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.

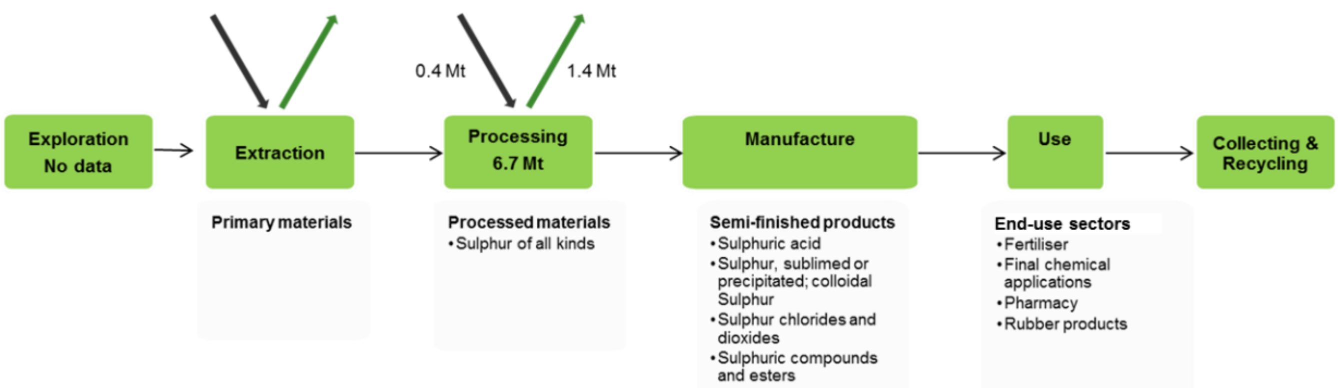

Figure 225: Simplified value chain for sulphur

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.

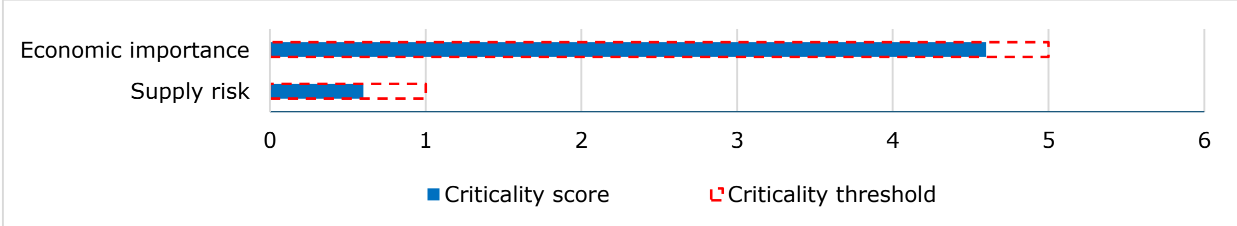

Figure 226: Economic importance and supply risk scores for sulphur

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

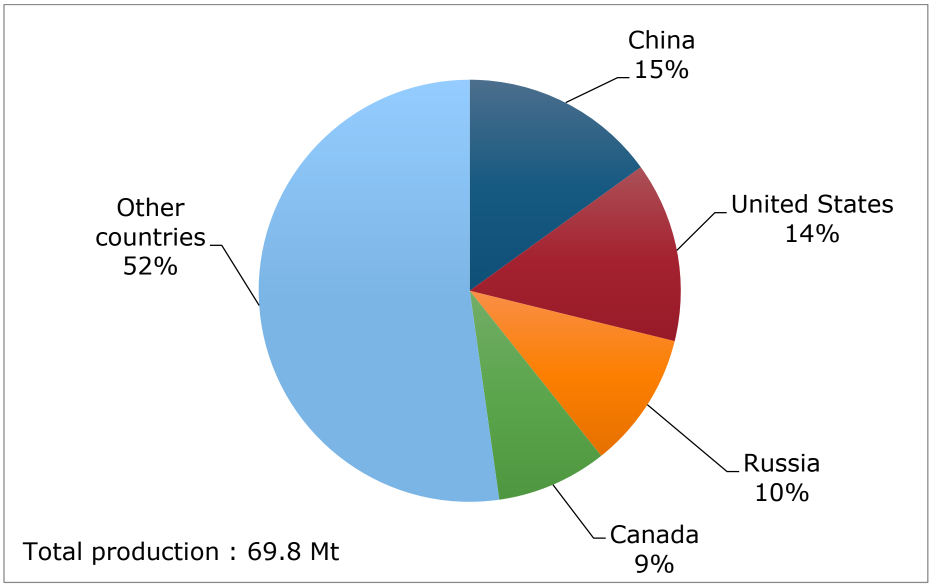

Figure 227: Global production of sulphur, average 2010–2014 (Data from BMWFW, 2016)

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.

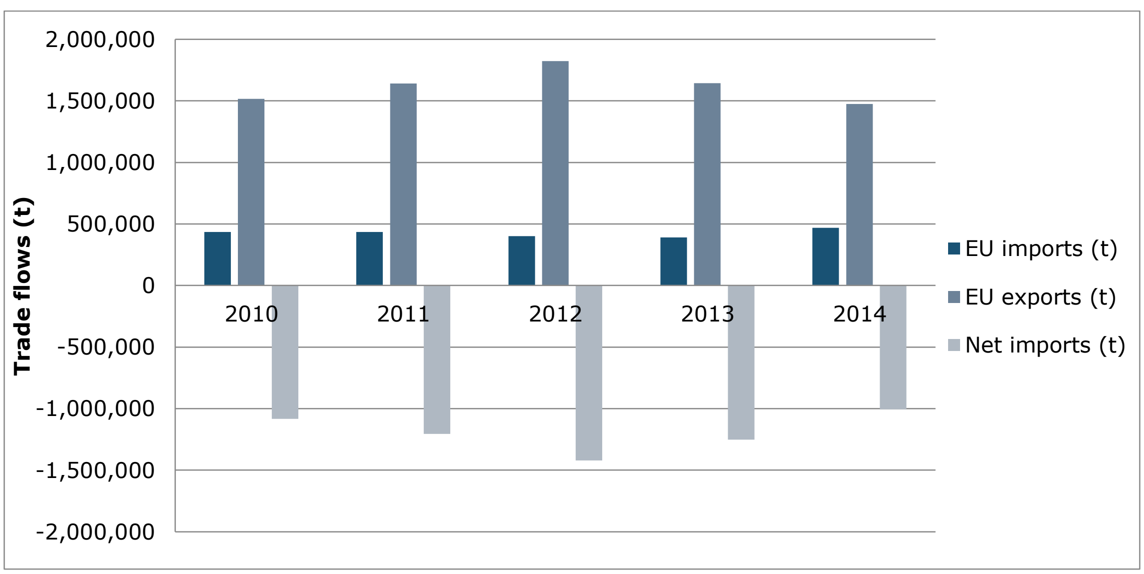

Figure 228: EU trade flows for sulphur (Data from Eurostat Comext 2016)

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%).

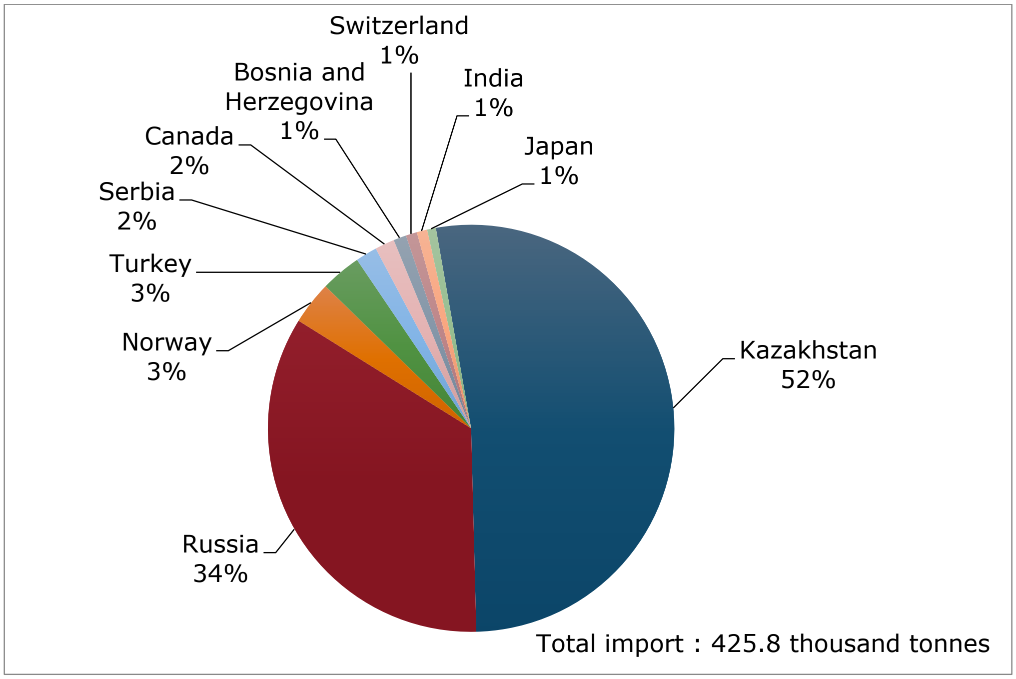

Figure 229: EU imports of sulphur, average 2010-2014 (Data from Eurostat Comext, 2016)

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.

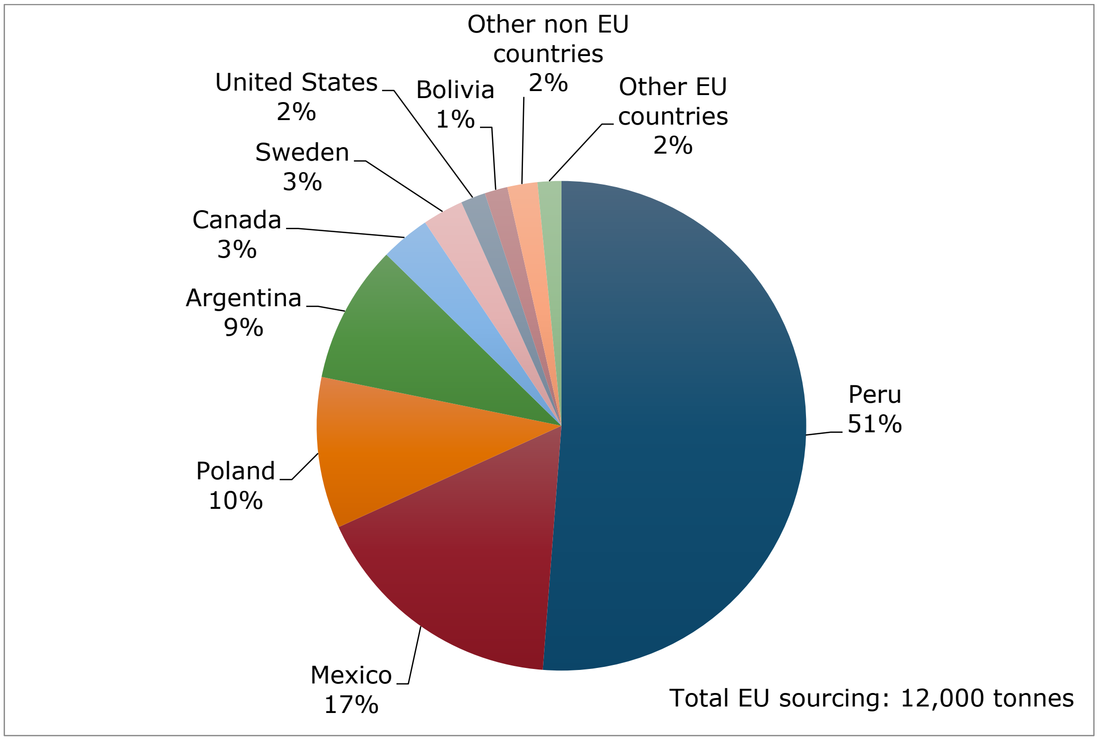

Figure 230: EU sourcing (domestic production + imports) of sulphur, average 2010-2014 (Eurostat, 2016; USGS, 2016a)

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).

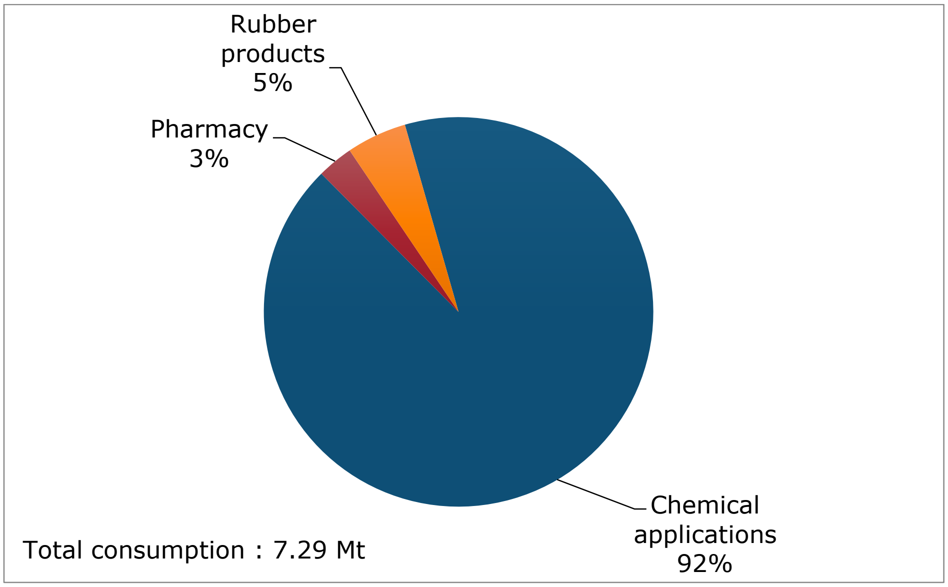

Figure 231: Global/EU end uses of sulphur, average 2010-2014 (Data from Sulphur institute 2016)

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.

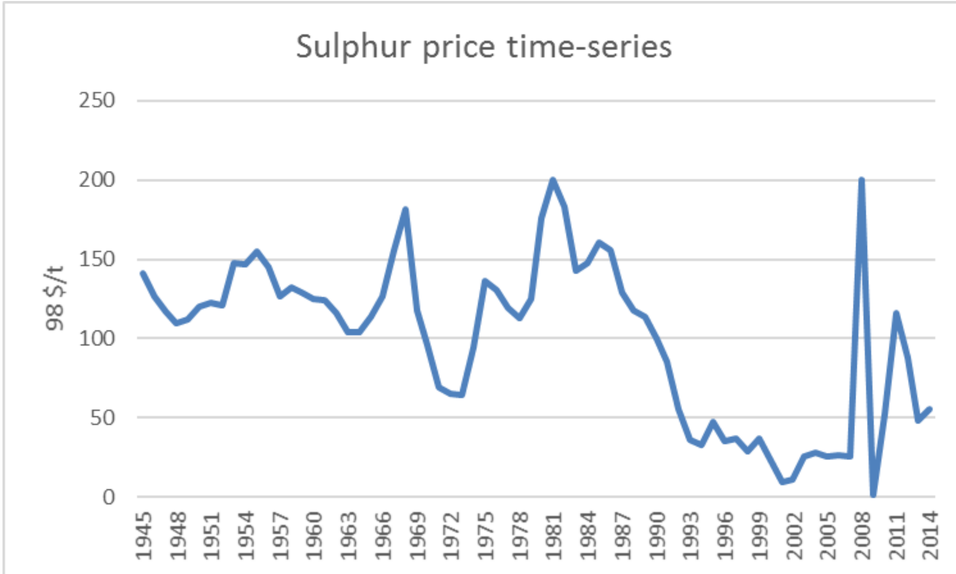

Figure 232: Global developments in price of sulphur, average 1945-2014 (USGSb, 2016)

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

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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

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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.

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Vandenbroucke, J. (2016). Expert consultation.

29.8 Acknowledgments

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