5 BISMUTH

5.1 Overview

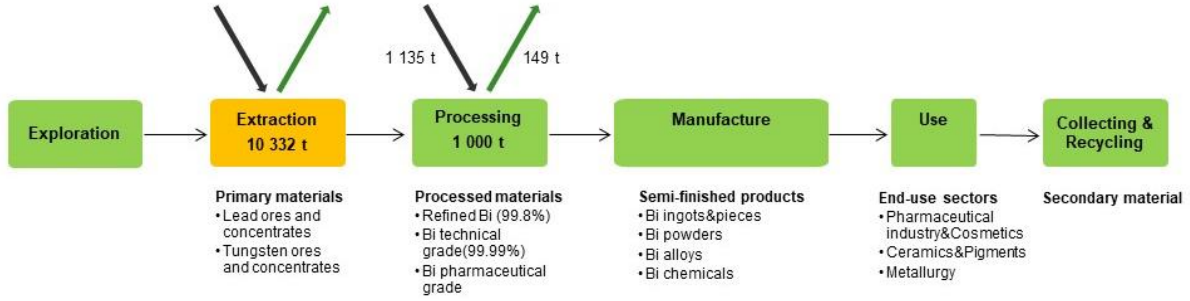

Figure 61: Simplified value chain for Bismuth (2012-2016 average figures)[33]

Bismuth (chemical symbol Bi) is a very brittle metal with a pinkish metallic lustre. It occurs naturally in the minerals bismuthinite (sulfide), bismutite (carbonate) and bismite (oxide). Very rarely extracted as main metal, it is mainly a by-product of lead and tungsten. Bismuth was on the list of CRMs in 2017 and not assessed before.

For the purpose of this assessment bismuth at processing stage is analysed. Bismuth is assessed in the form of bismuth metal (99.8% Bi contained, CN8 code CN8 81060010) Quantities expressed in tonnes of bismuth content.

The world market value of refined bismuth production is estimated to USD 6.828/t over the period Oct 2018- Sept 2019 (DERA 2019). Over the period 2012-2016 China was the top producer of mined and refined bismuth. Bismuth is not traded on any metals exchange, and there are no terminal or futures markets where buyers and sellers can fix an official price. New environmental policies that came into effect in China in 2018, resulted in many bismuth smelters shutting down temporarily for inspections or permanently for infractions (USGS 2019). Global bismuth prices decreased from USD 10.635/t in the period Jul 2017 – Jun 2018 to USD 6.828/t in Oct 2018- Sept 2019 (DERA 2019).

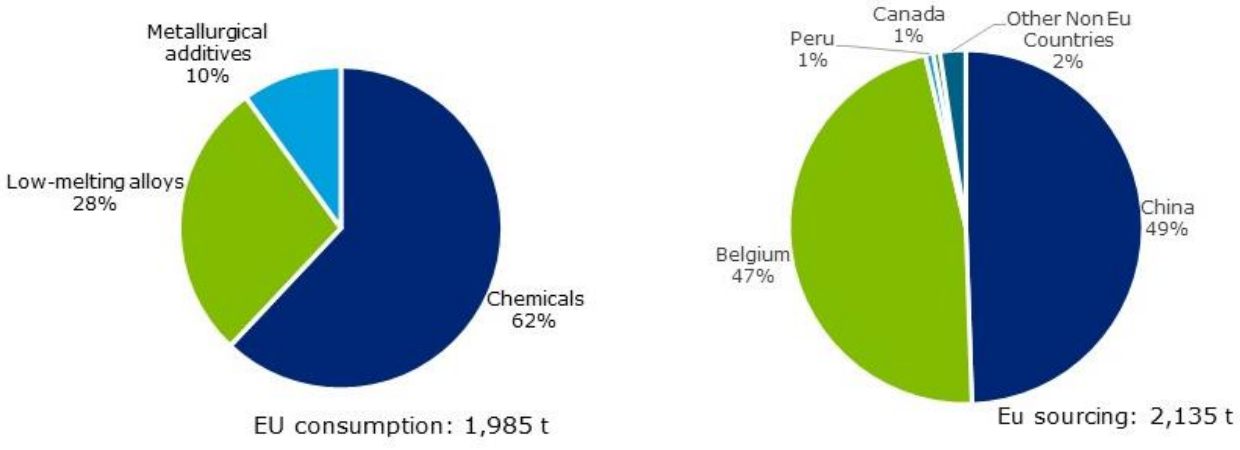

Figure 62: End uses (Blazy 2013) (SCRREEN Workshop 2019) and EU sourcing of Bismuth. (2012-2016 average) (DERA 2015)(USGS 2016)(Eurostat 2019b)

The EU consumption of bismuth is 1,985 t, which is imported mainly from China and sourced through domestic production in Belgium. The EU is a net importer of refined

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

bismuth. EU import reliance on refined bismuth is almost 50% (average of 2012-2016) due to the predominant share of imports from China in the EU supply for this period, which represents 93% of the total EU imports (1,135 t).

Bismuth is mainly used in the pharmaceutical and animal-feed industries (62%). Fusible alloys represent the second most important use (28%). Other uses include metallurgical additives and a number of other industrial applications such as coatings, pigments, and electronics (Ecclestone 2014) (Blazy 2013) (SCRREEN workshops 2019). Substitutes exist for bismuth in many applications as in some of them it is primarily used for its non-toxicity as a replacement for already existing materials (metals).

During the Minerals4EU (2019) project, resources of bismuth were reported only in Bulgaria in the category "No statistical data available but resources known or believed to exist". Exploration projects were mentioned in Portugal and Slovakia with no further information (Minerals4EU 2019). World reserves of bismuth are estimated at around 370,000 t of contained bismuth (USGS 2017). However, these estimations have been unchanged for many years (except for Vietnam) and are likely to be incomplete since they are based on bismuth content of lead ores only, overlooking bismuth content in copper and tungsten ores.

The world annual production of refined bismuth (99.8% Bi content) (average 2012-2016) is about 19,183 t with 80% of production in China (USGS 2016). In Europe, US.Geological Survey Minerals Yearbook (2016) mention mine production in Bulgaria (3.8 t, average 2012-2016), stopped in 2014.

Bismuth is difficult to recycle because it is mainly used in dissipative applications, such as pigments and pharmaceuticals. Given the type of applications, bismuth is not recyclable (MSA,2019-2020).

Several bismuth-containing substances are registered with REACH. However, none of them is on the list of substances of very high concern. Even though the REACH dossier indicates that data is lacking on the physical, health and environmental hazards of bismuth, this element is generally acknowledged for its non-toxicity in many of its uses.

5.2 Market analysis, trade and prices

5.2.1 Global market analysis and outlook

Global demand for bismuth is estimated to grow at 4-5% by year averaged over 2012-2016, thanks to high demand in pharmaceutical applications. There may also be growth in applications where there is a requirement for very low temperature solders, where bismuth is competitive. Another emerging market could come from the substantial interest in developing new classes of semiconductor, thermoelectric materials and topological insulators. It could lead to the development of emerging semiconductor compounds and alloys that contain bismuth (BIWS 2018).

On the supply side, Fortune Minerals Ltd. in Canada (London, Ontario) was granted final approval for a Type A water license for the NICO gold-cobalt-bismuth-copper mine in the Northwest Territories in 2014. The water license was one of the final steps in the permitting process, allowing construction to begin once financing had been received. Output was expected to be 41,500 troy ounces per year of gold, 1,600 metric t per year (t/yr) of cobalt, 1,700 t/y of bismuth, and 250 t/y of copper (USGS 2016) (Fortune 2019b). Fortune continues to pursue off-take agreements and financing solutions with the objective of commencing construction activities as soon as project financing is secured. Feasibility studies, test mining, pilot plants and environmental assessments have already been completed (Fortune 2019a).

New environmental policies that came into effect in 2018 in China resulted in many bismuth smelters shutting down temporarily for inspections or permanently for infractions. However, smelters still in operation increased their output to offset the loss of production from the closures (USGS 2019).

Table 26: Qualitative forecast of supply and demand of Bismuth

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

5.2.2 EU trade

EU is a net importer of refined bismuth. With about 1,134 t per year (Bi content), import is eight times higher than export in the period 2012-2016, according to Comext (Eurostat 2019b). Export is about 150 t year. Imports for 2016 was two times higher than in 2015. Such increase could be linked with a reaction to the speculative accumulation of stocks in the Fanya Metal Exchange or to intra-company material transfer from 5N Plus subsidiary in Belgium.

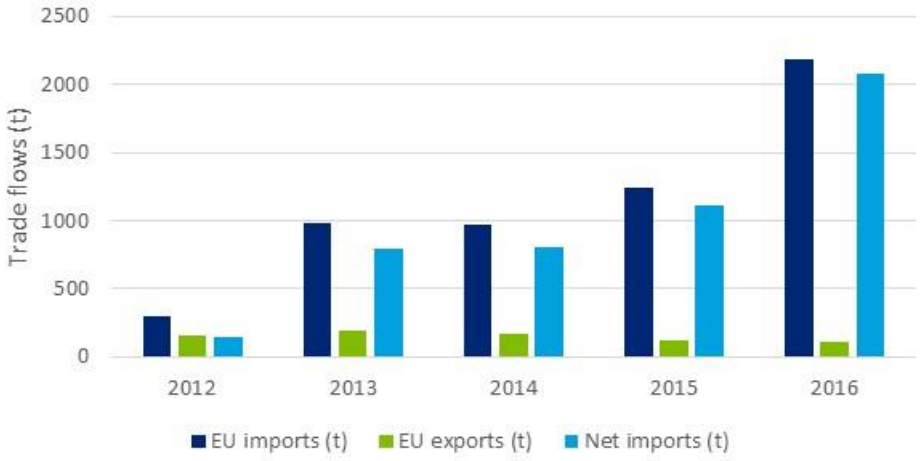

Figure 63: EU trade flows for refined Bismuth (Eurostat, 2019b)

EU import reliance on refined bismuth is almost 50% (average of 2012-2016) due to the predominant share of China in the EU supply for this period, which represents 93% of the total EU imports.

At the moment, there are no exports, quotas or prohibition in place between the EU and its suppliers (OECD 2019).

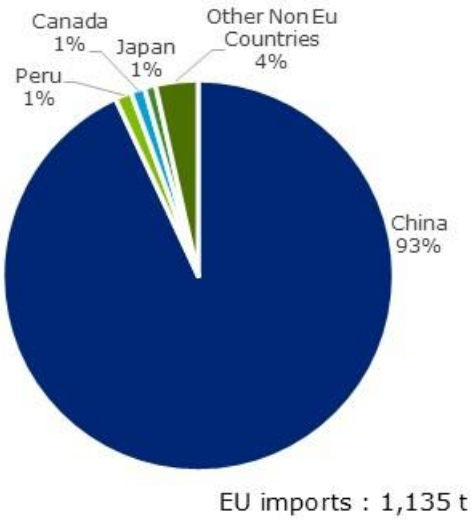

Figure 64: EU imports (average 2012-2016) of refined Bismuth (Eurostat 2019b)

5.2.3 Prices and price volatility

Bismuth 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).

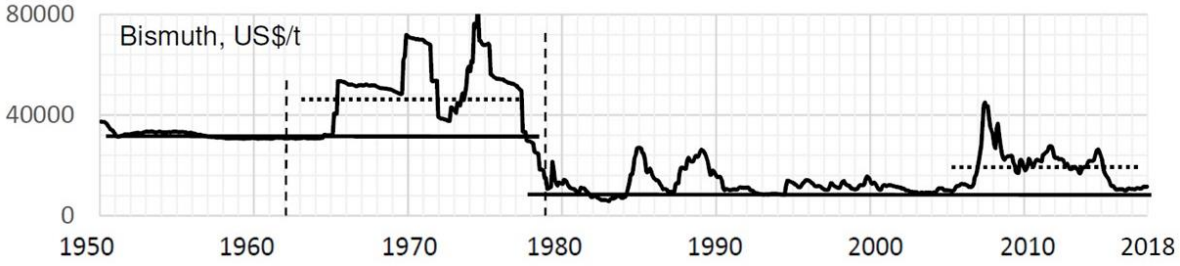

Figure 65: Bismuth long term prices. USD/t. (Buchholz et al. 2019)

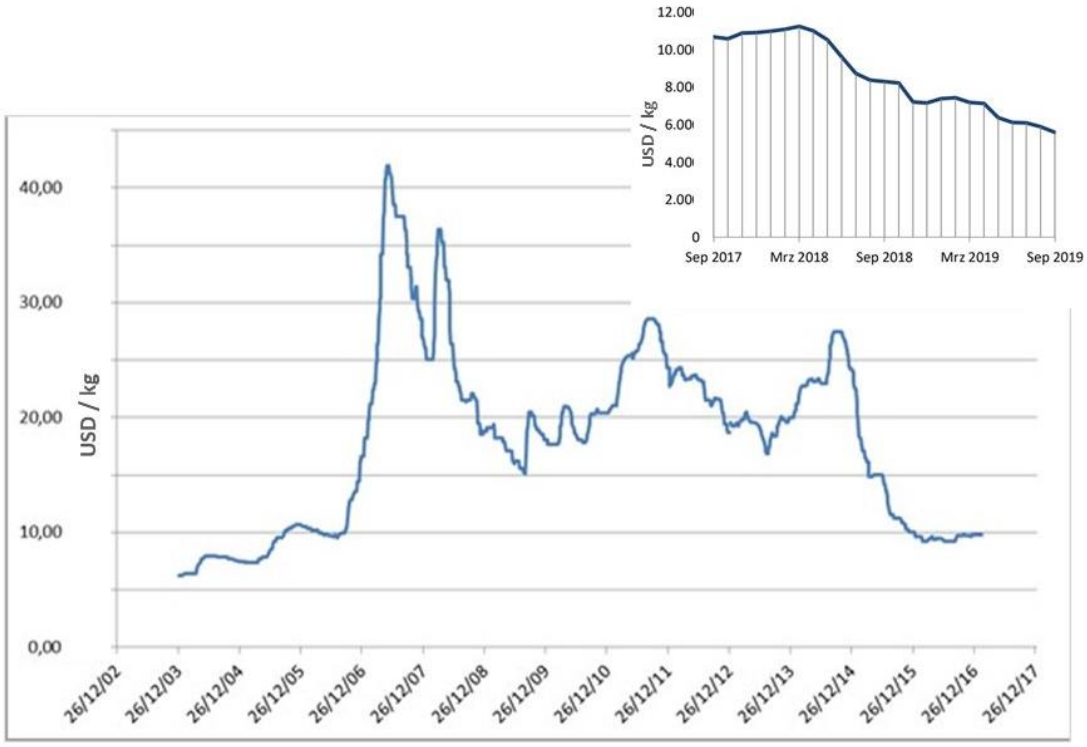

Figure 66: Bismuth prices (99.99% Bi) in USD/kg (DERA, 2016)

Over the past decade, the bismuth price has highly fluctuated. Prices rose dramatically in 2007 following a state-directed effort to concentrate bismuth production in China. This led to the closure of numerous smelters in the country, which accounts for 80 to 90% of global refined bismuth production. The global financial crisis brought bismuth back to prices close to 15 USD/kg in 2009. Between 2010 and 2014, speculative investment in bismuth metal by the Fanya Metal Exchange - which claimed to have bought over 18,000 t of bismuth in about a two year period - brought prices back up, until investigations into activities at the Exchange resulted in an abrupt end to these purchases and prices falling dramatically to around 10 USD/kg by 2015 and 2016 (Wilburn et al., 2016).

The trade dispute between the two largest global economies has directly resulted in the introduction of import tariffs in both China and the US, making it more expensive to trade and causing oversupply because of slower downstream consumption. The US introduced a 10% import tariff on Chinese bismuth products in September 2018 and increased it to 25% in May 2019. The import duties forced suppliers to cut their offer prices during the first half of 2019 to stimulate export demand. The bismuth price in Europe has fallen close to the cost of production; suppliers are now operating at very low margins. The price of bismuth 99.99% Bi min., in-whs Rotterdam was assessed at 5.60-6.40 USD/kg in October 2019 (Fastmarkets 2019).

5.3 EU demand

5.3.1 EU demand and consumption

The European apparent consumption in the period 2012- 2016 (5 year average figure) is estimated at 1,985 t per year, of which 1,000 t per annum is the domestic production, in Belgium, 1,135 t per annum is the imports to the EU from extra EU countries and 150 t per annum is the exports from the EU in the same period

5.3.2 Uses and end-uses of Bismuth

Figure 67 presents the main uses of bismuth (average 2012-2016).

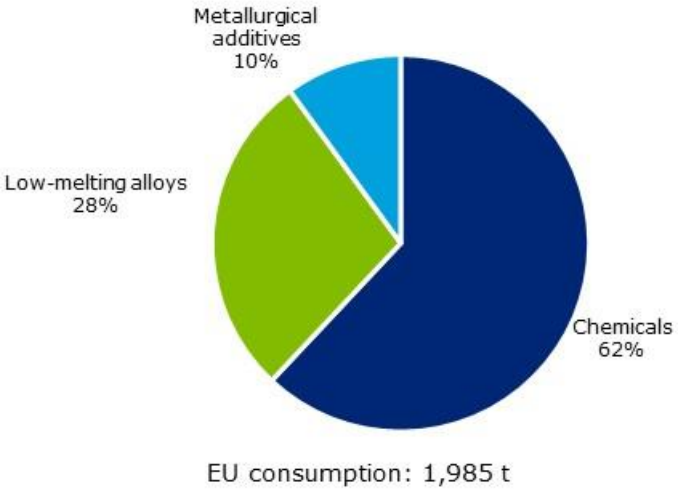

Figure 67: End uses of bismuth. Data from (Blazy 2013) (SCRREEN workshops 2019) (2012-2016 average figures)

Bismuth is considered as an "eco-friendly" material. As a result, its first sector of application is in the pharmaceutical and animal-feed industries (62% of total uses for bismuth chemicals – see Figure 67). In modern medicine, compounds of bismuth are mainly applied clinically for gastrointestinal disorders as anti-ulcer agents. Examples are De-Nol and Pepto-Bismol used to treat and prevent gastric and duodenal ulcers. The use of bismuth (III) is also seen in nuclear medicine, anticancer, antitumor and antimicrobial studies (Yang 2007).

Fusible alloys represent the second most important use (28%). Bismuth is notably used as a replacement for more harmful metals (on top of which is lead) in solders. Other uses include metallurgical additives and a number of other industrial applications such as coatings, pigments, and electronics (Ecclestone 2014).

With an increasing focus on reducing the consumption of lead globally, bismuth alloys have found roles as efficient substitutes. Its low melting point has increased its use in electronics and its low toxicity makes it ideal for use in food processing equipment and copper water pipes. The medical industry has also found it to be a highly effective in X-ray shielding (Masan Resources 2019).

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

Table 27: Bismuth applications, 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat 2019a)

Applications	2-digit NACE sectors	Value added of NACE 2 sectors (M€)	4-digit NACE sectors
Chemicals	C20 - Manufacture of chemicals and chemical products	105,514	C2029 - Manufacture of other chemical products n.e.c.
Fusible alloys	C32 – Other manufacturing	39,160	C3290 - Other manufacturing n.e.c.
Metallurgical alloys	C24 - Manufacture of basic metals	55,426	C2431 – Casting of iron

5.3.3 Substitution

Substitutes exist for bismuth in many applications as in some of them it is primarily used for its non-toxicity as a replacement for already existing materials (metals).

In pharmaceutical applications, it can be replaced by alumina, calcium carbonate, and magnesia. In pigment uses, by titanium dioxide-coated mica flakes or fish-scale extracts, and in devices such as fire sprinklers, by glycerine-filled glass bulbs. Resins can replace bismuth alloys for holding metal shapes during machining. Free-machining alloys can contain lead, selenium, or tellurium as a replacement for bismuth (USGS 2019).

5.4 Supply

5.4.1 EU supply chain

As a by-product, bismuth supply chain is firstly dependent on primary production of lead and tungsten. At the world level, the bismuth supply chain is in large part relying on Chinese supply of primary refined materials (purity of 99.8% Bi) still containing a lot of impurities. Those materials are massively exported to Europe, North America and South-East Asia for further refining.

Chinese control of the first steps of the bismuth market is an important aspect of this metal's criticality. China became one of the only producers of bismuth by reducing costs of production and increasing capacities in the early 2000s. In 2007, China announced the consolidation of the sector by the merging of six Hunan bismuth producers accounting for 30% of China's refined bismuth metal production in a single consortium (Hunan Bismuth Industry Co). This was done in response to the merging of the two largest players in Europe (MCP Aramayo Ltd in the UK and Sidech SA in Belgium to create MCP group, then acquired in 2011 by Canada's 5N Plus).Also, China announced the reduction of production due to environmental and mine safety issues, together with export restrictions. It succeeded in its objective to tighten supply to the rest of the world and become by far the leading producer in the following years.

In the EU, several companies are active in high added-value bismuth applications, for instance:

- 5N Plus, which controls around 50% of the bismuth market and specialty products (refined bismuth, bismuth chemicals, and low melting point alloys) and which subsidiary in Belgium is among the largest world importers of Bi (5N Plus, 2015).
- BASF, which is one of Europe's largest producers of bismuth vanadate ($BiVO_4$), a key pigment for use in coatings and paints.

No trade restrictions were identified for bismuth (OECD 2019). The only stocks that are known to exist on bismuth were at the Fanya Stock Exchange.

5.4.2 Supply from primary materials

5.4.2.1 Geology, mining and processing of bismuth

Geological occurrence: Bismuth mineralization can occur in various geological settings. Main occurrences are notably in tungsten, copper, gold and lead skarn deposits, as a by-product in tin pegmatites, and in magmatic-hydrothermal mineralization related to granites (Pohl 2011). As a by-product, extraction methods depend on the type and mineralogy of the ore. Bismuth has been mined as a main product only in the Cerro Tasna mine (Bolivia) and also in China (Shizhuyuan). In China, artisanal mining for bismuth also exists, with manual separation of bismuth-rich mineralization contributing significantly to global production of concentrates (Blazy 2013).

The two main sources for the recovery of bismuth metal are known to be lead and tungsten extraction and processing, with 50 to 60% coming from lead processing according to industry experts. Minor recovery of bismuth can also come from metallurgy of tin and copper, for instance in Japan, although in most cases it is seen as a penalizing impurity in those treatments(Blazy, 2013; Krenev, 2015; SCRREEN workshops 2019).

Recovery as a by-product of lead extraction

During the production of high purity lead from primary sources, two cases can be distinguished (Blazy 2013):

- If the bismuth content of lead bullion is higher than 4%, the electrolytic route is preferred (Betts process). Bismuth is recovered from the impure mixture of metals left in the residual anode slimes. The slime is heated, and bismuth is finally recovered after a reduction step using carbon. Concentration reaches 70-75% bismuth;
- If the bismuth content is 0.05-3.5%, the thermal route is preferred (Kroll-Betterton process). It is based on the precipitation of bismuth using calcium and magnesium which are added to molten lead. Concentration reaches 15-40% bismuth.

Recovery as a by-product of tungsten extraction

Not much is known concerning Chinese operations to recover bismuth from tungsten. An important part comes from artisanal mining and uses standard gravity concentration equipment including jigs and shaking tables. At the industrial scale, one example is the Xihuashan plant, where the ore is composed of scheelite, wolframite, cassiterite, bismuthinite, molybdenite, copper sulphides and REE-bearing minerals. A commercial concentrate of bismuthinite is obtained through various flotation processes and sold for further transformation (Blazy 2013). In Vietnam, first commercial production of bismuth concentrates occurred in September 2014 at the Nui Phao mine. These concentrates are also obtained through bismuth flotation, followed by leaching and cementation (Masan Resources, 2015).

Global resources and reserves[34]*:* For reserves, the only reference at the global level is from USGS (USGS 2017). However, these estimations have been unchanged for many years (except for Vietnam) and are likely to be incomplete since they are based on bismuth content of lead ores only, forgetting bismuth content in copper and tungsten ores.

Table 28: Global reserves of bismuth (Data fromUSGS, 2017)

Country	Reserves (t of contained Bi)
China	240 000
Vietnam	53 000

[34] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of bismuth 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.[34], 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.

Mexico	10 000
Bolivia	10 000
Canada	5 000
Other countries	50 000
Total	*368 000*

EU resources and reserves[35]*:*

During the Minerals4EU (2019) project, resources of bismuth were reported only in Bulgaria in the category "No statistical data available but resources known or believed to exist". Exploration projects were mentioned in Portugal and Slovakia with no further information.

5.4.2.2 World and EU mine production

Regarding mine production, China is the main producer in the world, although figures vary according to different sources (BGS, 2018; USGS, 2016; WMD 2019), partly due to the difficulty of assessing the part of artisanal production. Another important producer is Vietnam, where commercial production of bismuth concentrates started in September 2014 at the Nui Phao mine. Objectives of the company are to produce 2,000 t per year and to become the second most important producer in the world (Masan Resources 2019).

The distortion of the bismuth market due to speculative investment in the Fanya Minor Metal Exchange in China impacted the bismuth production. Fanya began trading bismuth in March 2013 and accumulated huge stocks of the metal in a 2-year period. In November 2014, bismuth stocks were reported to reach 16,900 t for about 2 years of world production equivalent (Wilburn et al., 2016). The consequences were a dramatic fall of prices and a stronger constraint on current producers.

In Europe, BGS Mineral Statistics mention mine production in Bulgaria of 3 t in 2013. Bismuth is produced in Bulgaria as a Lead-Bismuth alloy (7% Bi content) by the Bulgarian smelter KCM 2000 Group (KCM 200 Group 2019). EU Production of a Lead-Bismuth alloy (6-12% Bi content) is also sited in Germany and produced by Aurubis (Aurubis 2019) (CRM experts 2019).

The world annual production of mined bismuth in average between 2012 and 2016 is around 10,332 t of bismuth content, mainly in China (WMD 2019).

[35] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for bismuth. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for bismuth, 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 bismuth the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019).Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However, a very solid estimation can be done by experts.

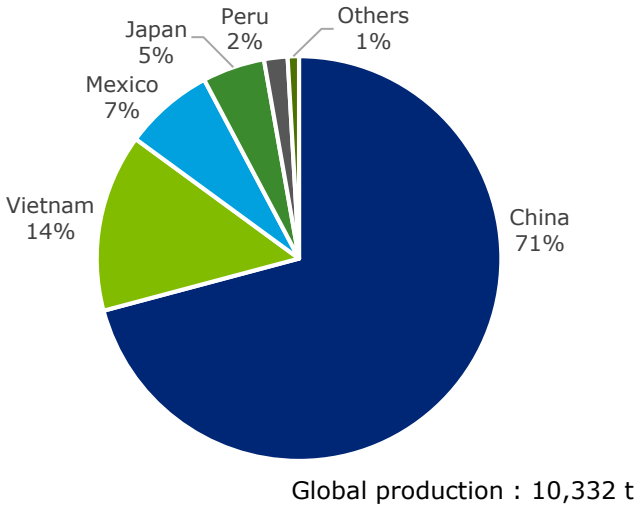

Figure 68: Global mining production of bismuth (average 2012-2016) (WMD 2019)

5.4.2.3 Refining of Bismuth

"Refined bismuth" refers to the bismuth metal of a purity of at least 99.8%, in opposition to "Bi mine production" referring to bismuth sulphide concentrates quantities. However, confusions are often made between these two categories when considering global bismuth production (BGS, 2018; WMD 2019; USGS, 2016). Furthermore, as for many other minor metals, obtaining production figures for bismuth is quite difficult because of the opaque nature of the market and its size.

The criticality assessment was performed at the refining stage because of the import reliance of the EU on refined bismuth products. There are only a few producers in the world at this stage. The main one is in China, responsible for 80% of total world production (19,183 t), the main company being Hunan Jinwang Bismuth Industrial Co Ltd (www.en.jin-wang.com.cn) with capacities of 8,000 t.

In the EU, the company 5N Plus is a huge player on the bismuth market and specialty products (refined bismuth, bismuth chemicals, and low melting point alloys) and has a subsidiary in Belgium. DERA (2015) reports 1,000 t of bismuth metal produced in Belgium over 2012-2014. Belgium bismuth metal production is supplied from various EU producers manily, i.e. Umicore in Belgium, Aurubis Cu plant in Germany, Boliden in Sweden and for some years from the Nui Phao mine in Vietnam (BGR 2019).

Refining is needed to obtain bismuth metal of a purity of at least 99.8%. Most of the time, the thermal route is preferred. During this process, caustic soda and potassium nitrate are added to the molten bismuth to remove impurities (As, Sb, Se, Te, Sn). An addition of zinc metal can be necessary when impurities include copper, silver and gold (Blazy 2013). Final treatment with soda ash can bring purity to 99.99% Bi (technical grade).

Others processes exist depending on the nature of the impurities and the required quality of final products. Electrolytic refining is preferred to obtain higher purity, up to 99.999% (pharmaceutical grade). Bismuth can be commercialised in the form of high purity ingots, pieces, pellets, or even as powdered oxide.

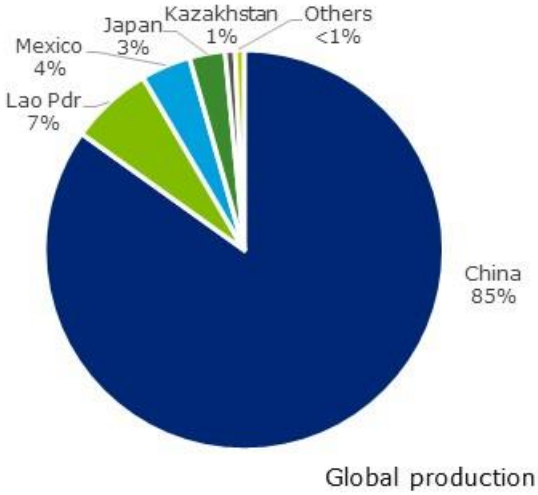

Figure 69: Global production capacity of refined bismuth. (USGS 2016), average 2012-2016

5.4.3 Supply from secondary materials/recycling

Bismuth is not recycled (MSA, 2019-2020) (SCRREEN workshops 2019). Bismuth is difficult to recycle because it is mainly used in many dissipative applications, such as pigments and pharmaceuticals (Umicore 2019).

Table 29: Material flows relevant to the EOL-RIR of Bismuth

MSA Flow	Value (t)
B.1.1 Production of primary material as main product in EU sent to processing in EU	0.00
B.1.2 Production of primary material as by product in EU sent to processing in EU	800.00
C.1.3 Imports to EU of primary material	3000.00
C.1.4 Imports to EU of secondary material	0.00
D.1.3 Imports to EU of processed material	1134526.00
E.1.6 Products at end of life in EU collected for treatment	0.00
F.1.1 Exports from EU of manufactured products at end-of-life	0.00
F.1.2 Imports to EU of manufactured products at end-of-life	0.00
G.1.1 Production of secondary material from post consumer functional recycling in EU sent to processing in EU	0.00
G.1.2 Production of secondary material from post consumer functional recycling in EU sent to manufacture in EU	0.00

5.5 Other considerations

5.5.1 Environmental and health and safety issues

Several bismuth-containing substances are registered with REACH. However, none of them is on the list of substances of very high concern. Even though the REACH dossier indicates that data is lacking on the physical, health and environmental hazards of bismuth, this element is generally acknowledged for its non-toxicity in many of its uses.

EU OSH requirements exist to protect workers' health and safety, employers need to identify which hazardous substances they use at the workplace, carry out a risk

assessment and introduce appropriate, proportionate and effective risk management measures to eliminate or control exposure, to consult with the workers who should receive training and, as appropriate, health surveillance[36].

5.5.2 Socio-economic issues

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

5.6 Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. Supply risk has been analysed at processing stage.

The results of this and earlier assessments are shown in Table 30.

Table 30: Economic importance and supply risk results for Bismuth in the assessments of 2011, 2014, 2017, 2020 (European Commission 2011a),(European Commission 2014), (European Commission 2017)

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Bismuth	Not assessed		Not assessed		3.6	3.8	4.01	2.22

Since 2017, the value-added criticality assessment corresponds to a 2-digit NACE sector rather than a 'megasector', which was used in the previous assessments.

5.7 Data sources

The choice of data source for production data of processed bismuth was a combination of USGS (2016) and DERA (2015) as these sources cover refined bismuth. Production data from World Mining Data may contain a mix of pure "mine producers" and "refiners". For instance, it reports figures from Japan and Vietnam, but in the first country there is no mining of bismuth and in the second, there is no refining (only bismuth concentrates are sold). Trade data were extracted from the Eurostat Easy Comext database for the Combined Nomenclature CN8 code 81011000: 'unwrought bismuth; bismuth powders; bismuth waste and scrap (excl. ash and residues containing bismuth)' (Eurostat 2019b). Data on trade agreements are taken from the DG Trade webpages, which include information on trade agreements between the EU and other countries (European Commission 2019). Information on export restrictions are derived from the OECD Export restrictions on the Industrial Raw Materials database (OECD 2019).

5.7.1 Data sources used in the factsheet

5N Plus (2015) Annual report - Specialty metals + chemicals. Available at: https://www.5nplus.com/files/15/5NPlus-AR2015-EN_2016-06-15-16-57.pdf.

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[36] https://ec.europa.eu/social/main.jsp?catId=148

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5.8 Acknowledgments

This factsheet was prepared by the JRC. The authors would like to thank the EC Ad Hoc Working Group on Critical Raw Materials and the experts participating in SCRREEN workshops for their valuable contribution and feedback.