the EU. The black arrows pointing towards the Extraction and Processing stages represent imports of material to the EU and the green arrows represent exports of materials from the EU. EU reserves are displayed in the exploration box.

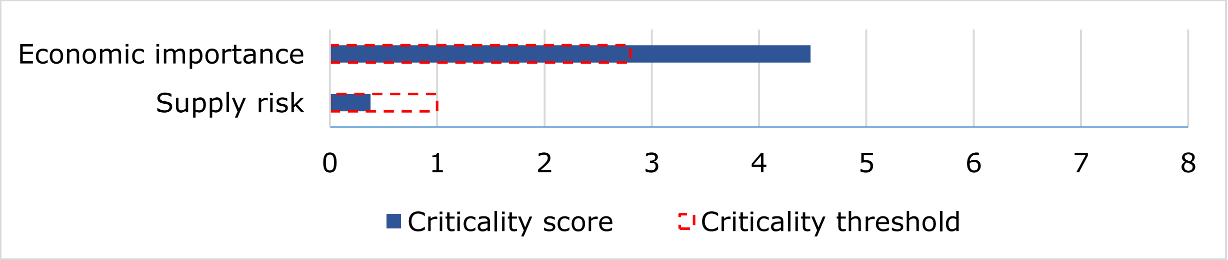


Figure 267: Economic importance and supply risk scores for zinc

34.1 Introduction

Zinc is a chemical element with symbol Zn and atomic number 30. It is a shimmering, bluish metal. It has a low melting point of 419.5°C, a boiling point of 906°C and a density of 7.14 g/cm3 at 20°C. At room temperature zinc is brittle, between 100°C and 150°C it becomes malleable, above 200°C it is brittle again and can be ground into a powder. Above 900°C zinc burns with a bluish-green flame to zinc oxide (ZnO) or 'philosopher's wool'.

34.2 Supply

34.2.1 Supply from primary materials

34.2.1.1 Geological occurrence and exploration

Zinc has an average presence in the earth's upper crust, with 67 parts per million crustal abundance (Rudnick & Gao, 2003).Worldwide, sphalerite or zinc blende (ZnS) is the most common ore for zinc mining and production.

Zinc ore occurs in two types of deposit: as primary zinc ore in thin veins known as rakes, or a secondary deposit formed by weathering of the primary mineral veins. Zinc ore is most commonly found as zinc carbonate ($ZnCO_3$), known as calamine or smithsonite. Calamine is actually a secondary mineral, found principally in the oxidized zone of the zinc-bearing ore deposits. It is derived from the alteration of the primary zinc sulphide (ZnS) mineral sphalerite (BGS, 2004).

The primary zinc ore, sphalerite is typically found in thin veins cutting through the rock. In these veins, the ore occurs as either thin layers encrusting on the walls of the vein, or as thin bands, pockets or crystals within the vein. The veins were always associated with other waste minerals known as 'gangue', usually calcite ($CaCO_3$), pyrite (FeS_2) or barytes ($BaSO_4$). Many of these veins were very thin, sometimes only a few centimetres wide, and often pinched and swelled along their length, sometimes forming complex anastomosing networks with other veins (BGS, 2004).

34.2.1.2 Exploration

According to the Minerals4EU website, some exploration for zinc in done in Greenland, the United Kingdom, Spain, Portugal, Sweden, Poland, Slovakia, Hungary, Romania and Kosovo, but with no more details (Minerals4EU, 2014).

34.2.1.3 Processing and refining

A selective flotation method has been developed from the early 20th century. Improved versions of this flotation process, such as the Jameson flotation cell are used world-wide today (FDE, 2016). Given the increased demand for zinc, the recovery of lead-zinc oxide ores becomes more significant. Recent work has focused on treatment of lead and zinc oxide ores in reagent scheme, flotation flowsheets, and joint process. Sliming is one of the main reasons why the lead-zinc oxides are difficult to recover (Liu et al., 2012).

34.2.1.4 Resources and reserves

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[32], 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.

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 at the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU, 2015).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.

According to USGS, identified zinc resources of the world are about 1.9 billion tons (USGS, 2017). Resource data for some countries in Europe are available in the Minerals4EU website (Minerals4EU, 2014) but cannot be summed as they are partial and they do not use the same reporting code.

Zinc is fairly abundant, and global reserves are estimated at 220 million tonnes (USGS, 2017). The known reserves are spread all over the globe given the large reported reserve in "other countries". The Table 163 below is based on governmental reports. Reserve data for some countries in Europe are available in the Minerals4EU website (see Table 164) but cannot be summed as they are partial and they do not use the same reporting code.

Table 163: Global known reserves of zinc (USGS, 2017)

Country	**Zinc known reserves (tonnes)**
Australia	63,000,000
China	40,000,000
Peru	25,000,000
Mexico	17,000,000
United States	11,000,000
India	10,000,000
Bolivia	4,000,000
Canada	5,700,000
Kazakhstan	11,000,000
Ireland	1,100,000
Sweden	3,000,000
Other countries	32,000,000
World total (rounded)	*220,000,000*

---

[32] www.crirsco.com

Table 164: Reserve data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2014)

Country	Reporting code	Quantity	Unit	Grade	Code Reserve Type
Portugal	NI43-101	16.521	Mt	5.83%	Proven
Ireland	JORC	14.77	Mt	7.39%	Proven & Probable
Finland	NI43-101 JORC	7.4 2.4	Mt Mt	1.8% 0.68%	Proven Proved
Sweden	NI43-101 FRB-standard	12.31 17.19	Mt Mt	6.69% 5.27%	Proven Proven
Italy	None	3.4	Mt	24.6%	Estimated
Poland	Nat. rep. code	8.18	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

34.2.1.5 World mine production

The global mine production of zinc between 2010 and 2014 was annually 13.1Mt on average. According to its traded weight, zinc is forth among the metals worldwide. Only iron, aluminium and copper are traded in greater amounts. Since zinc ore deposits are widely distributed all over the world, and they are mined in several countries worldwide

Between 2010 and 2014, China was the world's largest producer of zinc, followed by Australia and Peru. About 742,000 tonnes or about 7% of the world's zinc production was mined in the EU28, with Ireland and Sweden being the largest producers.

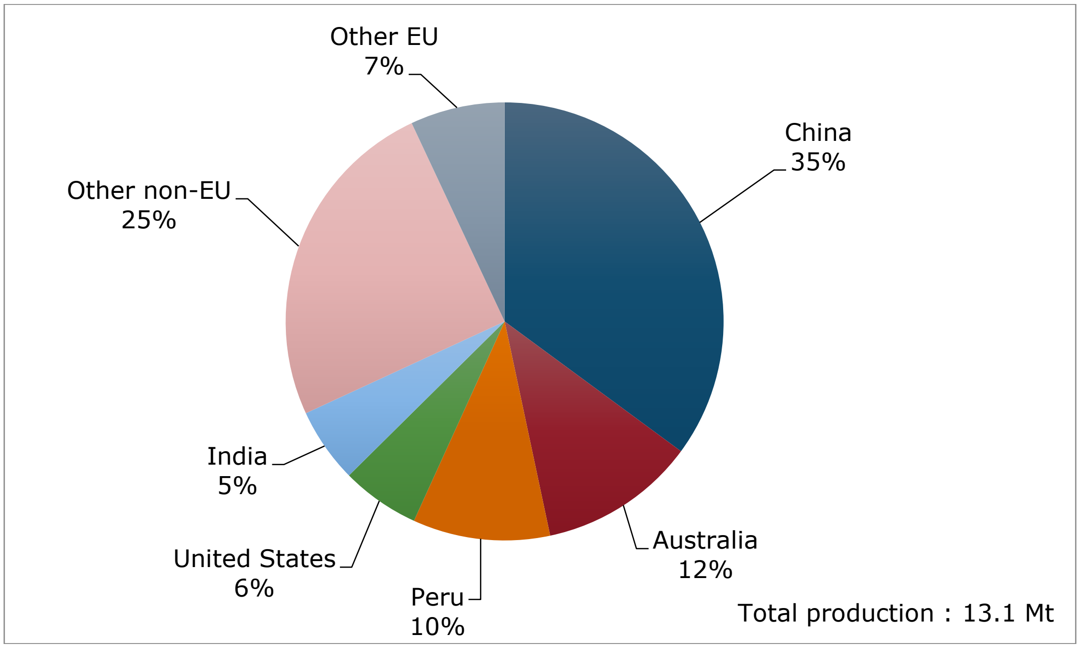


Figure 268: Global mine production of zinc, average 2010–2014 (Data from BGS World Mineral Statistics database, 2016)

34.2.2 Supply from secondary materials

Zinc can be sourced from secondary materials in many ways. Treatment of used metal products is a viable options, as is the use of zinc scrap. Zinc can also be obtained from galvanizing residues and electric furnace dust that contains crude zinc oxide.

Zinc is not itself used widely as the metal in products and therefore, except for the residues arising from the steel galvanizing industry and other much less significant applications zinc does not usually occur as a separate waste in isolation. A significant source of zinc for recycling is old and new brass scrap. The motor industry where a number of automobile parts are made from die-cast zinc alloys which contain a high percentage of zinc, is a significant source also. Automobile breakers are able to separate out such zinc containing parts either manually or as one of the products separated in fragmentizer processes. Old and new brass scrap together with foundry dusts collected in filtration plants, skimmings and drosses from galvanizing processes and die cast zinc alloys separated in fragmentizer plants, all of which contain more than around 50% zinc, are the main sources of zinc for recycling (OECD 1995).

For the estimation of the end-of-life recycling rate, we applied the UNEP methodology (UNEP 2011) resulting in a recycling input rate of 31%.

34.2.3 EU trade

Around 1,5Mt of zinc was imported to the EU between 2010 and 2014. This applies to zinc that is part of zinc ores and concentrates, which are assumed to contain 75% zinc metal (BGS, 2004). As Figure 269 shows, there is relatively little change in the imports and exports of this commodity.

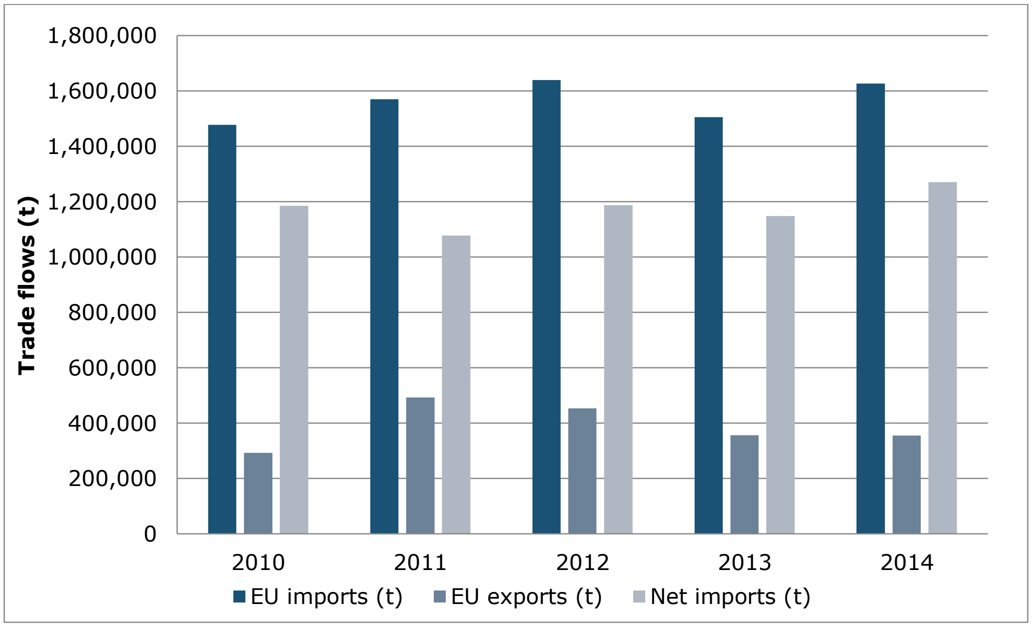


Figure 269: EU trade flows for zinc (Data from Eurostat Comext 2016)

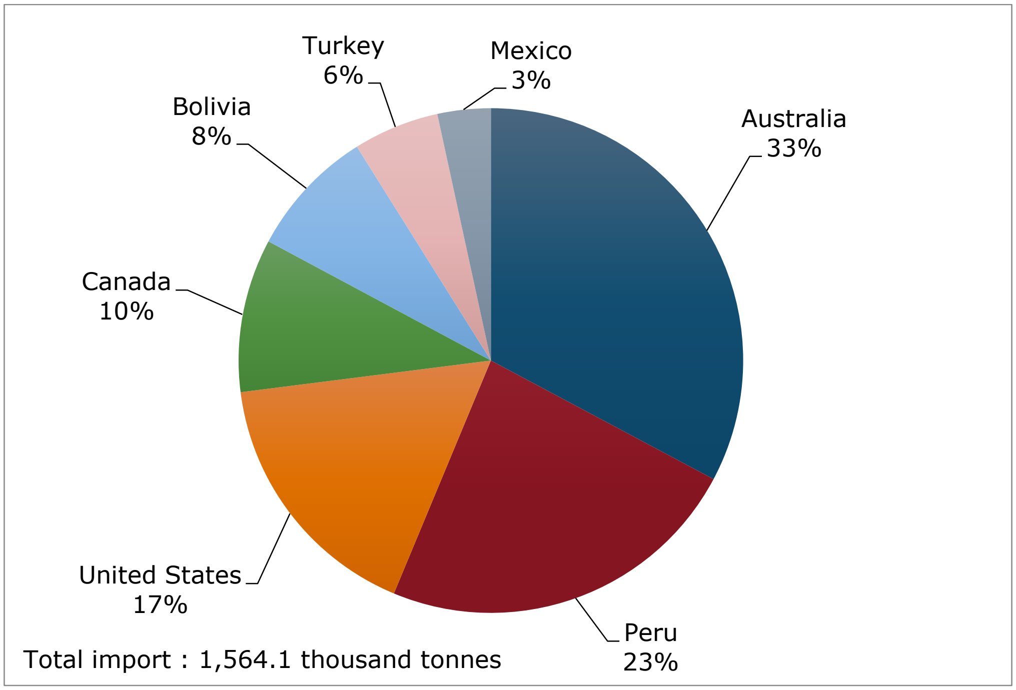


Figure 270: EU imports of zinc, average 2010-2014 (Data from Eurostat Comext 2016)

As Figure 270 shows, the dominant supplier of the EU between 2010 and 2014 was Australia. Other volumes of zinc ore come mostly from the American continent.

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.

34.2.4 EU supply chain

Important zinc processing takes places in the EU, especially in the lowlands. These chains are either manufacturing zinc containing products for the metal manufacturing industry, or chemical industry.

The import reliance of the EU was 50%. This is due to the relatively smaller use of zinc as compared to non –EU economies, the EU production of zinc ore itself and the average export flow of 400 kt. Compared to many other metals, the EU is relatively less reliant on external suppliers.

China imposes an export tax on zinc ores with less than 80% ZnO, but exempts ore with a higher grade. It also requires a license, as does Russia and Australia.

Several countries have trade restrictions concerning zinc containing products. China uses a VAT rebate reduction on zinc bars, rods, profiles, wire, plates, sheets, strip and foil. Russia uses export taxes of 30% on zinc waste and scrap.

Figure 271 shows the EU sourcing (domestic production + imports) for zinc.

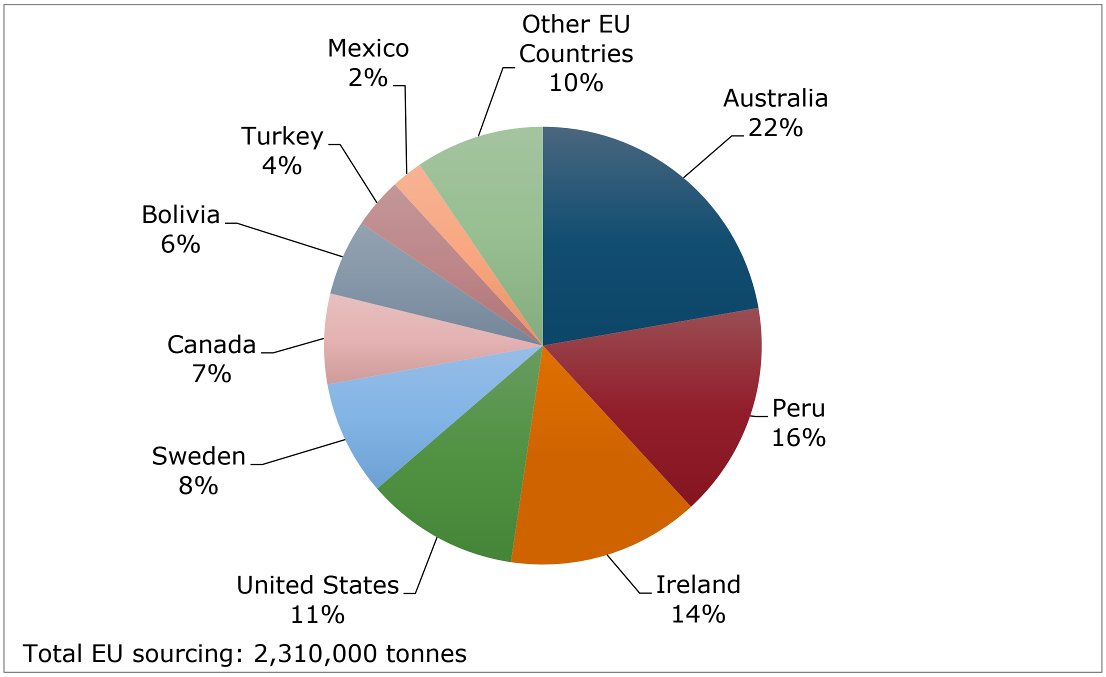


Figure 271: EU sourcing (domestic production + imports) of zinc, average 2010-2014. (Eurostat, 2016)

34.3 Demand

34.3.1 EU consumption

The EU consumption of zinc was around 2.3 Mt in the period between 2010 and 2014. The manufacturing of metal products and base metal in de EU has a large demand for galvanizing products, even though these applications require relatively small quantities of material (Kasteren, 2016).

34.3.2 Applications / End uses

Zinc has many different industrial applications, see Figure 272. About 51% of zinc is used for galvanizing to protect steel from corrosion, certain zinc based chemicals applications are listed here as well. An estimated 34% goes into the production of zinc base alloys to supply e.g. the die casting industry and the production of brass and bronze. Low-alloy zinc grades, which have a better creep resistance than zinc itself, are used for roof drainage parts (e.g. gutters, down-pipes) and for covering buildings. Another field of application of zinc are pigments in the shape of pressure die castings, which primarily supplies the automotive industry (ILZSG, 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 165). The value added data correspond to 2013 figures.

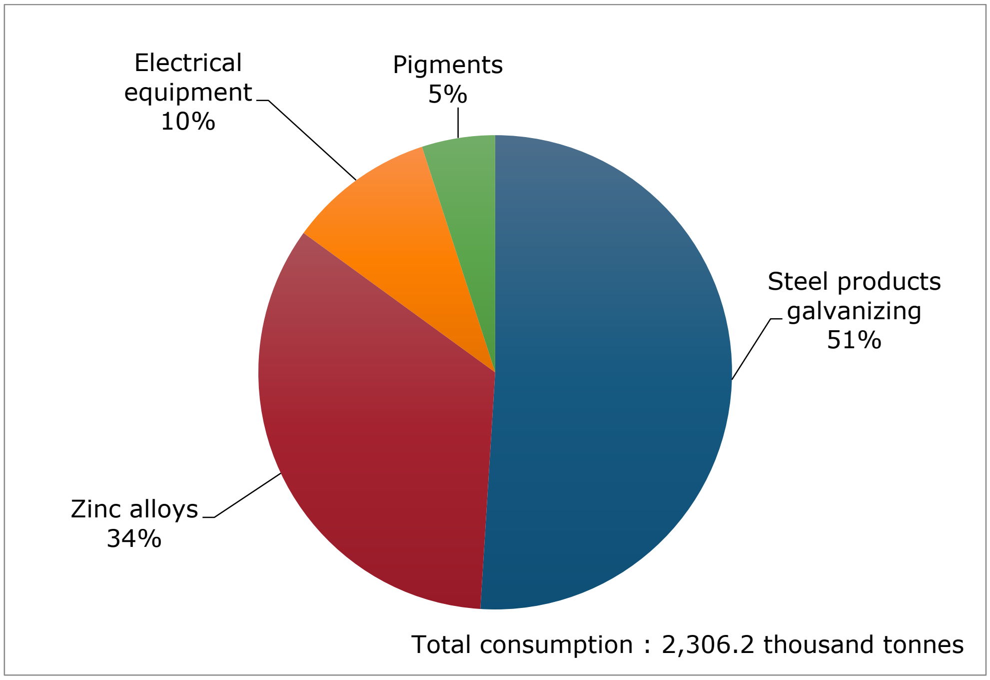


Figure 272: Global/EU end uses of zinc, average 2010-2014 (ILZSG 2016)

Table 165: Zinc applications, 2-digit NACE sectors and value added per sector (Data from the Eurostat database, Eurostat, 2016)

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (millions €)
Pigments	C20 - Manufacture of chemicals and chemical products	C20.30 -Manufacture of paints, varnishes and similar coatings, printing ink and mastics	110,000.0
Zinc alloys	C24 - Manufacture of basic metals	C24.43 - Lead, zinc and tin production	57,000.0
Metal final products	C25 - Manufacture of fabricated metal products, except machinery and equipment	C25.61 -Treatment and coating of metals	159,513.4
Electrical equipment	C27 - Manufacture of electrical equipment	C27.20 - Manufacture of batteries and accumulators	84,608.9

34.3.3 Prices

Figure 273 shows how the different supply and demand situations worldwide influenced zinc prices during the last century. Due to the elevated demand for ammunition during World War I, more zinc was required in this period and, with supply difficulties at sea, zinc prices dramatically increased. The next price spike followed in 1973/1974 due to increased production costs and closed zinc mines. The most recent price peak in 2007 was induced by the fast growing Asian economy, when limited production capacities were unable to immediately meet the demand. World recession has resulted in decreased demand for zinc. In 2009, decreased production and closing of mines in the USA resulted in an excess of demand over supply that was dampened by increased Chinese production. The average price of zinc metal (>99.85%) on the London Metal Exchange between 2011 and 2015 was 2,028.89 US$/tonne – see Figure 274 (DERA, 2016).

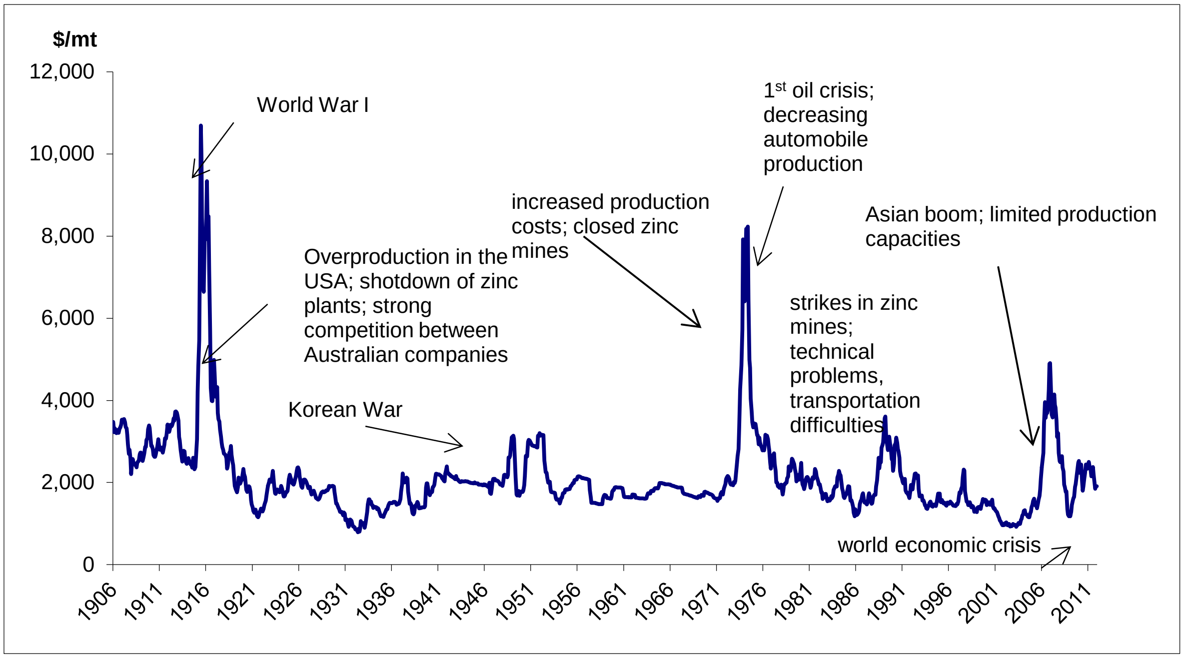


Figure 273: Global developments in price of zinc (Data from DERA 2013)

Figure 274: Monthly average cash price for zinc in US$ per tonne (data from LME, 2017)

34.4 Substitution

For the purpose of corrosion protection zinc is substituted by aluminium alloy, cadmium, and plastic coatings. Galvanized plates can be replaced by aluminium, plastics or steel. Diecast zinc parts principally are replaced by aluminium, magnesium, and plastics. (European Commission 2014)

Especially in the thin film using industries, such as for solar panels, zinc is reported to be a useful substitute for other materials. Zinc oxide (ZnO) could be 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 five years to commercialization. (Hovestad e.a. 2015)

34.5 Discussion of the criticality assessment

34.5.1 Data sources

Trade data is analysed using CN code 26140000 which is labelled "zinc ores and concentrates".

The data has a very strong coverage. It is on EU level, is available for time series and updated at regular intervals and is publicly available.

34.5.2 Calculation of Economic Importance and Supply Risk indicators

Zinc is assessed at the extraction stage. Mining and refining activities have a wide geologically spread. The presence of zinc metal in several product groups as galvanized material makes it difficult to perform a consistent study of zinc metal at the refined stage.

The supply risk was assessed for zinc ore using both the global HHI and the EU-28 HHI as prescribed in the revised methodology.

34.5.3 Comparison with previous EU assessments

The assessment of zinc is one of the typical cases that demonstrate the new allocation of economic importance. The supply risk of zinc is hardly influenced by the new methodology. The "metals" mega sector in the previous sector had a value added of 164 bio. EUR, that is higher given the sum of the products of value added data and application shares of the base metal and metal products sectors separately. See Table 166.

Table 166: Economic importance and supply risk results for zinc in the assessments of 2011, 2014 (European Commission, 2011; European Commission, 2014) and 2017

Assessment year	2011		2014		2017	
Indicator	EI	SR	EI	SR	EI	SR
Zinc	9.4	0.4	8.66	0.45	4.5	0.3

34.6 Other considerations

34.6.1 Forward look for supply and demand

As an established metal, zinc is not foreseen to experience supply or demand shocks in the coming years (Vandenbroucke, 2016).

The future use of zinc could be accelerated in case the demand of redox flow batteries will increase at an accelerating pace (Marscheider-Weidemann, 2016).

Table 167: Qualitative forecast of supply and demand of zinc

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
Zinc		x	+	+	+	+	+	+

34.6.2 Environmental and regulatory issues

An overview is available of the effects of zinc on human health as a result of industrial processes in China, also referencing to activities in the US and the EU over the last decades (Zhang et al., 2012). The low concentrations of zinc in combination with the dissipative nature of some applications of zinc require consistent monitoring, but no effects where found that urgently require the current regulation of the use of zinc to be expanded.

34.6.3 Supply market organization

Zinc ores are also an important source for indium, germanium, silver, bismuth, tellurium and gallium metal. Any supply and/or demand changes related to zinc ore will influence the supply of these by-products.

The global concern for antidumping measures also affects zinc, given its purpose as galvanizer. In June 2015, six steel producers with operations in the United States filed antidumping and countervailing duty petitions asserting that imports of galvanized steel from China, India, Italy, the Republic of Korea, and Taiwan during the past three years have materially injured the domestic steel industry and that producers in these countries have benefitted significantly from Government sponsored subsidy programs that allowed them to price products at less than fair value. (USGS, 2016)

34.7 Data sources

34.7.1 Data sources used in the factsheet

BGS (2004) Mineral profiles zinc. Available at: https://www.bgs.ac.uk/mineralsuk/statistics/mineralProfiles.html

DERA (2013.) Rohstoffi nformationen. Ursachen von Preispeaks, -einbrüchen und -trends bei mineralischen Rohstoffen. Available at : http://www.deutsche-rohstoffagentur.de/DE/Gemeinsames/Produkte/Downloads/DERA_Rohstoffinformationen/rohstoffinformationen-17.pdf?__blob=publicationFile&v=2

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

Eurostat (2016)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

FDM (2016). Beneficiation process of Lead Zinc(Zn) Or. Available at: http://www.zcrusher.com/files/Beneficiation-process-of-lead-zinc-ore.html

Liu, S. Q., Wang, W. P., Song B. X., Zhang, M., (2012). Present Situation on Beneficiation of Lead-Zinc Oxide Ore, Advanced Materials Research, Vols. 524-527, pp. 1017-1022. Available at: http://www.scientific.net/AMR.524-527.1017

London Metal Exchange (2017). Zinc pricing. https://www.lme.com/metals/non-ferrous/zinc/#tab2

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

Minerals4EU (2014). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

OECD (1995). Recycling of copper, lead and zinc bearing wastes. OCDE/GD(95)78. Available at: http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=OCDE/GD(95)78&docLanguage=En

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.

USGS (2014). Tolcin, A., C. 2014 Minerals yearbook zinc. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/zinc/myb1-2014-zinc.pdf

USGS (2017). Mineral Commodity Summaries: zinc. Available at: https://minerals.usgs.gov/minerals/pubs/commodity/zinc/mcs-2017-zinc.pdf

Willis P., Chapman A., Fryer A. (2012) Study on by-products of copper, lead, zinc and nickel.

Zhang, X., Yang, L., Li, Y. (2012) Environ Monit Assess 184: 2261. doi:10.1007/s10661-011-2115-6. Available at: http://link.springer.com/article/10.1007%2Fs10661-011-2115-6

34.7.2 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

Hovestad, A., Tercero Espinoza, L., Hummen, T., Brunot, 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. Available at: http://www.criticalrawmaterials.eu/wp-content/uploads/D3.3-Raw-Materials-Profiles-final-submitted-document.pdf

ILZSG (2016). End uses of zinc. Available at: http://www.ilzsg.org/static/enduses.aspx?from=5

Kasteren, J. van, (2016) Expert consultation. Eindhoven University of technology.

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

UNEP (2011). Recycling rate of metals. Available at: http://www.unep.org/resourcepanel/portals/24102/pdfs/metals_recycling_rates_110412-1.pdf

Vandenbroucke, J., (2016) Expert consultation. Nyrstar.

34.8 Acknowledgments

This Factsheet was prepared by the Netherlands Organisation for Applied Scientific Research (TNO). The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials for their contributions to the preparation of this Factsheet. Specific experts that have contributed their input and feedback to the factsheet and criticality assessments are listed in the data sources section.

ET-04-15-308-EN-N

Publications Office

doi:10.2873/49178