20 PHOSPHATE ROCK AND ELEMENTAL PHOSPHORUS

20.1 Overview

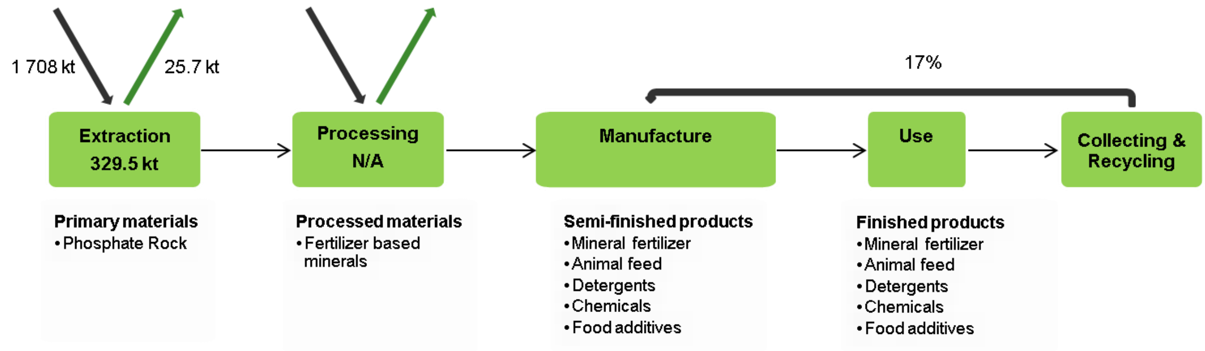

Figure 303: Simplified value chain for phosphate rock, data in tonnes of P_2O_5 for the EU, averaged over 2012-2016.

Phosphate rock is the main anthropogenic source of phosphorus (chemical symbol P) and is in effect an "indicator" of phosphorus in different forms (mineral, organic) used in agriculture and industry (fertiliser chemicals or phosphoric acid, but also organic fertilisers, manures, crop products used as animal feed). Phosphorus is one of the six main building blocks of life (together with oxygen, hydrogen, potassium, nitrogen and carbon) and is vital for all life on planet earth, including plants, animals and humans, and so for the bio based economic processes that take place in the global economy. Phosphate rock refers to rocks containing different phosphate minerals, in particular calcium phosphate as apatite which can be commercially exploited.

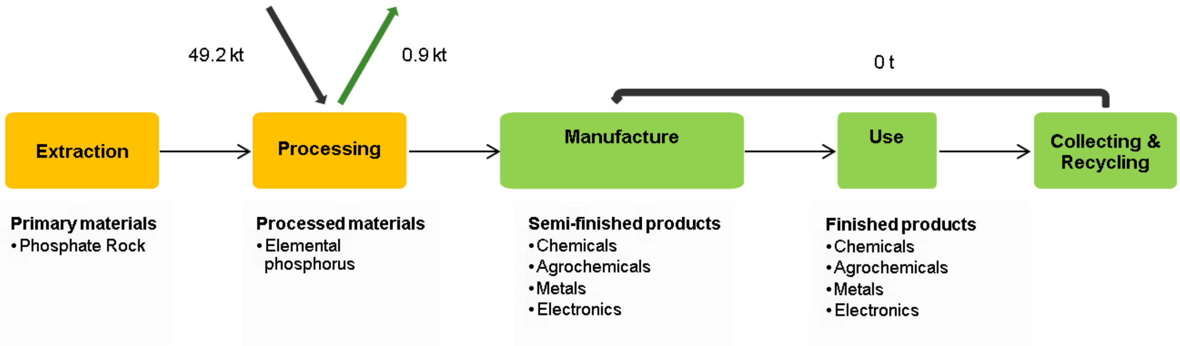

Figure 304: Simplified value chain for elemental phosphorus, data in tonnes of P_4 for the EU, average 2012-2016

Elemental phosphorus here refers to the specific forms of the element phosphorus (P) in which it is produced as an isolated element (P_4) in dedicated electrothermal reducing furnaces (in different forms: white/yellow or red phosphorus). Such isolated elemental phosphorus is generally transformed and transported in the form of chemical vectors such as phosphorus trichloride (PCl_3, the main precursor for organic phosphorus chemistry) or sulphides, oxides or very pure (electronics grade) phosphoric acid. Elemental phosphorus thus represents only a small part of the total use of "phosphate rock", most of which is processed to less pure phosphoric acid for production of fertilisers or other inorganic phosphate chemicals.

The orange boxes of the production and processing stages in Figure 304 suggest that activities are not undertaken within the EU for extraction and processing stages. Even if phosphate rock is extracted within the EU the extracted amount is not used to produce elemental phosphorus (e.g. white phosphorus). It is assumed that there is no functional recycling of elemental phosphorus.

Trade flows can be estimated using the following CN8 codes: 25101000 (natural calcium phosphates and natural aluminium calcium phosphates, natural and phosphatic chalk, unground) and 25102000 (natural calcium phosphates and natural aluminium calcium phosphates, natural and phosphatic chalk, ground). For elemental phosphorus the considered code was CN 28047000 (phosphorus).

In the period between 2012 and 2016, the global market for phosphate rock was on average 76,719 kt of P_2O_5 per year. Although most phosphate rock resources are located in Morocco, China is the dominant producer. For secondary raw materials there are various sources of phosphorous, such as animal manures, sewage and food waste. For this assessment an EOL-RIR (End-of-Life Recycling Input Rate) of 17% was assumed, it is however recognised that further research is needed to estimate the actual amount of phosphorus that is being replaced by these organic wastes and by manure (ESPP, 2019).

Regarding elemental phosphorus the main producer was China with 87% of the world production in 2016 (IHS, 2017). However, in China the majority of the production is used internally. Additionally, Chinese production has decreased significantly over the las years since 2012 (ESPP, 2019). Kazakhstan is the second biggest producer and the major world supplier. Elemental phosphorus is only produced outside the EU in electrothermal reducing furnaces. The exact world production was not known but should be around 1,200 kt of P_4 per year (averaged over 2012-2016) (IHS, 2017).

The average price of phosphate rock ore (70%) from Morocco between 2014 and 2018 was US$ 103.76 per tonne (DERA, 2019). In 2019 over 6 months the prices of elemental phosphorus ranged between US$ 2.1 per kilogram and US$ 3.7per kilogram (180 and 450 EUR/kg) (ECHEMI, 2019).

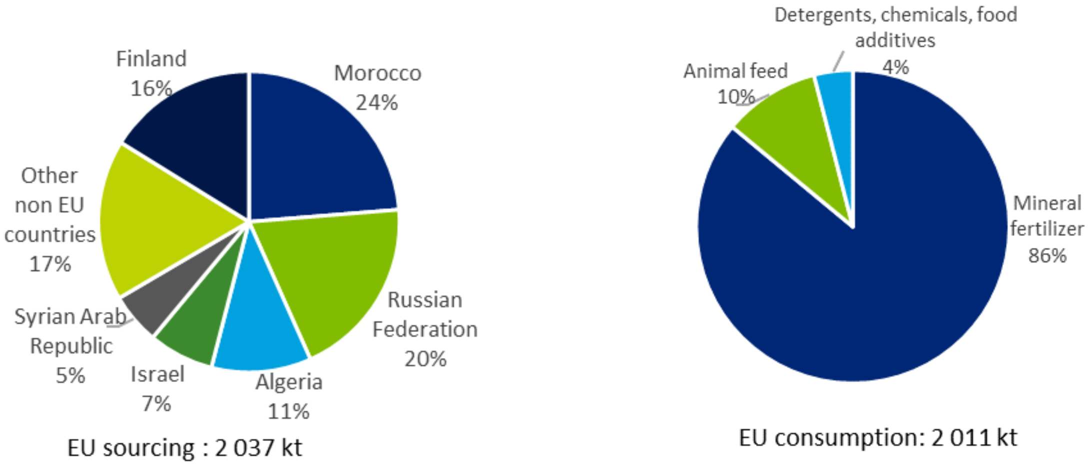

Figure 305: EU sourcing and end uses of Phosphate Rock, data in tonnes of P_2O_5 (Eurostat, 2019), (ESPP. 2019).

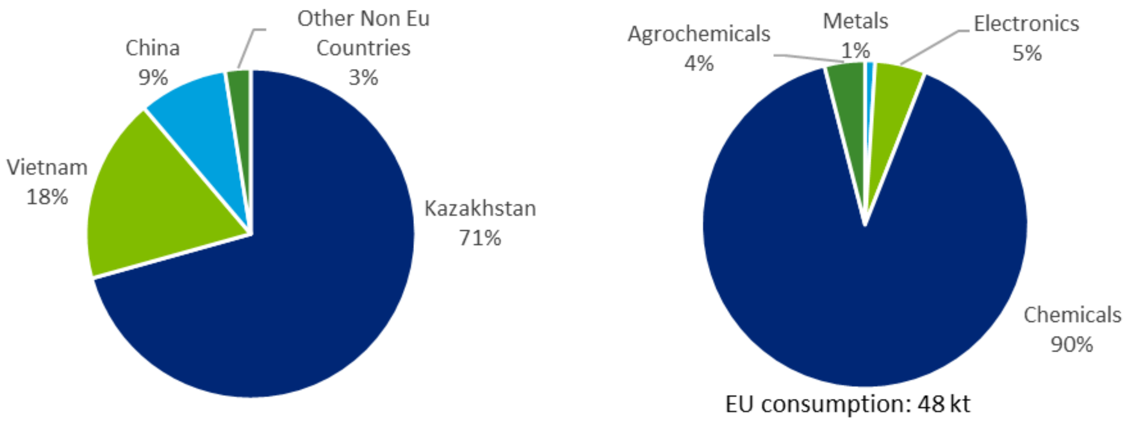

Figure 306: EU sourcing and end uses of Elemental Phosphorus, data in tonnes of P_4 (Eurostat, 2019), (ESPP. 2019).

The EU demand of phosphate rock is on average 2 011 kt of P_2O_5 per year between 2012 and 2016. EU's import reliance of phosphate rock was around 84% (average 2012-2016), given the input from Finland. Main exporting countries to the EU are Morocco and Russian Federation.

The EU annual consumption of elemental phosphorus was 48.3 kt of P_4 on average between 2012-2016 period. EU's is completely dependent on imports with 71% of EU supply coming from Kazakhstan (Eurostat, 2019).

Phosphorus is a vital part of plant and animal nourishment. Phosphate rock is globally utilised for the fertilisation of food crops. Pure elemental phosphorus, obtained from phosphate rock, is used for the production of chemicals (e.g. flame retardants, oil additives, industrial water treatment, emulsifying agents).

The resources are relatively abundant globally 68,705,000 kt and known reserves are documented and sedimentary phosphate deposits occur on every continent but known reserves are highly concentrated in a few countries, mainly Morocco.

For reserves, Minerals4EU (2019)only reports phosphate rock reserves in Ukraine, with 115,800 kt of apatite ore, and 4,550 kt of P_2O_5 contained in the apatite ores according to Russian Classification (RUS)A.

For the 2012-2016 period, export taxes were put in place by China, Morocco and Vietnam for the relevant product groups containing natural calcium phosphates. Egypt had introduced an exports prohibition. There is also an export quota imposed by China of 1,000 kt of natural calcium phosphates.

The export taxes are imposed by Kazakhstan and China.

20.2 Market analysis, trade and prices

20.2.1 Global market analysis and outlook

The estimations in the Table 136 regarding future demand and supply trends are based on (International Fertilizer Association, 2019), (FAO, 2019), and (European Commission, 2017b).

Globally the production of food at current yields is dependent on mined phosphate rock for the production of fertilisers. Therefore, the future market of phosphate rock is in a great extend controlled by changes in supply and demand of fertilisers used in agriculture and strongly connected with the global population growth. According with the International Fertiliser Association (IFA) (International Fertilizer Association, 2019) and Food and Agriculture Organization (FAO, 2019), global demand of fertilisers is expected to increase on average by 1.1% per annum (between 2018 to 2023), with a 1.2% per annum demand increase for phosphorus (in fertilisers). The highest rate of growth in demand is anticipated in Africa (especially Sub-Saharan Africa), followed by Eastern Europe and Central Asia (region), South Asia and Latin America and North America. Demand will remain stable in East Asia and Western and Central Europe and would increase only modestly in Oceania and West Asia.

Estimates reveal that population growth will foster the increase in demand of phosphate rock. However, in developed countries and in an increasing number of emerging economies several secondary sources of phosphorus are already being considered (e.g. animal manure, wastewater and food waste) to reduce the dependence on phosphate rock for fertiliser production. According with SCRREEN estimates, by 2035 the reliance of the agriculture sector on mineral fertilisers (and in turn on phosphate rock) will be very low. In particular if the phosphorus accumulation in soils is taken into account for agriculture (Monnet and Ait Abderrahim, 2018).

On the supply side the production of phosphate rock is expected to increase during the studied periods. More precisely, the IFA projects an increase from 235Mt in 2018 to 255 Mt in 2023 of the global phosphate rock supply (an increase of 8%). Africa would account for 75% of the net increase during this period. Supply and demand are expected to grow modestly in the near term.

Phosphorus is one of the most abundant elements in the planetary crust, although concerns exist regarding supply shortage. Studies predict that phosphate rock reserves will be depleted sometime in the next 100 years (Tercero et al., 2018). In addition, it should be noted that the "20 years" scale is approximately the delay time between planning new phosphate rock mining capacity. Its production coming onto the market, given delays in authorization, funding, machinery investment, transport and processing infrastructure (ESPP, 2019). Most of the phosphate reserves are not developed yet for production. According to SCRREEN, taking into account the current production and demand growth an inelastic supply gap at market may occur in the decade of 2020 to 2030 (Tercero et al., 2018). The use of secondary sources of phosphate may attenuate this situation allowing to extend reserves viable life by 50 years, this taking into account a reference of 2018 (Monnet and Ait Abderrahim, 2018).

The main producing country of Phosphate rock is China (however it is not an important global supplier). Morocco has 71% of the world's reserves.

Regarding elemental phosphorus, the demand has declined during the past 10 to 20 years. Which resulted in a significant capacity decrease in both Europe and North America. In contrast, the production capacity in China has increased rapidly and is now the top producing country with 87% of the annual capacity in 2016. Like China, also Vietnam has increase production capacity in the last 10 years. However, this expansion have slowed down in the last years (IHS, 2017).

Table 136: Qualitative forecast of supply and demand of Phosphate rock and Phosphorus

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
Phosphate rock	x		+	+	+	+	+	+
White Phosphorus	x		0	0	-	+	+	0

20.2.2EU trade

Overall, the EU is a net importer of phosphate rock, importing over 1,708 kt of P_2O_5 net per year (average between 2012 to 2016) in the form of natural calcium phosphates and natural aluminium calcium phosphates, natural and phosphatic chalk, unground and ground (Figure 307). Average between 2012 and 2016 exports are lower thank 25 kt (Eurostat Comext, 2019)

Morocco was between 2012 and 2016 the largest exporter of phosphate rock into the EU, covering around 28% of all imports. Other major importers include Algeria, Russia and Israel (Figure 307), with shares between 8% and 23%. EU exports are mainly towards Norway; however, these amounts are negligible compared to imports.

The following CN codes were used for this analysis: 25101000 "natural calcium phosphates and natural aluminium calcium phosphates, natural and phosphatic chalk, unground" and 25102000 "natural calcium phosphates and natural aluminium calcium phosphates, natural and phosphatic chalk, ground" . A content of 30% of P_2O_5 was assumed based on estimates calculated from comparison of (WMD, 2019, BGS, 2019, USGS, 2017).

On average between 2012 and 2016 the EU imports were 49.2 kt of P_4 per year. Kazakhstan was the biggest exporter of elemental phosphorus into the EU, covering around 71% of all imports. Other major importers are China and Vietnam (Figure 309). The code CN 28047000 "phosphorus" was used for this analysis. The exports of P_4 are alsmost not existent between 2013 and 2016, the low amounts exported <1t are probably due to re-exports, since no production is observed in the EU.

For the 2012-2016 period, export taxes are put in place by China, Morocco and Vietnam for the relevant product groups containing natural calcium phosphates. Egypt had introduced an exports prohibition. There is also an export quota imposed by China of 1,000 kt of natural calcium phosphates (OECD, 2019), (European Commission, 2019).

The export taxes are imposed by Kazakhstan and China restrictions for phosphorus.

There are free trade agreements with Marocco, Algeria and Israel.

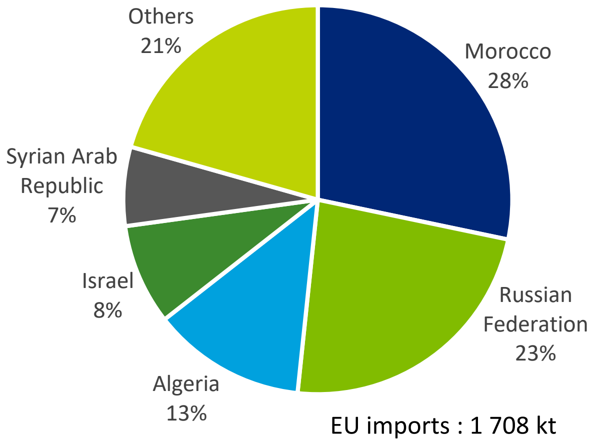

Figure 307: EU imports of phosphate rock (in P_2O_5 content), 2012-2016 average (Eurostat, 2019b).

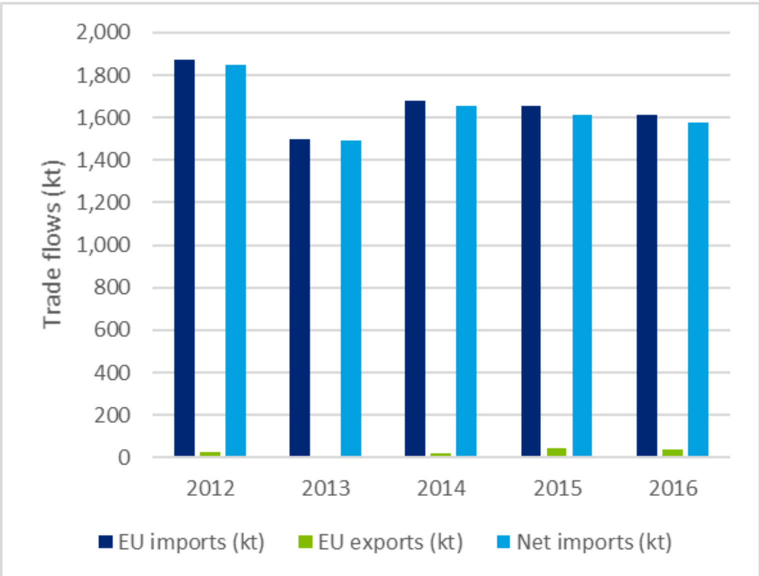

Figure 308: EU trade flows for phosphate rock (in P_2O_5 content), data from (Eurostat, 2019b).

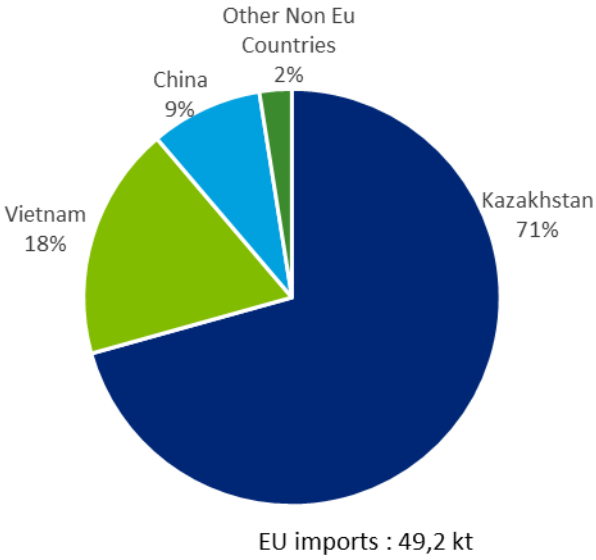

Figure 309: EU imports of elemental phosphorus in P_4, average 2012-2016 (Eurostat, 2019b).

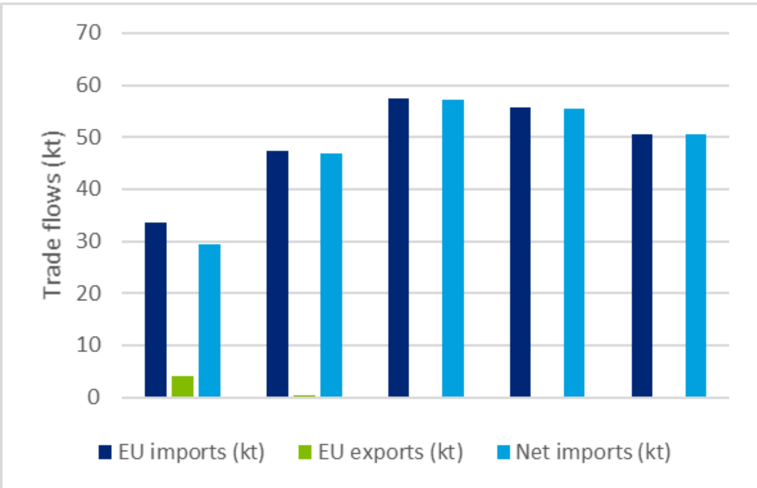

Figure 310: EU trade flows for elemental phosphorus, in P_4, data from (Eurostat, 2019b).

20.2.3Prices and price volatility

The development of prices for phosphate rock is shown in Figure 311. The price spike around 2008 originated from an imbalance between supply and constantly expanding demand over decades, especially in Asia. This imbalance has several causes, such as: 1) lack of investment in mining and the very long delay time between planning new mining capacity and its effective production start; 2) implementation of export tariffs by some countries; 3) political unrest fuelling concerns about supply security (Arab Spring); 4) increased demand for fertilizers to produce biofuels in the United States, Brazil, and Europe; 5) Increased livestock production created still more demand for grain and thus for fertilizers (IFDC, 2010). Demand was particularly strong in China and India, countries with large and growing populations. The price spike also affected other commodities such as potassium. Overall, phosphate rock and fertiliser prices are both tied to global food prices. The global economic crises caused the prices to fall relatively fast, but prices remain more volatile ever since.

The annual average price of Phosphate rock ore from North Africa (Morocco) between 2014 and 2018 was US$ 103.75 per tonne (which is a proximally 93.78 EUR/t). The annual average price from October 2018 to September 2019 was US$ 93.91 per tonne (84.52 EUR/t), which shows a decrease of 9.5% in comparison with the previous 4 years average (DERA and BGR, 2019).

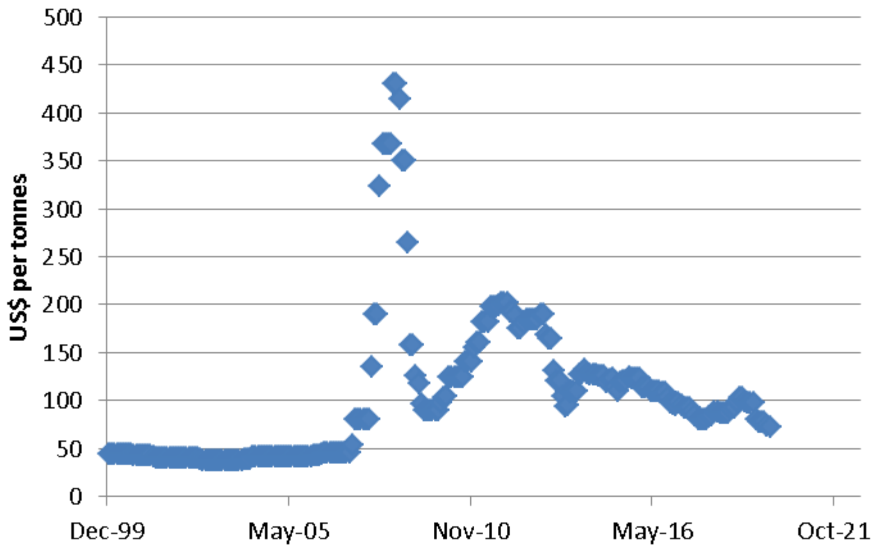

Figure 311 Global developments in price of phosphate rock (Morocco), 70% BPL (Indexmundi, 2019):

In 2019 over 6 months the prices of elemental phosphorous ranged between 2.1 and US$ 3.7 per kilogram (180 and 450 EUR/kg) (ECHEMI, 2019). The average value of exports of elemental phosphorous from the United States between 2015 and 2016 was around US$ 3.4 per kilogram (Jasinski, 2016).

20.3 EU demand

20.3.1 EU demand and consumption

The EU annual apparent consumption of phosphate rock was 2,011 kt of P_2O_5 on average over the 2012-2016 period. The EU consumption of elemental phosphorus is 48.3 kt of P_4.

20.3.2 Uses and end-uses of phosphate rock and phosphorus in the EU

Phosphorus is a vital part of plant and animal nourishment. Globally 91% of phosphate rock is utilised for production of fertilisers, while in the EU this share is 85%. Other applications include animal feed, detergents, food additives and other chemicals, see Figure 312.

For fertilisers phosphate is generally used with the other two main nutrients (natrium, potassium) and often with other nutrients (sulfur, magnesium, calcium, copper etc.).

Approximately, 10% of phosphate rock used in the EU is in the production of nutritional supplements for animal feed mainly in form of mono- and dicalcium phosphate (Tercero et al., 2018). There is no substitute for use of phosphorus in food chains.

A smaller fraction around 4% of phosphate rock is used in the production of detergents and other chemicals. There are different detergents and their composition depends on their application purpose; laundry and dishwasher detergents contain phosphate mainly in the form of sodium tripolyphosphate (STPP). In 2018, its use in detergents has experienced a strong reduction due to concerns related with rising levels of phosphorus in surface waters which causes eutrophication (Tercero et al., 2018).

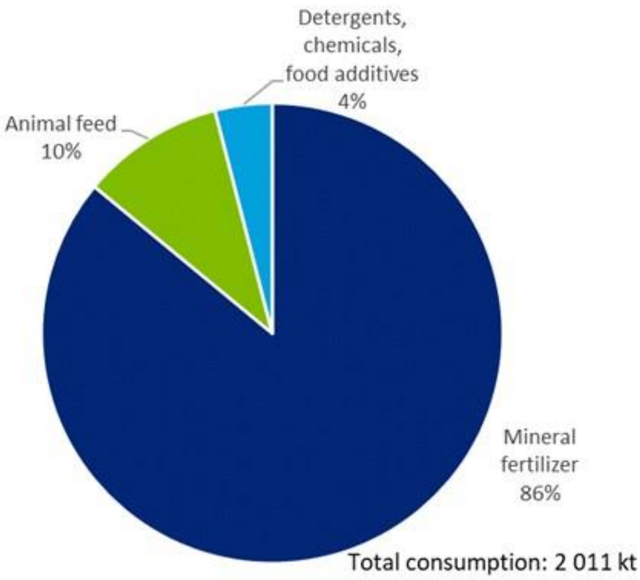

Figure 312: EU end uses of phosphate rock (in P_2O_5 content). Average figures for 2012-2016 (ESPP, 2019).

Elemental phosphorus, obtained from phosphate rock, is used for the production of chemicals (e.g. flame retardants, oil additives, industrial water treatment, emulsifying agents). Around 5% of world phosphate rock production is used in applications other than agriculture (other than fertilisers and animal food). The "industrial" applications include: lubricant additives, pharmaceuticals (both in the pharmaceutical molecule, and as intermediates in drug synthesis), agrochemicals, anti-scaling agents, detergents, flame retardants, oil additives, industrial water treatment, emulsifying agents, matches and pyrotechnics, nickel plating, asphalt and plastic additives, catalysts, luminescent materials, metal extraction (most of the world's cobalt is produced using a phosphorus intermediate) (ECI, 2019).

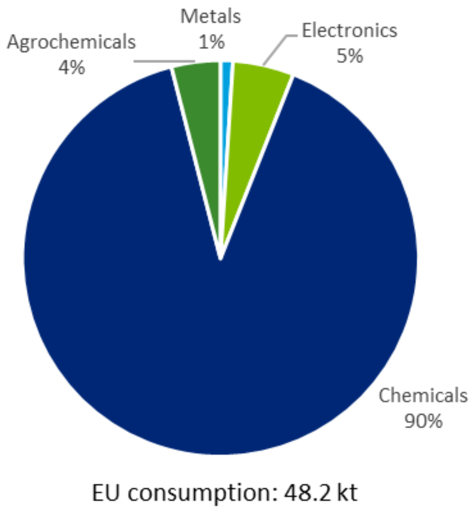

Figure 313: EU end uses of elemental phosphorus, in P_4. Average figures for 2012-2016 (ECI, 2019), (ESPP, 2019).

The calculation of economic importance is based on the use of the NACE 2-digit codes and the value added at factor cost for the identified sectors (Table 137).

Table 137: Phosphate rock or white phosphorus applications, 2-digit NACE sectors, associated 4-digit NACE sectors and value added per sector (Data from the (Eurostat, 2019a)

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (millions €)
Animal feed	C10 - Manufacture of food products	All subsectors (meat, starch, dairy etc.)	155 880
Fertilisers, chemicals and detergents	C20 - Manufacture of chemicals and chemical products	20.15 Manufacture of fertilisers and nitrogen compounds	105 514
Metals	C25 - Manufacture of fabricated metal products, except machinery and equipment	25.61 Treatment and coating of metals	148 351
Electronic parts	C26 - Manufacture of computer, electronic and optical products	26.11 Manufacture of electronic components	65 703

20.3.3Substitution

There are no substitutes for phosphate rock for the production of fertilisers. (ESPP, 2019) The existing opportunities for other sources of phosphorus are represented by the applied end-of-life recycling rate of 17% (see section on secondary materials) of rather than a reduction of supply risk from substitution.

Substitution of elemental phosphorous P_4 and thus also of phosphate rock in other chemical applications is also set to 0% because many of these are specific phosphorus chemicals where no substitute is available to date (ESPP, 2019) (example: fire safety, where phosphorus-based flame retardants are developing to replace halogenated substances).

20.4 Supply

20.4.1 EU supply chain

The EU is an exporter of high value products and food products, between 6% and 7% of the value of total external EU exports per year (Eurostat, 2019c). All agro-food related activities cannot take place without a supply of phosphorous into the agricultural system.

Europe's import reliance of phosphate rock or phosphoric acid was between 2012 to 2016 around 84%. The recurring comment is that these figures do not capture use, stock accumulation and extraction potential of phosphorous in the downstream lifecycle stages of these materials. Therefore, care is needed when interpreting the dependency of the EU on external supply of phosphorus to cover EU necessities. The EU sourcing (domestic production + imports) for phosphate rock is presented in Figure 314. An annual average 329.6 kt of P_2O_5 were produced in the EU between 2012 and 2016. The only currently operating mine extracting Phosphate rock in the EU is in Finland, in Siilinjärvi, explored by the company Yara International. The concentrate produced in the mine is used for phosphoric acid and fertilizer production in the adjacent plant. The resource estimate (JORC) for the Siilinjärvi deposit is 1,617 Mt of ore with P_2O_5 content of 3.694% (FODD 2017).

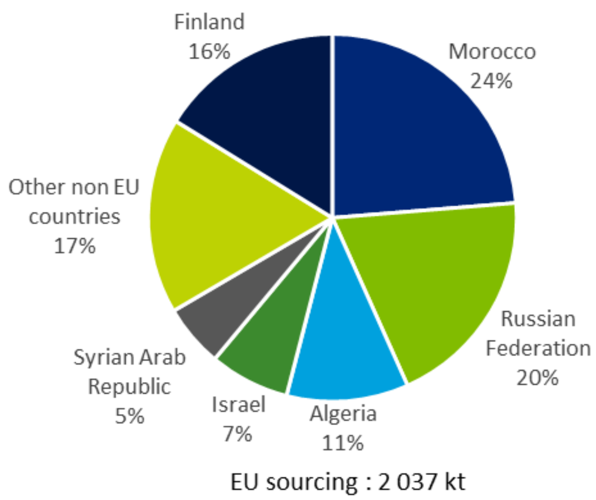

Figure 314: EU sourcing (domestic production + imports) of phosphate rock (in P_2O_5 content), average 2012-2016 (Eurostat, 2019b).

Figure 315 show the phosphate material flows in the EU economy from the phosphate rock 2015 MSA study conducted by Bio by Deloitte (BIO Intelligence Service, 2015).

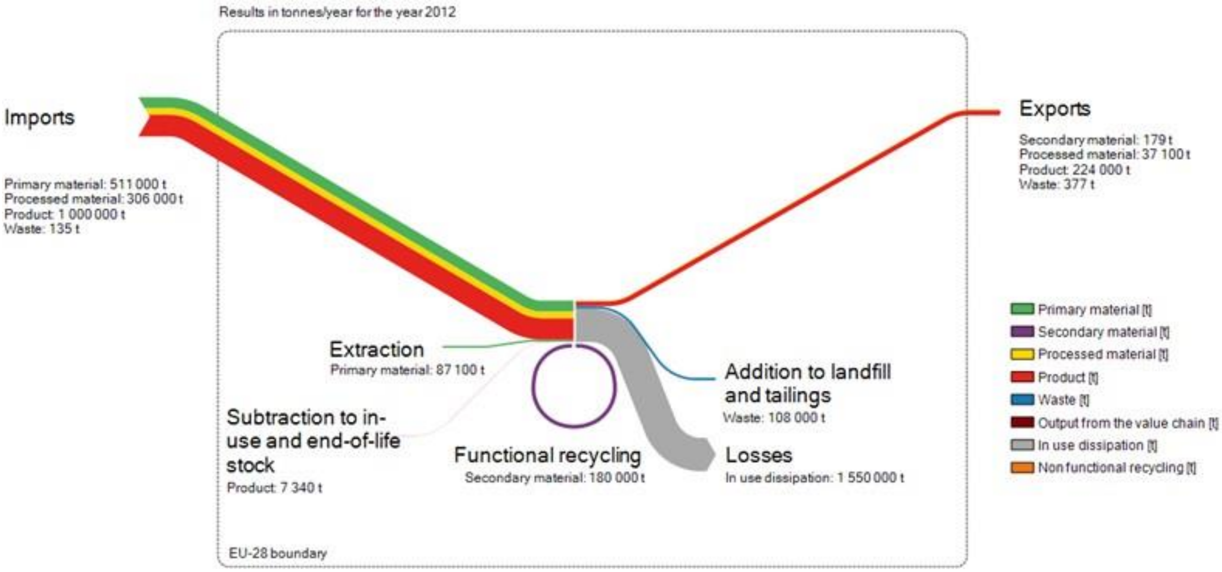

Figure 315: Sankey diagram showing the material flows of phosphate in the EU economy in 2012 (BIO Intelligence Service, 2015).

Regarding white phosphorus the EU is 100% dependent from imports.

20.4.2Supply from primary materials

20.4.2.1 Geological occurrence/exploration

The abundance in the earth's crust of phosphorus pentoxide (P_2O_5) is about 0.13% of the total crust, which indicates a relatively high presence of P (Rudnick & Gao, 2013). Sedimentary marine phosphorites are the principal deposits for phosphate rock. Depending on the mineralogical, textural and chemical characteristics (e.g. ore grade, impurities), as well as the local availability of water around the mining site, different refining processes are applied to obtain phosphate rock concentrates. Although these resources are found worldwide, known reserves are highly concentrated (over 70% in Morocco). It is estimated that world resources of phosphate rock total 300,000 million tonnes; known world reserves are shown in Table 138. The biggest deposits are located in northern Africa, China, the Middle East, and the US. Large deposits of phosphates are also located on the continental shelf and on seamounts in the Atlantic and Pacific Oceans, but exploiting these deep-sea sources is still not considered an economically viable option. Besides the sedimentary phosphate deposits, some igneous rocks are also rich in phosphate minerals. However, sedimentary deposits are more abundant and usually higher in grade (P content, but also higher in contaminants). About 80% of the global production of phosphate rock is exploited from sedimentary phosphate deposits ((McKelvey, 2016); (Kauwenbergh, 2010)).

Exploration activities and mine expansions took place in Australia and Africa in 2011. There are two major projects in Africa: the expansion of a phosphate mine in Morocco and a new project off the Namibian coast. Smaller projects are under various stages of development in several African countries, such as Angola, Congo (Brazzaville), Guinea-Bissau, Ethiopia, Mali, Mauritania, Mozambique, Uganda, and Zambia. Expansion of production capacity was planned in Egypt, Senegal, South Africa, Tunisia, and Togo. Other development projects for new mines or expansions are on-going in Brazil, China, and Kazakhstan (Jasinski, 2016). In the EU there is a mining operating in Finland (De Ridder et al., 2012).

Apart from known geological reserves, organic sources of phosphorites are possible. Guano, bone meal or other organic sources are of less economic importance as phosphate rock sources, because of supply issues, processing costs, or simply because quantities available are much smaller.

20.4.2.2 Resources and reserves

The resources are relatively abundant globally and known reserves are documented and sedimentary phosphate deposits occur on every continent (McKelvey, 1967) but known reserves are highly concentrated in a few countries, mainly Morocco, see Table 138.

Resource data for some countries in the EU are available at Minerals4EU (2019), see Table 139, but cannot be summed as they are partial and they do not use the same reporting code. For reserves, Minerals4EU (2019) only reports phosphate rock reserves in Ukraine, with 115,800 kt of apatite ore, and 4,550 kt of P_2O_5 contained in the apatite ores according to Russian Classification (RUS)A.

Table 138: Global known reserves of phosphate rock in year 2015 (Data from (Jasinski, 2016))

Country	Estimated phosphate rock known reserves (kt)	Percentage of total (%)
Morocco	50,000,000	73
China	3,700,000	5
Algeria	2,200,000	3
Syria	1,800,000	3
South Africa	1,500,000	2
Jordan	1,300,000	2
Russia	1,300,000	2
Egypt	1,200,000	2
United States	1,100,000	2
Australia	1,000,000	1
Saudi Arabia	960,000	1
Peru	820,000	1
Iraq	430,000	1
Brazil	320,000	0
Others (including Finland)	1,075,000	2
World total (rounded)	*68,705,000*	*100*

Table 139: Resource data for the EU compiled in the European Minerals Yearbook at Minerals4EU (2019)

Country	Reporting code	Quantity	Unit	Grade	Code Resource Type
Spain	Adapted version of the USGS Circular 831 of 1980	30.8	Mt	11.78%	Proven reserves
UK	None	100.7	Mt	2.19%	Historic Resource Estimates
Finland	JORC	540	Mt	4%	Total
Norway	JORC	14.6	Mt	5.18%	Indicated
Ukraine	Russian Classification	131,930	kt	-	(RUS)P1
Estonia	Nat. rep. code	2,935.74	kt	-	Measured+Indicated
Greece	USGS	500	kt	10-25%	Measured
Serbia	JORC	72	Mt	9%	Total

20.4.2.3 World mine production

The global annual production of phosphate rock between 2012 and 2016 was 76,719 kt of P_2O_5, on average (WMD 2019). The production of phosphate rock is concentrated in a limited number of countries. Although most phosphate rock resources are located in Morocco, China is the dominant producer, however with limited exports. The largest phosphate rock mining countries are shown in Figure 316, with 48% of the global production in China, 11% in Morocco and 10% in the US leading the producing countries, manufacturing respectively, averaged over 2012 to 2016. Finland produced 329 kt of P_2O_5 per year on average between 2012 and 2016. This can be expected to change in the future because of the concentration of known reserves in Morocco and the progressive depletion of exploitable reserves in the US.

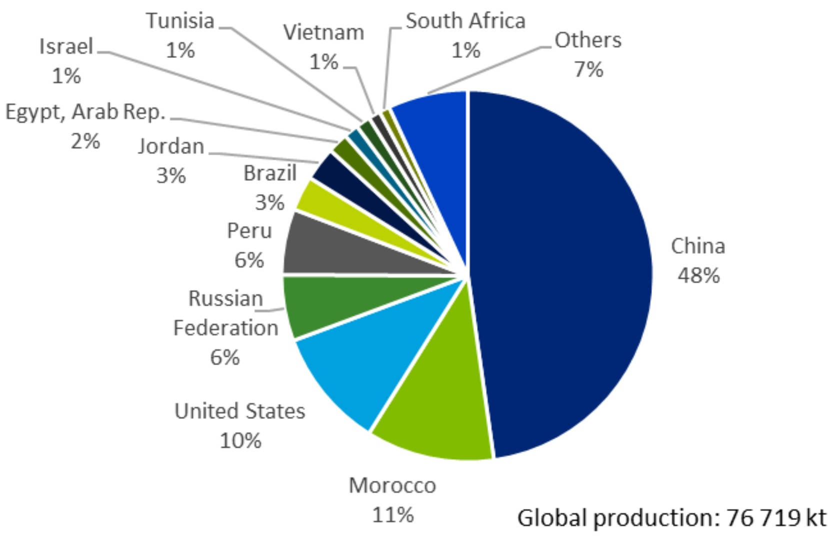

Figure 316: Global mine production of phosphate rock, averaged over 2012-2016 ((WMD, 2019)).

SCRREEN project listed the most relevant industrial actors beneficiating phosphate rock, see Table 140.

Table 140: Some of the largest industrial actors beneficiating phosphate ores (Yang et al., 2018).

Company	Mine site (location)
Vale	Bayóvar (Sechura, Peru)
	Catalão (Goiás, Brazil)
OCP	Benguérir (Morocco)
	Youssoufia (Morocco)
	Khouribga (Morocco)
	Boucraâ (Western Sahara)
Mosaic Co.	Four Corners (Florida, US)
	South Ford Meade (Florida, US)
	South Pasture (Florida, US)
	Wingate Creek (Florida, US)
	Hopewell (Florida, US)
China Molybdenum Co.	Ltd Chapadão (Goiàs, Brazil)
Sinochem Yunlong Co., Ltd.	Aurora (North Carolina, US)
Nutrien (merger of Agrium and Potash Corp.)	Dry Valley (Idaho, US)
	Swift Creek (Florida, US)
P4 Production, LLC.	Blackfoot Bridge (Idaho, US)
Foskor	Phalaborwa (South Africa)
Yara	Siilinjärvi (Finland)
Apatit	Kola (Russia)
EuroChem	Kovdorskiy GOK (Russia)

The precise global production of elemental phosphorus is not known, it was estimated to be close to 1,200 kt per year (between 2012, 2013 and 2016). The distribution of global production of elemental phosphorus is shown in Figure 317. The main producer in the world is China and its production capacity had increased at an accelerated pace between 2002-2012 (with 9% increase every year), but is now slowing down due governmental measures to protect phosphate resources. Even then, in 2016 China achieved 87% of the worlds production (IHS, 2017). Production in the United States was limited to one plant (8% per year, averaged over 2012-2016). The only other operating elemental phosphorus facilities in the world were in Kazakhstan and Vietnam (McKelvey, 2016).

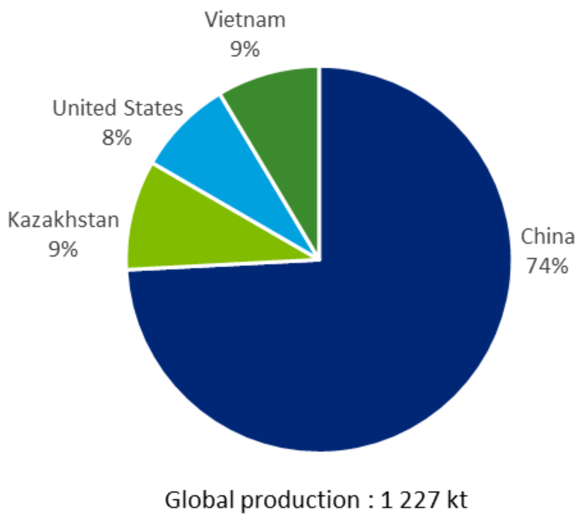

Figure 317: Global elemental phosphorus production, average of 2012, 2013 and 2016 (IHS, 2017).

Elemental phosphorus is produced only outside the EU. SCRREEN project listed the most relevant elemental phosphorus manufactures, see Table 141.

Table 141: Some of the largest elemental phosphorus manufactures .

Company	Plant location
Yunphos (Taixing) Chemical Co., Ltd.	China
Changzhou Qishuyan Fine Chemical Co. Ltd	China
5-Continent Phosphorus Co. Ltd.	China
Taj Pharmaceuticals Ltd.	India
UPL Europe Ltd.	India
Viet Hong Chemical and Trading Co. Ltd	Vietnam
Kazphosphate LLC	Kazakhstan

20.4.3Supply from secondary materials/recycling

For its applications in agriculture, phosphate rock can be replaced by secondary sources of phosphorous such as manure, sewage and food waste (biogenic waste flows).

The EoL-RIR (End-of-Life Recycling Input Rate) should translate the % by which recycling of biogenic waste flows substitutes the use of mineral phosphate fertilisers (i.e. primary input material). An EoL-RIR of 17% was assumed for the criticality assessment based on the raw material system analysis performed in 2015 (BIO Intelligence Service, 2015). Various flows of phosphorus can replace the input from primary phosphate rock. The total size of this flow was estimated by to be around 180 kt of phosphorus in in 2012 (BIO Intelligence Service, 2015) (listed as "G.1.2, the production of secondary material from post-consumer functional recycling in EU sent to manufacture in EU").

Other recycling rates indicators are also reported in the literature. Van Dijk et al. (2016) estimated recycling rates of 70% in crop production, 24% in animal production, 52% in food production and around 76% in non-food applications of phosphorous, in 2015.

There is evidence that increased flows of secondary phosphorous could potentially be extracted and recycled from current production and consumption flows ((Sutton, RISE foundation, 2016); (van Dijk et al., 2016); (Leip et al., 2015). Estimates of potential sources of secondary phosphorous are provided by the DONUTSS project (2019). Fresh pig manure contains 0.4% of P_2O_5, whereas dry pig manure has 5% and after incineration the ash contains 18.8%. For chicken litter, these numbers are 1.9%, 3.9% and 15.3% respectively. Kitchen waste generally contains 18.8% of P_2O_5. Garden waste, another source from households, is much lower given a high cellulose and water content. Additionaly, according with the literature the total amount of phosphorus in livestock manure potentially available for recycling in the EU28 from animal production is around 1,749 Mt phosphorus per year (van Dijk et al., 2016) to 1,977 Mt of phosphorus per year (Hermann, 2011).

However, today there is no useable data on the rate of effective reuse of phosphorus for manures and other organic forms, which replaces the use of fertiliser or other phosphate rock derived chemicals. Therefore, there is the need to generate appropriate data and define indicators for this recycling rate, in coherence with indicators for other policies (Circular Economy/Fertilising Products Regulation, Water Framework Directive, CAP, DG Research project impacts) (ESPP, 2019).

Processes exist to potentially produce elemental phosphorus P_4 from phosphorus-rich waste streams (e.g. ICL Recophos process to produce P_4 from sewage sludge incineration ash or meat and bone meal ash) but these are today only at the pilot scale and no industrial installation is yet under construction, nor operational, neither in the EU nor elsewhere (ESPP, 2019).

Several european countries have created legislation to ensure phosphate recovery, examples of such countries include Germany, Finland and Switzerland and the same is being considered.

Table 142: Material flows relevant to the EOL-RIR of phosphate rock data from 2012, tonnes of P (BIO Intelligence Service, 2015)

MSA Flow	Value (t)
B.1.1 Production of primary material as main product in EU sent to processing in EU	70 200
B.1.2 Production of primary material as by product in EU sent to processing in EU	0
C.1.3 Imports to EU of primary material	511 000
C.1.4 Imports to EU of secondary material	0
D.1.3 Imports to EU of processed material	306 000
E.1.6 Products at end of life in EU collected for treatment	271 000
F.1.1 Exports from EU of manufactured products at end-of-life	377
F.1.2 Imports to EU of manufactured products at end-of-life	135
G.1.1 Production of secondary material from post consumer functional recycling in EU sent to processing in EU	0
G.1.2 Production of secondary material from post consumer functional recycling in EU sent to manufacture in EU	180 000

20.4.4 Processing of phosphate rock

The most phosphate rock production worldwide is extracted using opencast dragline or open-pit shovel/excavator mining methods, e.g. in the United States, Morocco, Russia and China. During surface mining, overburden is drilled, blasted, and removed by dragline to the side of the mining area for subsequent reclamation. Very large draglines, electric shovels, and bulldozers recover the upper ore body. The intercalating limestone layer is then blasted and removed to expose the phosphate bed, which is loaded onto special large volume trucks (MEC, 2016).

Further processing of phosphate rock is needed to produce elemental phosphorus. Elemental phosphorus may be made by several methods. In one process tri-calcium phosphate, the essential ingredient of phosphate rock, is heated in the presence of carbon and silica in an electric furnace or fuel fired furnace, elementary phosphorus is liberated as vapour and may be collected under phosphoric acid, an important compound in making super-phosphate fertilisers (ECI, 2019). Worldwide, a gradual shift to manufacturing high-purity phosphoric acid from wet process acid has taken place because it has lower production costs and none of the hazardous waste disposal issues that are associated with elemental phosphorus (Jasinski, 2016). Production by thermal acid still accounts for more than 50% of annual world production capacity of high-purity phosphoric acid, primarily in China. Further processing of elemental phosphorus will result in compounds such as phosphorus trichloride, acids, sulphides, sodium hypophosphite, phosphine, phosphides.

20.5 Other considerations

20.5.1 Environmental and health and safety issues

The volumes of phosphorous that end up in soil and ground water considerably affect the biochemical processes in a negative way. Especially, aquatic ecosystems are affected due to the process of eutrophication, resulting in oxygen depletion. This has in turn an effect on biodiversity, since aquatic animal populations are affected by invasive new species that benefit from deferent resource balances (e.g. algae) (Sutton et al., 2013).

For example, in several EU member states, phosphorus discharge into the environment is the principal factor (other than morphological modification) causing freshwater bodies to fail to achieve EU Water Framework Directive quality objectives (Leaf, 2015).

Elemental phosphorus is the probably most dangerous form of phosphorus that is known to us. White phosphorus is highly reactive (it was used in phosphorus bombs of the Second World War) and poisonous and significant exposure can be fatal (Lenntech, 2016). For this reason, elemental phosphorus P_4 is usually reacted immediately on production to other "holding derivatives" (usually PCl_4), these derivatives can then be transported and used to produce the different phosphorus chemicals for which P_4 is a necessary raw material. The energy requirement of existing elemental phosphorus production techniques is high. Each tonne of phosphorus produced requires about 14 MWh (ECI, 2019), which is comparable with the average electricity requirement of a tonne of aluminium.

It is important to highlight that there is different composition of phosphate rock ores due to the nature of their sedimentary sources. Due to its use in fertilisers production there are concerns related with soil contamination with heavy metals coming from Phosphate ores sucha as cadmium. The Fertilising Products Regulation introduces limits for heavy metals, such as cadmium, in phosphate fertilisers to reduce potential health and environmental risks (Regulation (EU) 2019/1009).

20.6 Comparison with previous EU assessments

Phosphate rock was first assessed in the CRM assessment of 2014 (European Commission, 2014). The economic importance (EI) for phosphate rock has been always above 5 and the supply risk didn´t suffer substantial changes in the tree exercises (see Table 143).

Elemental phosphorus was assessed for the first time in 2017 with the EI and SR (supply risk) results presented in the following table. The differences showed in the supply risk are due to small decrease on the EU supply concentration (see Table 143).

Table 143: Economic importance and supply risk results for phosphate rock and elemental phosphorus in the assessments of 2011, 2014, 2017 and 2020 (European Commission, 2011)(European Commission, 2014)(European Commission, 2017a)

Assessment	2012			2014			2017			2020	
Indicator	EI	SR		EI	SR		EI	SR		EI	SR
Phosphate rock	Not assessed			5.8	1.1		5.1	1.0		5.64	1.09
White Phosphorus	Not assessed			Not assessed			4.4	4.1		5.30	3.62

20.7 Data sources

The CN codes used for the trade analysis are 25101000 and 25102000. These product groups describe ground and unground natural calcium phosphates, natural aluminium calcium phosphates and natural and phosphatic chalk. The CN code used for the trade analysis of elemental phosphorus is 28047000, and is labelled Phosphorous.

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

The data on the precise global production of elemental phosphorus is not fully available; it was possible to estimate an average figure taking into account the previous assessment form 2017 and two other sources (IHS, 2017). This value was confirmed in the CRM validation workshop, 12th September 2019.

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