Horizon 2020 Programme

SCRREEN2

This project has received funding from the European

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SCRREEN

Solutions for CRitical Raw materials - a European Expert Network

FACTSHEETS UPDATES WP3

CHROMIUM

AUTHOR(S):

TABLE DES MATIÈRES

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CHROMIUM

OVERVIEW

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

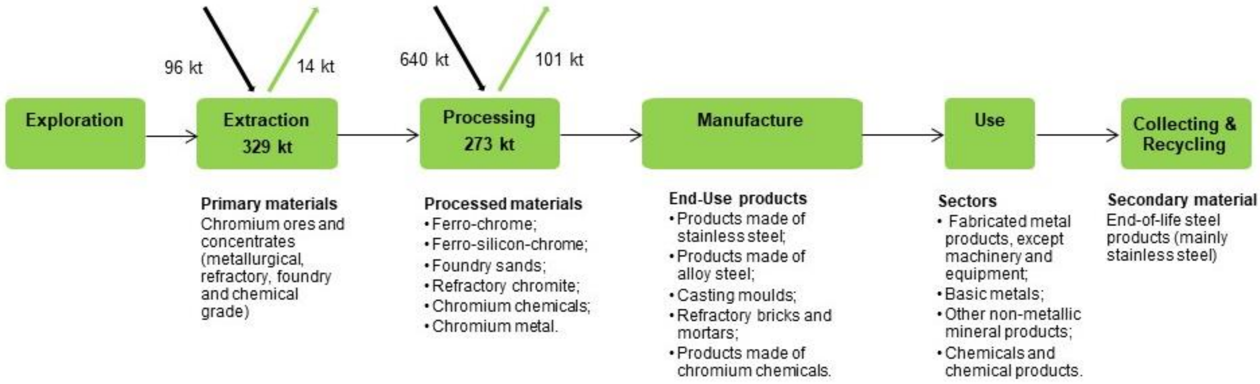

Figure 1. Simplified value chain for chromium in the EU[1]

Table 1: Chromium (extraction) supply and demand in metric tonnes, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
12 991 891	South Africa 56% Kazakhstan 16% India 12% Turkey 4% Finland 3% Zimbabwe 2%	471 288	3.6%	South Africa 48% Countries not specified 28% Turkey 19% India 2% Albania 2%	7%

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

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Table 2 Chromium (processing) supply and demand in metric tonnes, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
7 518 625	China 40% South Africa 24% Kazakhstan 14% India 9% Finland 3% Russia 3%	577 869	7.7%	South Africa 54% Countries not specified 11% Russia 8% Kazakhstan 6% Zimbabwe 5% Turkey 4%	42%

Prices: Chromium is traded in the form of chromium ores and concentrates, ferrochrome, chromium metal and chromium chemicals (Roskill, 2014) . Chromium ores and concentrates are priced in terms of gross weight and the price depends on specifications, i.e. metal content, impurities and ore type (e.g. lumpy, friable, concentrates). Trends in chromium ores and concentrates prices follow those of ferrochrome, which accounts for 96% of chromite consumption.

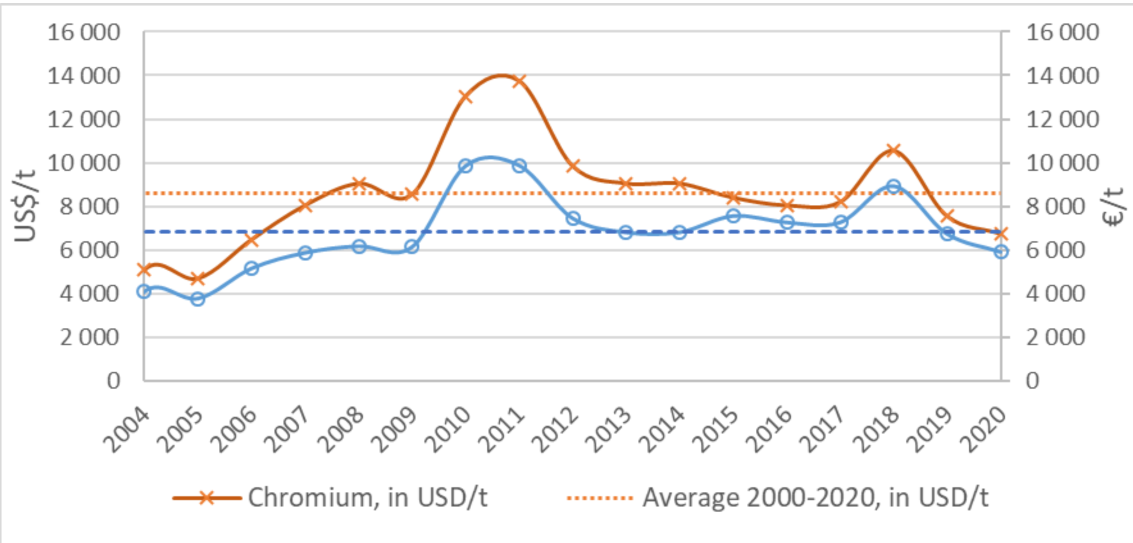

Figure 2. Annual average price of chromium between 2000 and 2020 (USGS, 2021)[2].

Primary supply: Chromium ore is generally mined as a primary product, except for South Africa, where increasing volumes of chromite concentrates are recovered from tailings from PGM operations (Roskill 2014). About 14% of the world production of chromite, corresponding to a quarter of South African production, is a by-product of PGM mining in the UG2 horizon in the Bushveld Igneous Complex (BRGM 2017). In EU, chromium concentrates are extracted only in Finland. The average annual production of chromium, expressed as Cr_2O_3 content during the period 2016-2020 was 474 kt. Ferrochromium is produced in Finland, Germany and Sweden (602 kt annually). About 1.013 kt of both chromium concentrates and ferrochromium were imported annually during 2016-2020 by South Africa, Turkey and Kazakhstan.

[2] Values in €/kg are converted from original data in US$/kg by using the annual average Euro foreign exchange reference rates from the European Central Bank (https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html)

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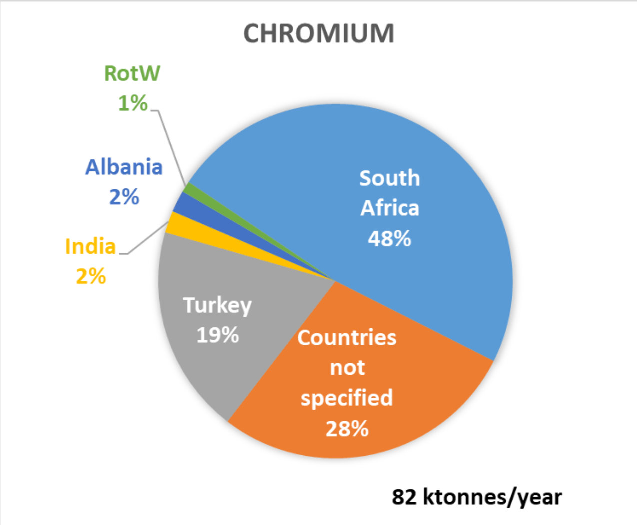
Secondary supply: There is no specific recycling scheme for pure chromium metal, as the vast majority of chromium is used in the form of alloys. However, stainless steel which accounts for approximatively 70% of chromium's consumption in the EU (BRGM 2017) is very well recycled. The post-consumer functional recycling of stainless steel reaches rates between 80% and 90%, depending on the product (UNEP 2011). In general, the scrap content in the production of stainless steel is estimated at 60%, of which 25% consists of old scrap and 35% of new scrap (BRGM 2017). Stainless steel is commonly recycled in separated flows as its properties will be lost if mixed with common steel scrap.



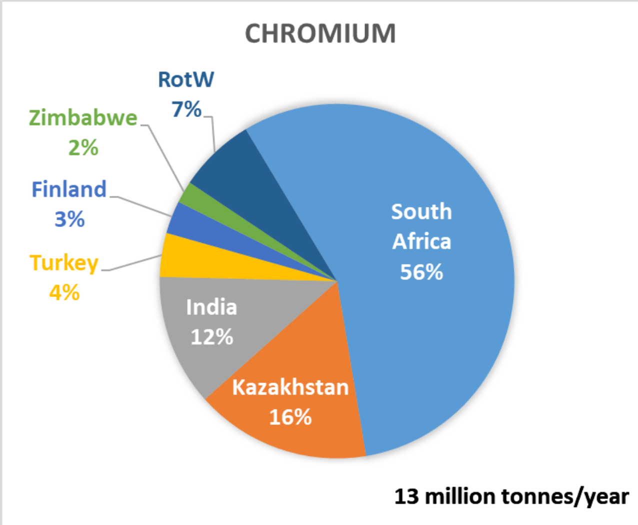


Figure 3. EU sourcing of chromium (extraction) and global mine production (2016-2020)

Uses: Chromium is mainly used in products made of stainless steel. It is also used alloy steel products. A small proportion is used in refractories and chemicals as well.

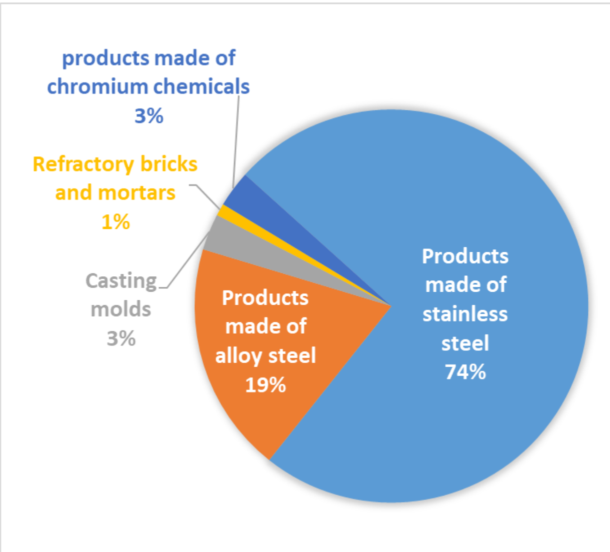


Figure 4: EU uses of chromium

Substitution: There are no substitutes for chromium its main end uses (USGS, 2022, SCRREEN experts, 2022).

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Table 3. Uses and possible substitutes

Use	Share*	Substitutes	Sub share	Cost	Performance
Products made of stainless steel	74%	No substitute			
Products made of alloy steel	19%	No substitute			
Casting moulds	3%	Not assessed below 10%			
Refractory bricks and mortars	1%	Not assessed below 10%			
Products made of chromium chemicals	3%	Not assessed below 10%			
Other uses (e.g., electroplating with Cr metal)	0%	Not assessed below 10%			
Products made of stainless steel	74%	No substitute			

** EU end uses of Chromium, 2012-2016 (SCRREEN CRM experts, 2022).*

Other issues: Chromium may be found in different oxidation states, with Cr^{II}, Cr^{III} and Cr^{VI} as most common compounds. While the first two compounds may be considered relatively harmless, in its sixth oxidation state, chromium becomes a hazardous compound. Exposure to Cr^{VI} through ingestion or inhalation may indeed result in various types of physiological damages: ulcerations (cuts and abrasions of skin, ulcerations of the nasal septum), dermatitis (skin irritation and sensitization), acute respiratory effects (irritation of mucous membranes), carcinogenic effects (e.g. lung cancer), and effects in other organs (e.g. necrosis of kidneys). In a life cycle perspective, the environmental impacts of chromium production on a per kilogram basis range among the lowest of the metals sector (out of 63 metals) considering the global warming potential, cumulative energy demand, terrestrial acidification and freshwater eutrophication impact categories. However, when considering the global annual chromium production volume (which is relatively significant compared to other metals), the impacts in terms of global warming potential appear among the highest of the metals sector (11th out of 63) (Nuss and Eckelman, 2014). The maximum discharge limit to the aquatic environment in the EU are 1 and 5 mg/l for CrVI and Cr(total), respectively. (Vaiopoulou et al. 2020)

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MARKET ANALYSIS, TRADE AND PRICES

GLOBAL MARKET

Table 4: Chromium (extraction) supply and demand in metric tonnes, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
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Table 5 Chromium (processing) supply and demand in metric tonnes, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
7 518 625	China 40% South Africa 24% Kazakhstan 14% India 9% Finland 3% Russia 3%	577 869	7.7%	South Africa 54% Countries not specified 11% Russia 8% Kazakhstan 6% Zimbabwe 5% Turkey 4%	42%

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

COVID-19 had a significant impact on chromium ore supply and demand due to increased market volatility and reduced demand and pressure on supply chains. According to USGS data (USGS, 2022) the EU consumption declined from 1,907 kt in 2018 to 1,290 kt in 2020, a 32% decline. At the same time the EU production of chromium lay slightly over the 2016-2020 average, with 514,130 metric tonnes in 2019 and 492,870 metric tonnes in 2020 according to the World Mining Data report (WMD, 2022). These data are far from the one reported by ICDA, which represent 12,992 kt in average on 2016-2020 for the extraction stage and 7519 kt at the processing stage. These data have been selected for the criticality assessment, but they are not available from 2000.

The world production of chromium ore is dominated by South Africa, which in 2017 accounted for nearly half of the world's chromium ore output (Reichl, Schatz, & Zsak, 2019) , two-thirds of which was exported (UN Comtrade, 2019) . South Africa is the top global exporter of chromium ore, while China is by far the major importer accounting for about 80% of the world's imports by value. After 2012, China overtook South Africa to become the world's largest ferrochrome producer at the processing stage. Three of the four leading

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chromite producers, i.e., South Africa, Kazakhstan and India, are also among the four largest ferrochrome producers.

The global chromium market size was estimated at USD 14.01 billion in 2019. Increasing demand from the stainless steel industry for various end-use markets such as automotive, aerospace, defence, marine, building and construction, and electronics is expected to be the key growth factor (Grand View Research, 2020). The global chromium market is partially consolidated in nature with a few major players dominating a significant portion of the market. Key players include Kermas Group Ltd, Assmang Proprietary Limited, CVK Group, Glencore PLC, Odisha Mining Corporation, among others (Mordor Intelligence, 2022).

EU TRADE

Chromium metal is assessed at Mining and processing/refining stage. The following table lists relevant Eurostat CN trade codes for Chromium metal.

Table 6: Relevant Eurostat CN trade codes for Chromium metal

Mining		Processing/refining	
CN trade code	**title**	**CN trade code**	**title**
2610	Chromium Ores and Concentrates	2819	Chromium oxides and hydroxide
		720241	Ferro-chromium, containing by weight > 4% of carbon
		720249	Ferro-chromium, containing by weight <= 4% of carbon
		720250	Ferro-silicon-chromium
		81122190	Unwrought chromium; chromium powders (excl. chromium alloys containing > 10% by weight of nickel)
		81122200	Chromium waste and scrap (excl. ash and residues containing chromium and chromium alloys containing > 10% by weight of nickel)

The listed CN codes referring to Chromium are: 2610-Chromium Ores and Concentrates, 2819-Chromium oxides and hydroxide, 720241-Ferro-chromium, containing by weight > 4% of carbon, 720249-Ferro-chromium, containing by weight <= 4% of carbon and 720250-Ferro-silicon-chromium; 81122190, Unwrought chromium; chromium powders (excl. chromium alloys containing > 10% by weight of nickel) and 81122200, Chromium waste and scrap (excl. ash and residues containing chromium and chromium alloys containing > 10% by weight of nickel)

Figure 5 shows the import and export trend of chromium ores and concentrates. The EU is a net importer of Chromium ores and concentrates. The EU exports are much lower than the EU import of Chromium ores and concentrates in all years. In 2008, the EU export unexpectedly decreased three times from 460,871 tonnes to 146,258 tonnes while the import did not change. The import of Chromium ores and concentrates fell during 2019 and 2020 as COVID-19 pandemic happened. Instead, the EU exports seemed to maintain the same level during this period.

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Figure 6 illustrates the EU's import of chromium ores and concentrates from various countries. The main import partners of EU are South Africa (68%), Turkey (18%) and Countries and territories not specified for commercial or military reasons in the framework of extra-Union trade (7%). South Africa used to be the main supplier during 2000-2021 except in 2014 and 2017-2019 which the import from Countries and territories not specified for commercial or military reasons were more.

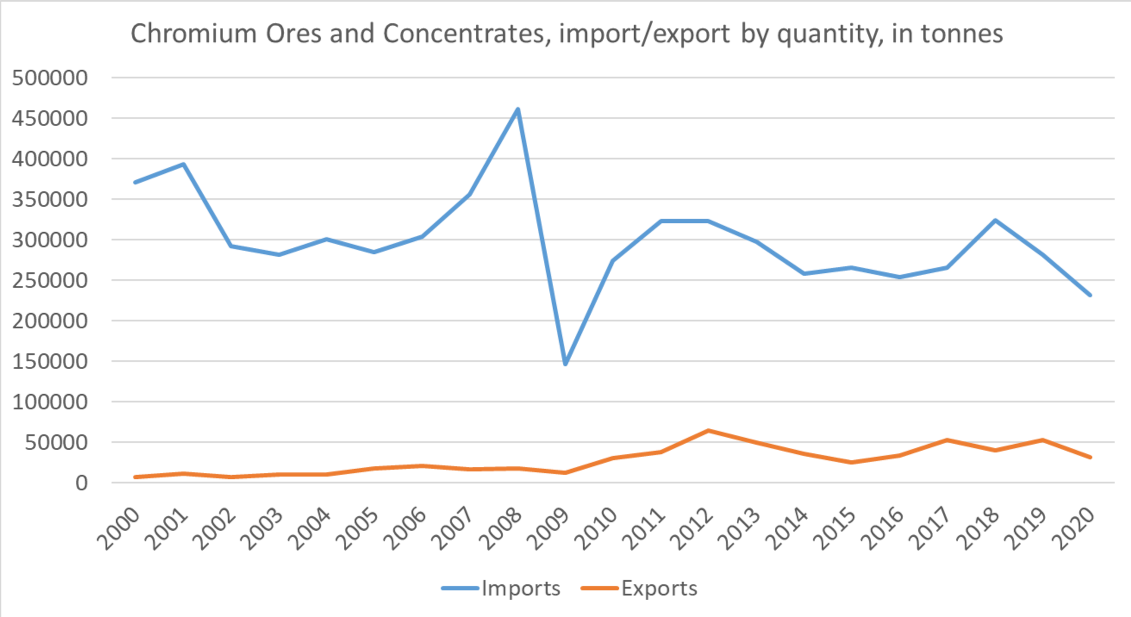

Figure 5. EU trade flows of chromium ores and concentrates (CN 2610) from 2000 to 2021 (Eurostat, 2022)

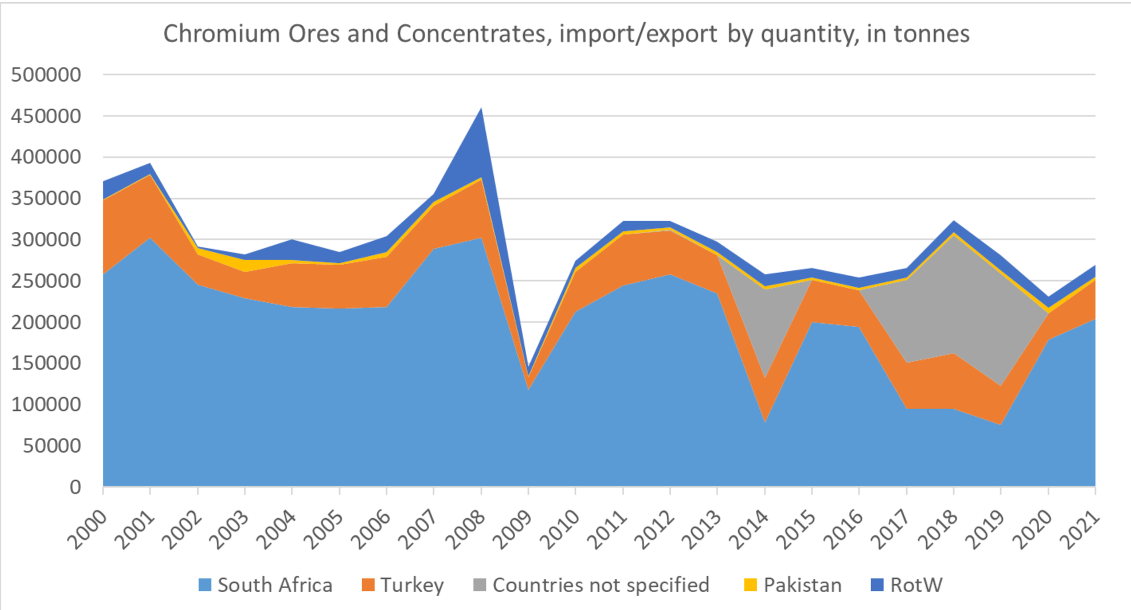

Figure 6. EU imports of chromium ores and concentrates (CN 2610) by country from 2000 to 2021 (Eurostat, 2022)

Figure 7 shows the import and export trend of chromium oxides and hydroxide. The EU is a net importer of Chromium oxides and hydroxide in the observed period (2000-2021). The import of Chromium oxides and

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hydroxide declined from 394.75 in 2000 tonnes to 248.98 tonnes in 2021 with some fluctuations during this period. The EU exports have been relatively stable compared to the imports, sitting at an average of 2195 tonnes/year.

Figure 8 illustrates the share of imports in the EU for chromium oxides and hydroxide from various countries. The main supplier to EU in the past two decades (2000-2021) was Kazakhstan (27% of share), followed by UK, Russia, and China (23%, 15%, and 11%, respectively). The most notable trend is the decreasing of imports from UK since 2015.

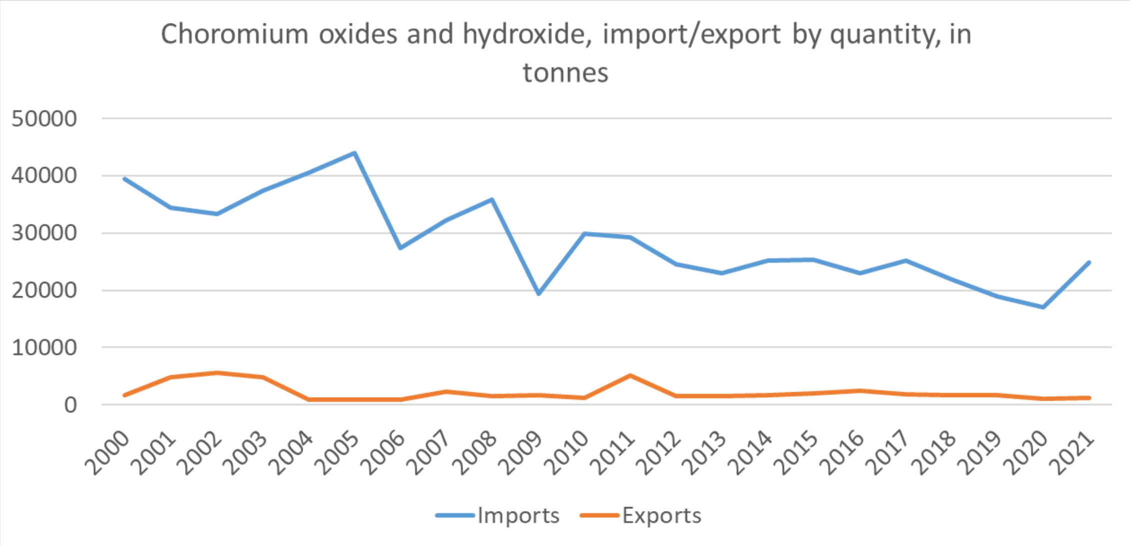

Figure 7. EU Trade flows of chromium oxides and hydroxide (CN 2819) from 2000 to 2021 (Eurostat, 2022)

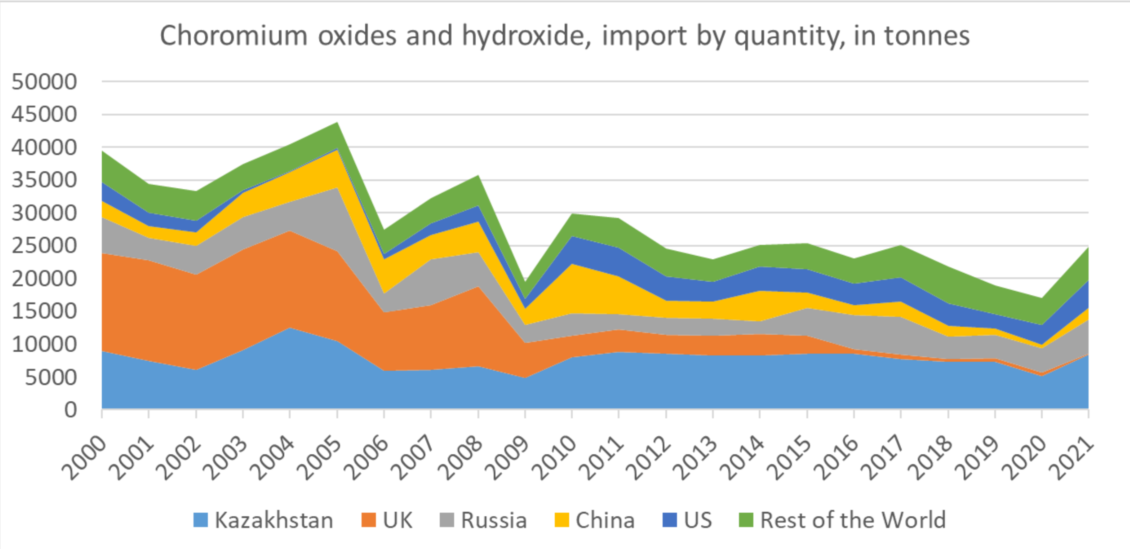

Figure 8. EU imports of chromium oxides and hydroxide (CN 2819) by country from 2000 to 2021 (Eurostat, 2022)

Figure 9 shows the import and export trend of ferro-chromium, containing by weight > 4% of carbon. The EU is a net importer of ferro-chromium, containing by weight > 4% of carbon in the observed period (2000-2021). However, there is a declining trend in this period and the import of ferro-chromium, containing by weight >

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4% of carbon decreased from 1,325,196 tonnes in 2000 to 486,745 tonnes in 2021. Furthermore, the EU imports decreased dramatically from 1,602,410 tonnes in 2008 to 945,839 tonnes in 2009, probably due to the global financial crisis.

Figure 10 illustrates the EU import of ferro-chromium, containing by weight > 4% of carbon from various countries. The main suppliers for import of ferro-chromium (containing by weight > 4% of carbon) during 2000-2021 were South Africa (64%) followed by Kazakhstan (10%), Zimbabwe (7%), Countries and territories not specified for commercial or military reasons in the framework of extra-Union trade (5%) and Russia (4%). The decline in imports during 2019-2020 and the increment in 2021, can be due to Covid-19 situation.

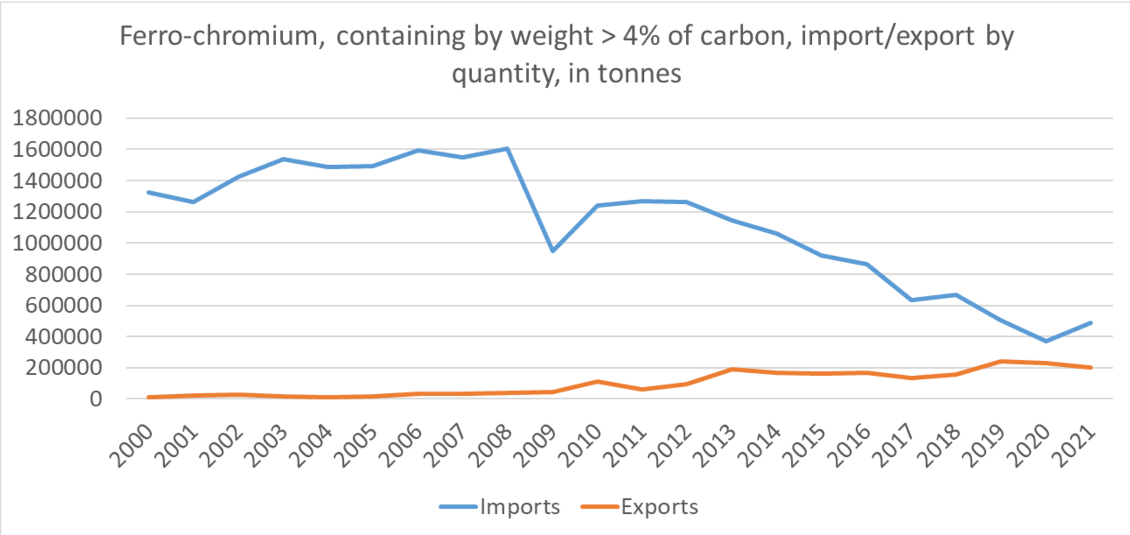

Figure 9. EU Trade flows of ferrochromium, containing by weight > 4% of carbon (CN 720241) from 2000 to 2021 (Eurostat, 2022)

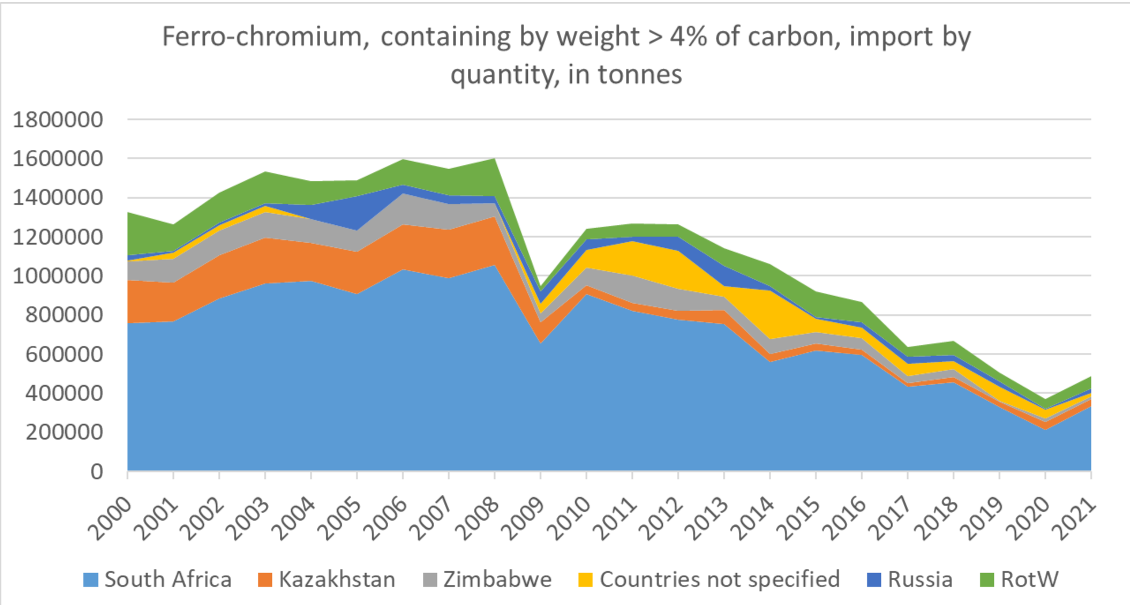

Figure 10. EU imports of ferrochromium, containing by weight > 4% of carbon (CN 720241) by country from 2000 to 2021 (Eurostat, 2022)

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Figure 11 presents the import and export trend of ferrochromium, containing by weight <= 4% of carbon. During the year 2000-2021, the EU import of ferrochromium, containing by weight <= 4% of carbon had a gradual decreased with some fluctuations. There is a sharp drop in the imports from 179,072 tonnes in 2008 to 97,288 tonnes in 2009 while the exports increased from 12,521 tonnes in 2008 to 44,900 tonnes in 2010.

Figure 12 illustrates the share of ferrochromium, containing by weight <= 4% of carbon from various countries. The import in the past two decades (2000-2021) fluctuated rather greatly. The main supplier to EU in the past two decades (2000-2021) was Russia (45% of share), followed by Countries and territories not specified for commercial or military reasons in the framework of extra-Union trade, South Africa, Kazakhstan and Turkey (14%, 14%, 11%, and 7%, respectively).

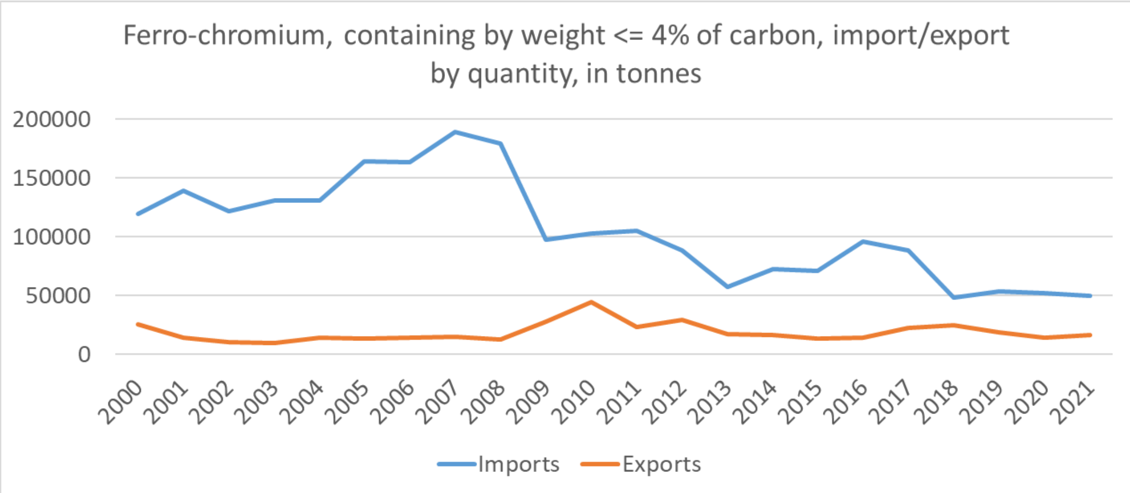

Figure 11. EU Trade flows of ferrochromium, containing by weight <= 4% of carbon (CN 720249) from 2000 to 2021 (Eurostat, 2022)

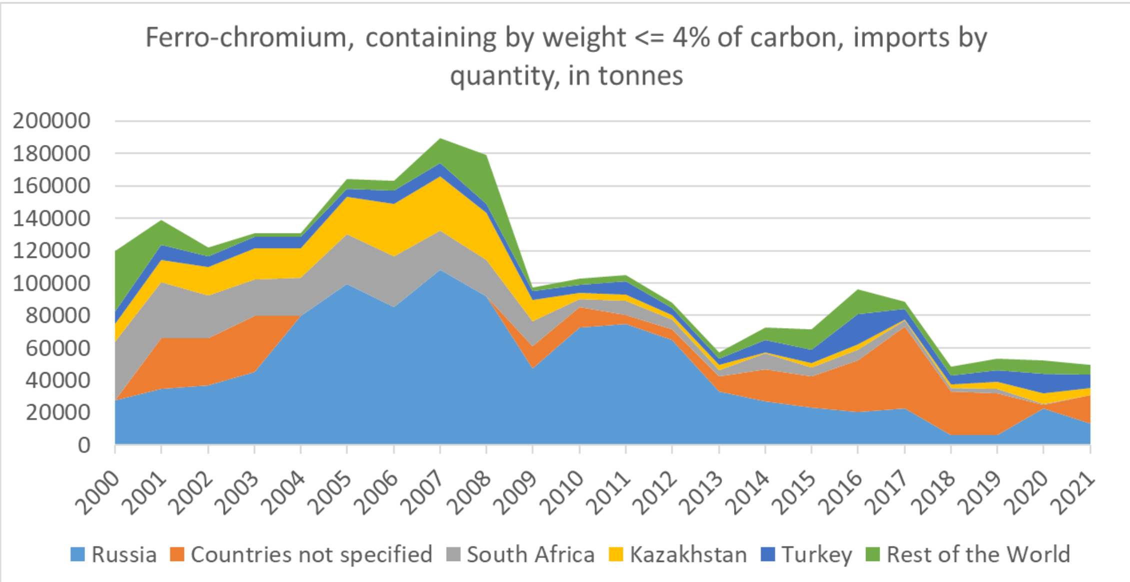

Figure 12. EU imports of ferrochromium, containing by weight <= 4% of carbon (CN 720249) by country from 2000 to 2021 (Eurostat, 2022)

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Figure 13 shows the import and export trend of Ferro-silicon-chromium. During the year 2000-2021, the EU import and export of Ferro-silicon-chromium had several fluctuations especially during 2008 to 2012, there are two sharp fluctuations in both import and export. It can be due to the stop of import from some sources such as countries and territories not specified for commercial or military reasons in the framework of extra-Union trade and South Africa (Figure 14). However, the import and export of Ferro-silicon-chromium, were changed from 22,752 and 249 tonnes in 2000 to 19,263 and 3 tonnes in 2021, respectively. Overall, the EU import was always higher than the EU export of Ferro-silicon-chromium.

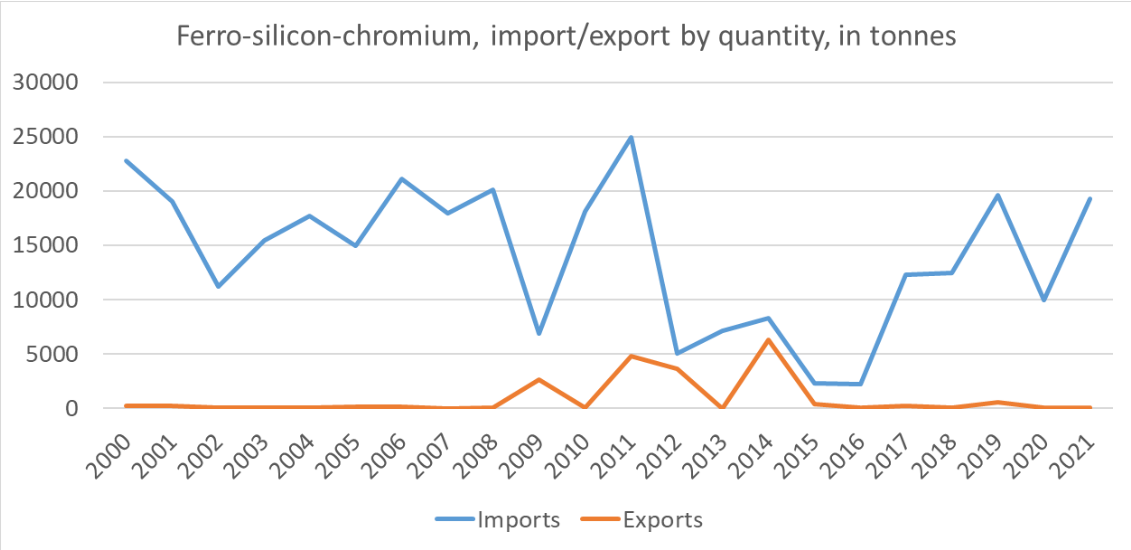

Figure 13. EU Trade flows of ferrosilicon-chromium (CN 720250) from 2000 to 2021 (Eurostat, 2022)

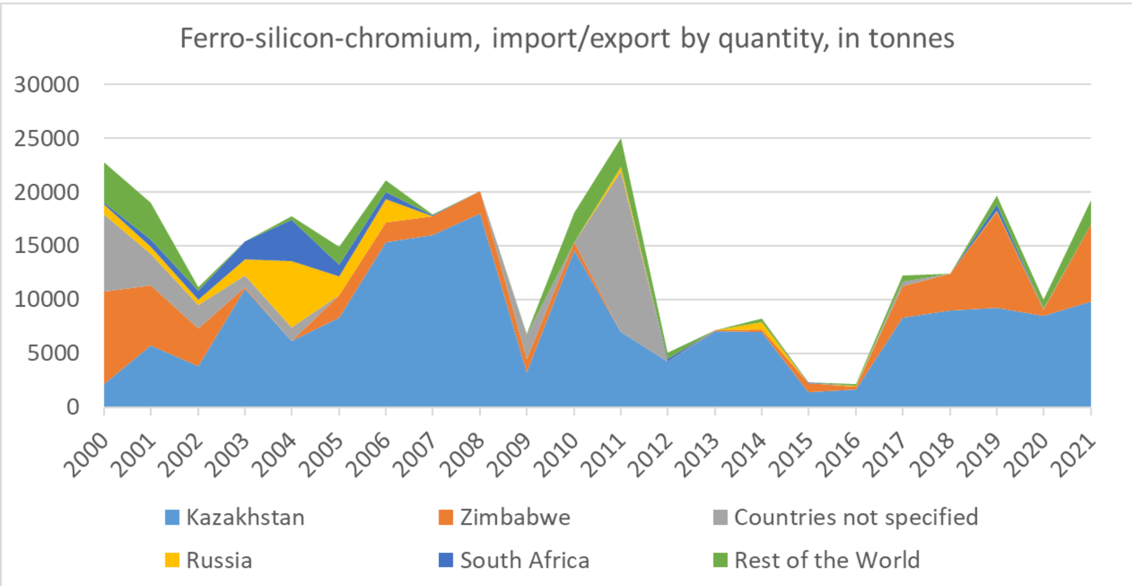

Figure 14. EU imports of ferrosilicon-chromium (CN 720250) by country from 2000 to 2021 (Eurostat, 2022)

Figure 15 presents the import and export trend of unwrought chromium; chromium powders (excl. chromium alloys containing > 10% by weight of nickel). During the year 2002-2022, the EU import more than doubled from 5,000 tonnes in 2002 up to more than 14,000 tonnes in 2022, while the exports only slightly increased from 4,000 tonnes in 2002 to 7,000 tonnes in 2010 and then remained quite stable.

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Figure 16 illustrates the share of unwrought chromium; chromium powders (excl. chromium alloys containing > 10% by weight of nickel) from various countries. The import in the past two decades (2002-2022) has been dominated by Russia (80%), followed by United Kingdom (14%).

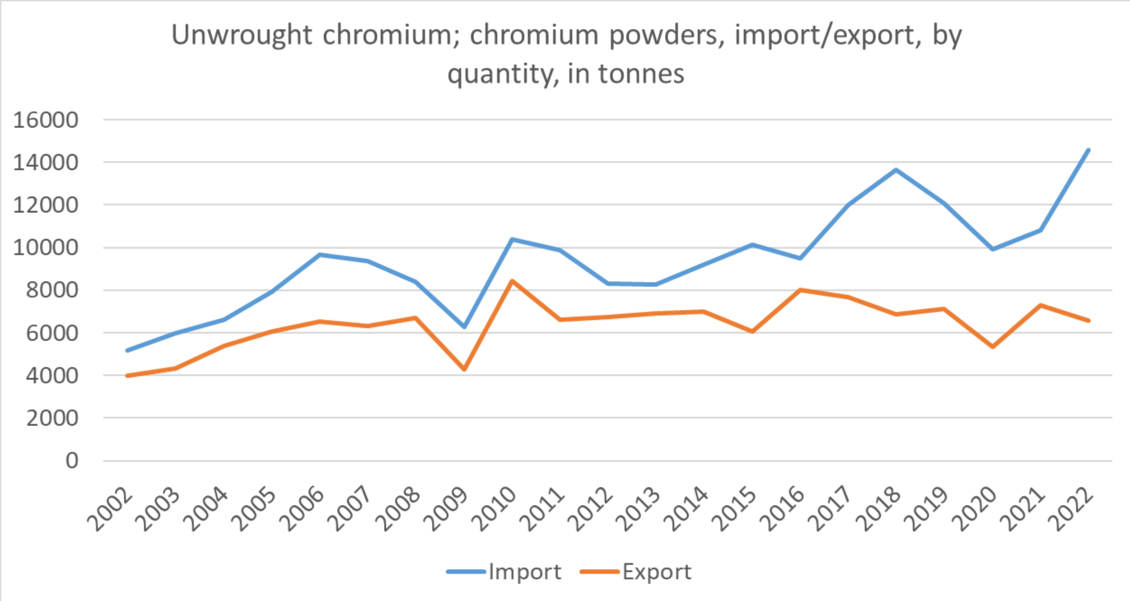

Figure 15. EU Trade flows of Unwrought chromium; chromium powders (CN 21122190) from 2002 to 2022 (Eurostat, 2022)

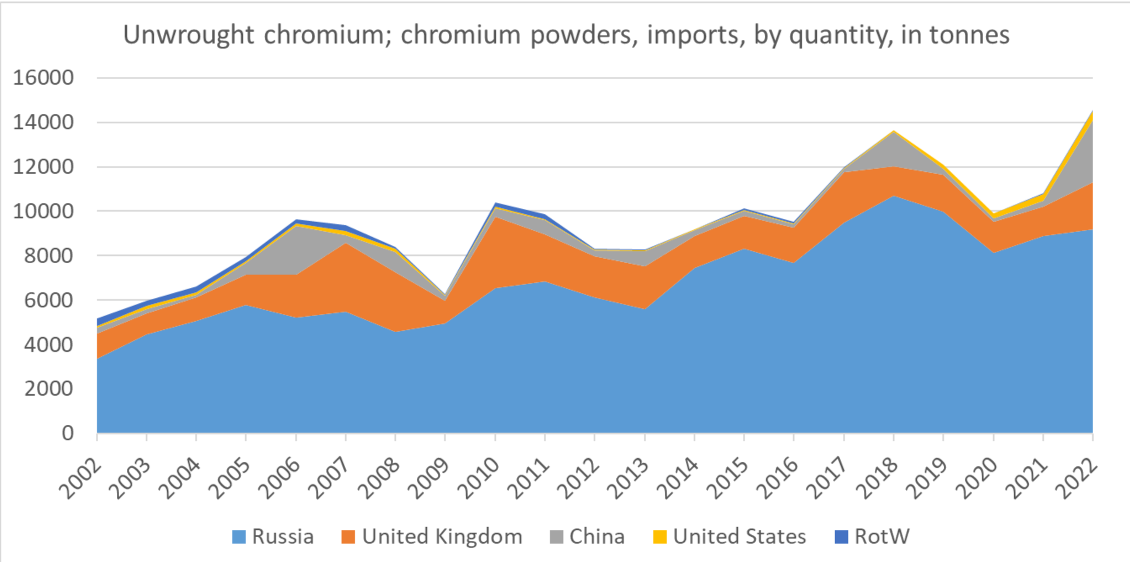

Figure 16. EU imports of Unwrought chromium; chromium powders (CN 21122190) from 2002 to 2022 (Eurostat, 2022)

Figure 17 presents the import and export trend of chromium waste and scrap (excl. ash and residues containing chromium and chromium alloys containing > 10% by weight of nickel). If the imports multiplied by four from 2002 to 2006, they remained stabled from 2006 to 2012 and then sharply decreased down to 1000-1500 tonnes per year since 201 whereas the exports remained low all along the period (about 300 tonnes)

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Figure 18 illustrates the share of chromium waste and scrap (excl. ash and residues containing chromium and chromium alloys containing > 10% by weight of nickel) from various countries. If the imports were dominated by Switzerland from 2002 to 2014 (more than 85%), followed by United Kingdom (14%) it is now led by UK (30%) followed by Switzerland (26%), Norway and Azerbaidjan (13% each).

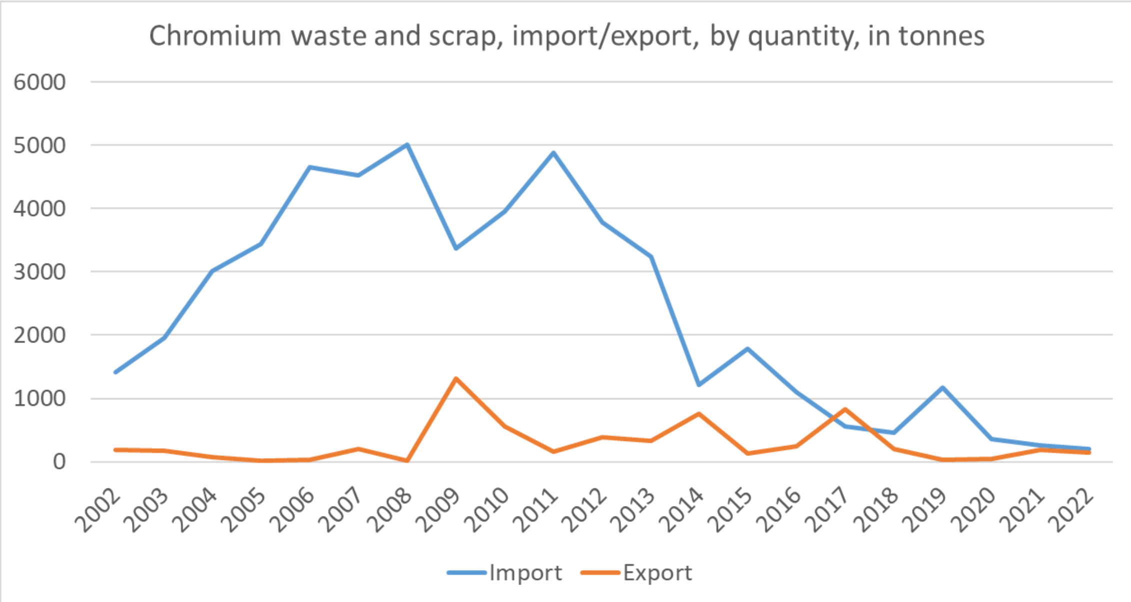

Figure 17. EU Trade flows of Chromium waste and scrap, (CN 21122200) from 2002 to 2022 (Eurostat, 2022)

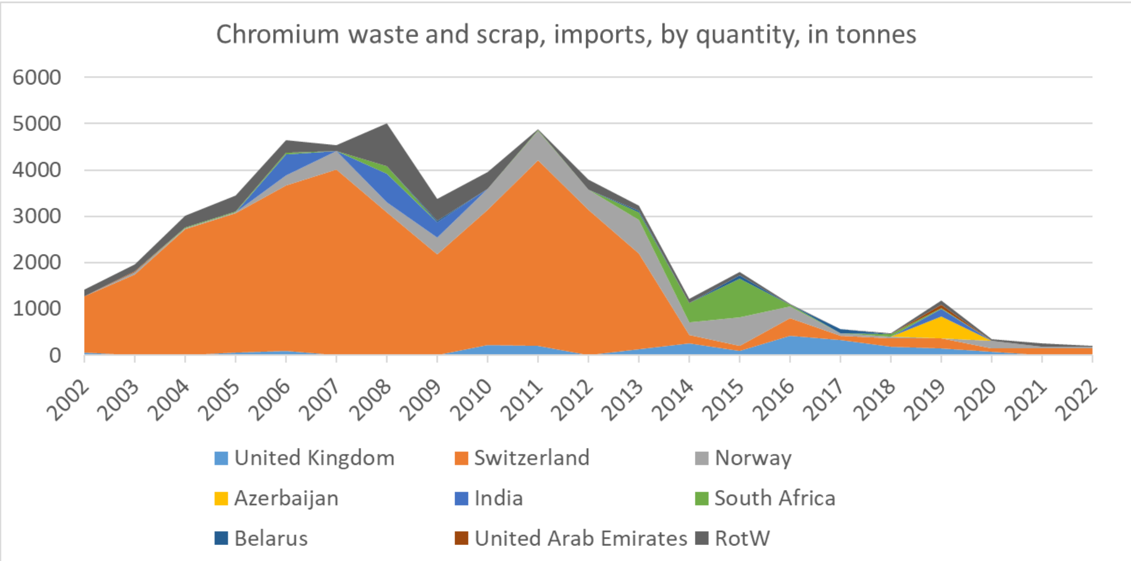

Figure 18. EU imports of Chromium waste and scrap, (CN 21122200) from 2002 to 2022 (Eurostat, 2022)

PRICE AND PRICE VOLATILITY

Chromium is traded in the form of chromium ores and concentrates, ferrochrome, chromium metal and chromium chemicals (Roskill, 2014) . Chromium ores and concentrates are priced in terms of gross weight and the price depends on specifications, i.e. metal content, impurities and ore type (e.g. lumpy, friable,

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concentrates). Trends in chromium ores and concentrates prices follow those of ferrochrome, which accounts for 96% of chromite consumption. Non-metallurgical grades attract a price premium in comparison to metallurgical-grade chromite because of their higher chromium content and the higher degree of processing required. Prices for refractory-grade chromite are generally higher than chemical-grade and foundry-grade chromite (ibid.). Ferrochrome prices follow the trends in the stainless steel industry with a time-lag. The volatility in year-on-year changes in demand and rates for ferroalloys reflects the periods of de-stocking and re-stocking by the stainless steel industry Prices of low-carbon ferrochrome consumed in special steels command premiums of up to 70-80% over those of charge chrome, because of their higher purity (ibid.).

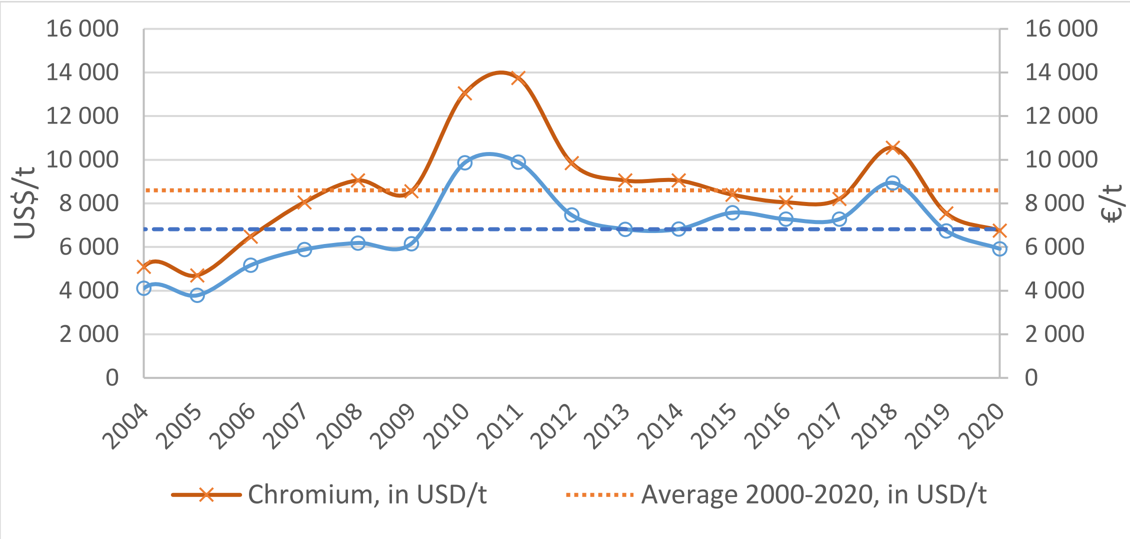

Figure 19. Annual average price of chromium 99% min FOB between 2004 and 2020, in US$/t and €/t[3]. Dash lines indicates average price for 2004-2020 (S&P Global, 2022)

Ferrochrome prices escalated to historical highs from 2007 up to the first months of 2008, reflecting the strong growth in stainless steel production. The onset of the global recession at the end of 2008 led to a significant fall in the stainless steel output, which in combination with de-stocking caused a sharp drop to ferrochrome prices. In 2010 prices rebounded driven by a remarkable rise in the Chinese production of stainless steel. The recovery was not sustained in 2012-2013 as world demand for stainless steel in the rest of the world remained stable, supply from South Africa and China increased, and Chinese producers covered a higher percentage of the domestic market (Roskill, 2014) . Within 2015, chrome prices collapsed because of a downturn in the Chinese economy, contracting the demand for stainless steel, and at the beginning of 2016, chrome prices reached a six-year low, which had significant implications for South African industry, where ferrochrome smelters closed and mines undertook care and maintenance programs. The resulting decrease in chrome supply was substantial and created a market deficit in the second half of 2016 when stainless steel demand revived in China. The shortage initiated a sharp recovery in prices which reached the levels before the global economic downturn, which in turn triggered a supply surge from producers in South Africa based on idled

[3] Values in €/kg are converted from original data in US$/kg by using the annual average Euro foreign exchange reference rates from the European Central Bank (https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html)

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ferrochrome capacity and other countries such as India and Kazakhstan. In 2017, prices followed the cyclical and temporary balances of supply and demand, affected mainly by increased Chinese smelting supply, electricity tariffs in South Africa, fluctuating stainless steel demand, and industry stockpiling (KPMG, 2018; Saxby, 2017) . In 2018, a severe shortage of chromium alongside a strong downstream demand caused prices to hit their highest level in almost seven years (Fastmarkets, 2018) . Chromite and ferrochrome prices fell below the 50th percentile of their respective cost curves near the end of 2019. The low prices were underpinned by weak markets and growing stainless steel inventories and by additional low-cost by-product chromite produced from tailings in South Africa (Backeberg, 2020).

OUTLOOK FOR SUPPLY AND DEMAND

The global chromium market is anticipated to expand at a compound annual growth rate (CAGR) of 2.7% from 2020 to 2025 (Grand View Research, 2020) . The consumption of chromium closely follows the trends in demand for steel, and stainless steel in particular (USGS, 2018) . Global stainless steel consumption has increased from 1980 to 2018 at a CAGR of 5.4% (International Stainless Steel Forum., 2019) .

The growth in the supply of chromium ore over the last two decades has strongly followed developments in China, where the country has been increasing ferrochrome capacity (requiring imported feed} to service its stainless steel industry (Backeberg, 2020) . Demand for stainless steel, the primary chromium application, will continue to grow, although at a slower rate compared to the previous decade. The long-term chromium market is forecasted to experience a demand growth of 2-3% per annum (Backeberg, 2020) .

Despite the moderate increase in demand for ferro-chrome, an increasing oversupply in the ferrochrome industry over the next five years is expected as a result of expansions in smelting capacity, coming mainly from Zimbabwe, which will outpace significantly the growth (Fastmarkets, 2018) .

In recent times, the production costs of ferro-chrome have risen significantly due to surging energy prices. Since energy prices are likely to continue rising in the short term, producers are looking at including these energy costs into the sales price or alternatively cutting production. Albania-based GSA is considering cutting production by 50% reducing output by about 2,000 tonnes a month. Albchrome, with a capacity of about 50,000 tonnes per year with two furnaces, or 100,000 tonnes per year with four, has already cut production by 50% because of energy costs (Patel-Campbell, 2022) . South Africa, the world's largest producer of chromium ore, has been experiencing ongoing challenges linked to the Covid-19 pandemic, shortages of truck drivers, along with energy supply issues which pose a significant to global supply (Patel-Campbell, 2022).

DEMAND

GLOBAL AND EU DEMAND AND CONSUMPTION

Chromium extraction stage EU consumption is presented by HS code CN 261000 Chromium ores and concentrates. Import and export data is extracted from Eurostat Comext (2022). As mentioned above, data from ICDA were considered for the criticality assessment; however, they were just provided for the 2016-2020 period. Below, EU27 production data (Finland and Greece) are extracted from WMD (2022).

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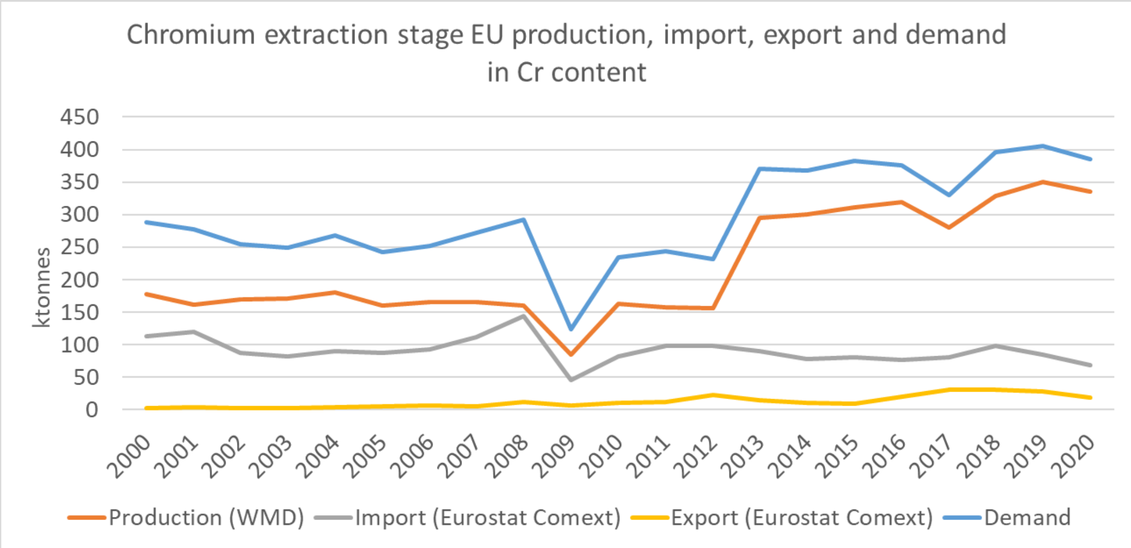

Figure 20. Chromium (CN 261000) extraction stage apparent EU consumption. Production data is available from WMD (2022). Consumption is calculated in CR_2O_3 content (EU production+import-export).

Chromium processing stage EU consumption is presented by HS codes CN 720241 "Ferrochromium, containing by weight > 4% of carbon", CN 720249 "Ferrochromium, containing by weight <= 4% of carbon", CN 720250 "Ferro-silicon-chromium", CN 21122190 "Unwrought chromium; chromium powders (excl. chromium alloys containing > 10% by weight of nickel" and CN 21122200 "Chromium waste and scrap (excl. ash and residues containing chromium and chromium alloys containing > 10% by weight of nickel)". Import and export data is extracted from Eurostat Comext (2022). Production data is extracted from USGS (2022) and BGS (2022).

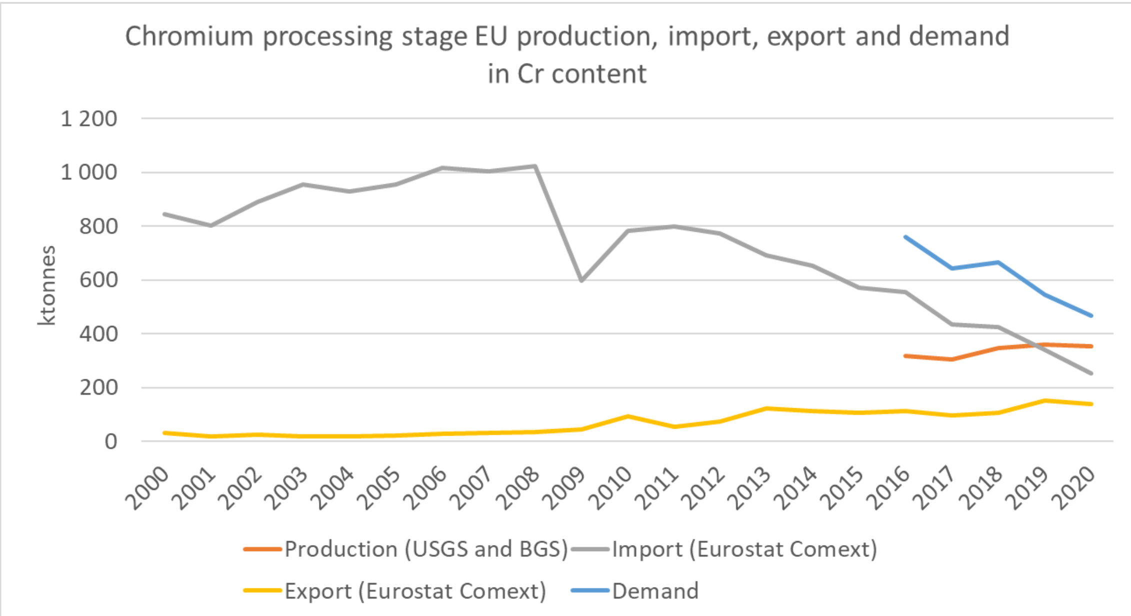

Figure 21. Chromium (CN 720241, CN 720249 and CN 720250) processing stage apparent EU consumption. Production data is available from USGS (2022) and BGS (2022) for years 2016-2020. Consumption is calculated in CR_2O_3 content (EU production+import-export).

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Average import reliance of chromium at extraction stage is 7% and at processing stage 42 % for 2016-2020.

EU USES AND END-USES

Chromium is mainly used in products made of stainless steel. It is also used alloy steel products. A small proportion is used in refractories and chemicals as well.

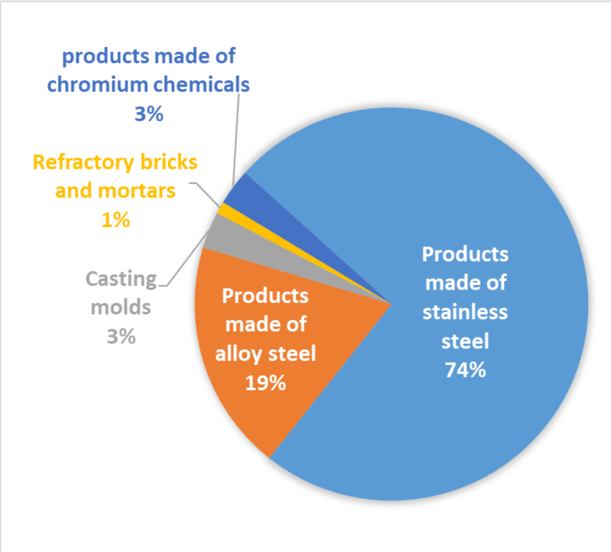

Figure 22. EU end uses of Chromium, 2012-2016 (SCRREEN CRM experts, 2022).

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 7. Chromium applications, 2-digit NACE sectors and examples of associated 4-digit NACE sector, and value-added per sector (Eurostat 2022)

Applications	2-digit NACE sector	Value-added of sector (millions €)	Examples of 4-digit NACE sector
Products made of Stainless Steel	C25 - Manufacture of fabricated metal products, except machinery and equipment	183,015.50	C2571- Manufacture of cutlery; C2591 - Manufacture of steel drums and similar containers; C2599- Manufacture of other fabricated metal products n.e.c.
Products made of Alloy Steel	C25 - Manufacture of fabricated metal products, except machinery and equipment	183,015.50	C2599- Manufacture of other fabricated metal products n.e.c.
Casting Moulds	C24 - Manufacture of basic metals	71,390.80	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	69,888.20	C2391- Manufacture of refractory products; C2395- Manufacture of mortars
Products made of chromium chemicals	C20 - Manufacture of chemicals and chemical products	117,093.2	C2011- Manufacture of dyes and pigments; C2029- Manufacture of other chemical products n.e.c.

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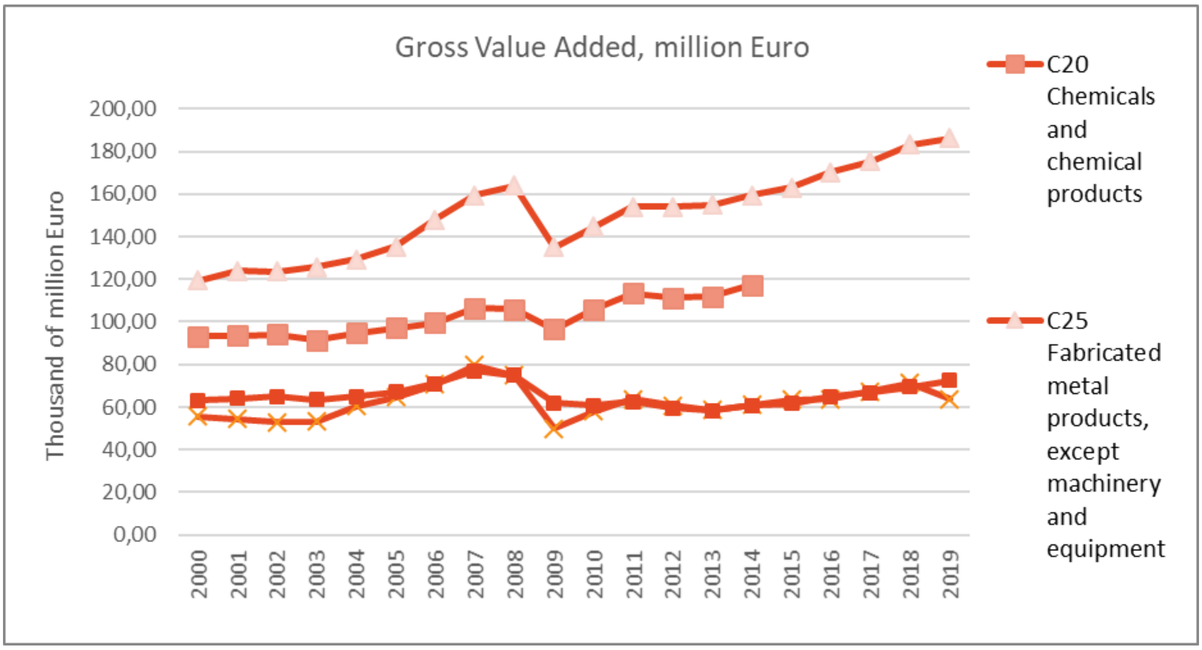

Figure 23. Value added per 2-digit NACE sector over time (Eurostat, 2022)

APPLICATIONS OF CHROMIUM IN THE EU

PRODUCTS MADE OF STAINLESS STEEL

Chromium is used in stainless steel to enhance its resistance to corrosion, increase hardness and reduce discolouration. The chromium content of stainless steels ranges from 12.5% to 26% (EUROFER 2019).

Ferrochrome, the main product of chromium ore refining, is a ferroalloy providing chromium to steel production. About 73% of the ferrochrome production is transformed into stainless steel. The finished products manufactured by stainless steel are used in industry, architecture, transport, kitchenware and other applications covering all end-use sectors (ISSF 2019a).

In 2021, according to the International Stainless Steel Forum (ISSF), 38% of stainless steel was consumed in the fabrication of metal products, 29% in mechanical engineering, 12% in construction, 8% in motor vehicles and parts, 8% in electrical machinery and 5% in other transport applications (ISSF 2022 – percentages rounded).

PRODUCTS MADE OF ALLOY STEEL

Remaining ferrochrome production (Ca. 27%) is consumed in speciality steel alloys used in industrial applications where enhanced properties are required (e.g., tools, injection moulds, camshafts, dies, bearings and mill rollers).

Chromium added to steel improves wear resistance, enhances corrosion and oxidation resistance, increases hardenability, and promotes strength at elevated temperatures (European Commission 2017) (USGS 2018b).

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CASTING MOULDS

Foundry sands from foundry-grade chromite are used to make casting moulds to produce ferrous and non-ferrous castings.

REFRACTORY BRICKS AND MORTARS

The high heat resistivity and high melting point makes chromite components for high-temperature refractory applications, like blast furnaces, cement kilns, moulds for the firing of bricks and as foundry sands for the casting of metals. In these applications, the refractory materials are made from mixtures of chromite and magnesite ($MgCO_3$) – although use is declining due to environmental regulations.

PRODUCTS MADE OF CHROMIUM CHEMICALS

Chromium chemicals are used in leather tanning, using chromium salts, mainly in the form of chromium sulphate.

Acidic chromate, or dichromate solutions, are used in metal finishing industry for the applications of coatings to other metals, including decorative chromium plating of everyday consumer durables and hard chromium plating for engineering requirements. Other metal plating applications in which chromium chemicals are involved are anodising and chromating.

The production of chromium metal by chromium (III) oxide is an important niche application of chromium chemicals (BIO Intelligence Service 2015). Chromium metal is used as an alloying element to specific grades of superalloys (USGS 2018a).

Due to their unique high-temperature and corrosion-resistance properties, superalloys are employed in critical applications in the aerospace, nuclear and energy sector (e.g., gas turbines). Chromium metal is also used in aircraft motor system as it resists high temperatures and very extreme conditions, and in certain widely used aluminium alloys as an alloying element (USGS 2018a).

SUBSTITUTION

Table 8. main uses and substitution potential

Use	Share*	Substitutes	Sub share	Cost	Performance
Products made of stainless steel	74%	No substitute			
Products made of alloy steel	19%	No substitute			
Casting moulds	3%	Not assessed below 10%			
Refractory bricks and mortars	1%	Not assessed below 10%			
Products made of chromium chemicals	3%	Not assessed below 10%			
Other uses (e.g., electroplating with Cr metal)	0%	Not assessed below 10%			
Products made of stainless steel	74%	No substitute			

** EU end uses of Chromium, 2012-2016 (SCRREEN CRM experts, 2022).*

There are no substitutes for chromium its main end uses (USGS, 2022, SCRREEN experts, 2022).

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SUPPLY

4.1 EU SUPPLY CHAIN

Chromium flows through the EU economy are shown in Figure 17 (2013 data). In the EU, chromium concentrates are extracted in Finland. The average annual production of chromium over 2016-2020, expressed as Cr_2O_3 content was 474 kt. Ferrochromium is produced in Finland, Germany and Sweden (602 kt annually). About 1,013 kt of chromium concentrates and ferrochromium were imported annually by South Africa, Turkey and Kazakhstan. At the same period 303 kt of various ferrochromium alloys (CN codes: 720249, 281910, 261000, 320620, 720241, 81122190) were extracted to third countries (mainly to China, Japan, Indonesia and Russia). The end-of-life recycling input rate of chromium in EU is estimated at 21% (Eurostat, 2021).

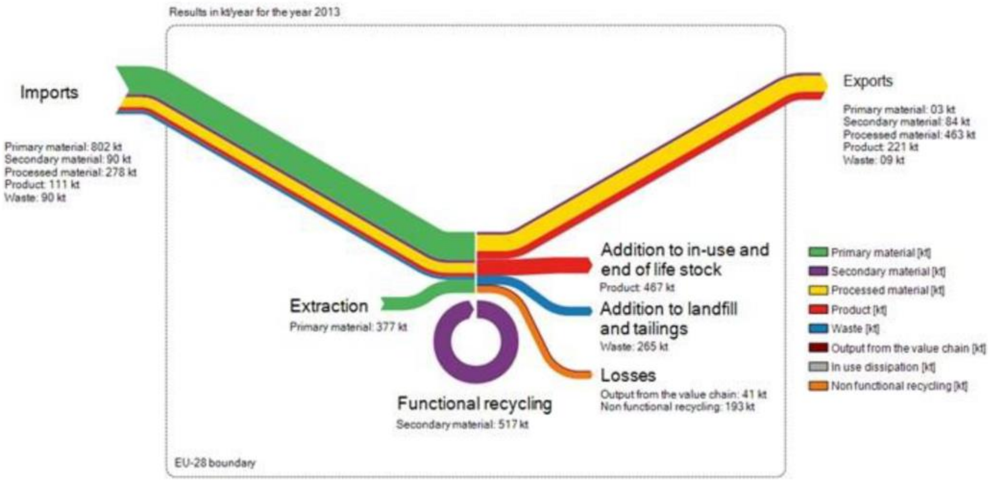

Figure 24. Simplified MSA of chromium flows in the EU. 2013. (BIO Intelligence Service 2015)

4.1.1 EU SOURCING OF CHROMITE

In the EU, chromium ores and concentrates are currently produced only in Finland. A minor production in Greece ended in 2012 according to production statistics from. The average annual chromite production in Finland, expressed as Cr_2O_3 content, was 465 kt during the period 2016-2020 (WMD, since 1984). Outokumpu's Kemi mine in Finland is the only operating chromite mine in the EU. The mine started production in 1968 as an open pit, and currently, all mining is underground. Ore is concentrated into upgraded lumpy ore, and fine concentrate, which are raw materials for Outokumpu's ferrochrome works in Tornio (Outokumpu 2015) (USGS, since 2000).

4.1.2 EU SOURCING OF FERROCHROME

Ferrochrome is currently produced in Finland, Sweden and Germany by three companies. Total EU production amounted to 493 kt of ferrochrome (estimated to 273 kt in chromium content) on average in the 2012-2016 period covering 30% of EU supply, while imports of ferrochrome reached 640 kt in chromium content. South Africa is the leading EU supplier with a 41% share of EU sourcing (Figure 2). A small ferrochrome production in Romania terminated in 2010 (BGS 2019).

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

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

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

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

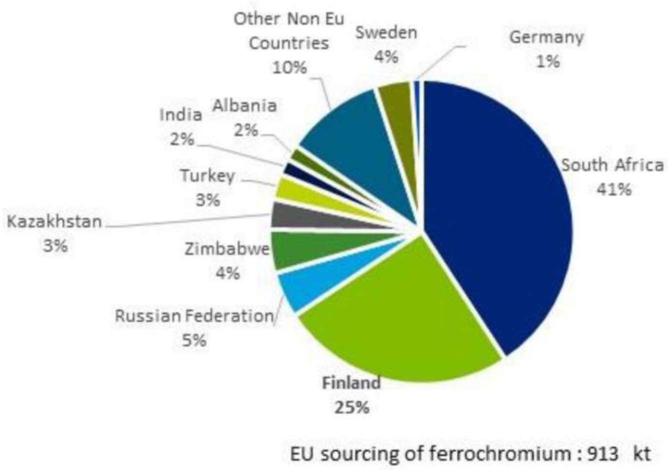

Figure 25. EU sourcing (domestic production+imports) of ferrochrome, average 2012-2016 (in Cr content). Background data from (BGS 2019) (Eurostat 2019b).

4.1.3 CHROME METAL AND CHROMIUM CHEMICALS SUPPLY

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

Chromium metal is produced in France and Germany. In France, DCX Chrome in Marly has an annual production capacity of 12 kt. It is reported as the world leader in the production of high-purity, aluminothermic chrome metal with applications in superalloys, special steels, hard-facing materials, weldings, powder metallurgy and aluminium alloys (BRGM, 2017)(DCX Chrome, 2019). GfE in Nürnberg, Germany, produces

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chromium granules, powders and lumps, and chromium alloys via an aluminothermic process. According to the US Geological Survey, capacity for chromium metal in Germany is 1 kt per year (GfE, 2020) (USGS, 2019).

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

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

4.2 SUPPLY FROM PRIMARY MATERIALS

4.2.1 GEOLOGY, RESOURCES AND RESERVES OF CHROMIUM

GEOLOGICAL OCCURRENCE

Chromium is quite abundant in the Earth's crust. According to (R. L. Rudnick and Gao 2014), the average concentration of chromium in Earth's crust is 135 ppm, and in the upper crust 92 ppm. Chromium ore (chromite) is found mainly in ultramafic igneous rocks as a chromium spinel, a group of minerals with a highly variable chemical composition. The generic formula of chromium spinels is (Fe,Mg)(Cr,Al)2O_4, a solid solution between chromite (FeCr2O4) and magnesio-chromite (MgCr2O_4). 'Chromite' is used as a general term to describe chromium-bearing spinel minerals. Large variations in the total and relative amounts of Cr, Fe, Al and Mg in the lattice occur in different deposits. These affect the ore grade not only in terms of the Cr_2O3 content but also in the reducibility of the ore and the chromium content of ferrochrome (ICDA 2011a). Commercial chromites contain between 40% and 60% of Cr_2O3 content with an average of about 45% (BRGM 2017). In this factsheet, the terms "chromite" and "chromium ore" are considered interchangeable.

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

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

GLOBAL RESOURCES AND RESERVES

At the end of 2018 the world's chromium resources were higher than 12 billion tonnes of shipping-grade chromite (containing 45% of Cr_2O_3), equivalent to about 3.7 billion tonnes of chromium content. Based on the current level of demand, the word resources are more than adequate to meet future demand. Global chromium resources are currently heavily geographically concentrated (95%) in southern Africa (i.e. South Africa and Zimbabwe) and Kazakhstan (Table 9). The identified world reserves are estimated to approximately 570 million tonnes of shipping-grade chromite, equivalent to about 176 million tonnes of chromium content. Kazakhstan, South Africa and India are hosts of the largest known chromium reserves (USGS, since 2000).

Table 9. Global reserves of chromium in 2020 (USGS, 2022).

Country	Estimated chromium reserves (kt of shipping-grade chromite of45% Cr_2O_3)
Kazakhstan	230,000
South Africa	200,000
India	100,000
Finland[35]	13,000
Turkey	26,000
USA	620
Other countries	Not available
World total (rounded)	570,000

EU RESOURCES AND RESERVES

Table 10. Chromium resources data in the EU

Country	Classification	Quantity (million tonnes of ore)	Grade (% Cr)	Reporting code	Reporting date	Source
Finland	Total resource	97.8	19.8	JORC	12/2017	(FODD2017)
	Historic resource estimate	127	14.9	None		
Greece	Historic resource estimate	2	35-40 (% Cr_2O_3)	USGS	11/2014	(Minerals4EU)
		5	18-20 (% Cr_2O_3)			
		4	35-40 (% Cr_2O_3)			

The currently known JORC-compliant resources of chromium are located in Finland (Kemi mine) and amount to 19.4 million tonnes of chromium content. Historical resource estimates of chromium resources for Greece are also available in theMinerals4EU website. The JORC-compliant reserves in Finland (not included in

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resources) are about 8.3 million tonnes in Cr content (Table 10 and **Erreur ! Référence non valide pour un signet.**)

Table 11. Chromium reserves data in the EU

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

4.2.2 EXPLORATION AND NEW MINE DEVELOPMENT PROJECTS IN THE EU

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

4.2.3 CHROMITE MINING

Chromium ore is generally mined as a primary product, except for South Africa, where increasing volumes of chromite concentrates are recovered from tailings from PGM operations (Roskill 2014). About 14% of the world production of chromite, corresponding to a quarter of South African production, is a by-product of PGM mining in the UG2 horizon in the Bushveld Igneous Complex (BRGM 2017). Open-pit and underground mining methods are employed for chromite mining. Underground mining of stratiform deposits is most often required but can be particularly difficult due to the thin seam thickness (less than 1.5m), weathering close to the surface and faulting. Open-pit mining is generally applied to the podiform ores at first, progressing to underground mining as deeper levels of the deposit are reached. Weathering through serpentinisation and faulting are often encountered (ICDA 2011b).

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

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

- Metallurgical-grade for the production of high-carbon ferrochrome (chromite with a typical composition of 48% Cr_2O_3 and a Cr/Fe ratio of 3:1), and charge chrome (chromite with 40-46 % Cr_2O_3 and Cr/Fe ratio of 1.5-2.0) used in argon oxygen decarburisation (AOD) steel production. Technological developments in ferrochrome smelting have made possible the use of lower-grade ore fines for charge-chrome production, e.g. agglomeration pre-treatment consisting of pelletising and sintering;

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- Refractory-grade (typical 47 % Cr_2O_3) with a combined Cr2O3+Al2O3 content of >60%, Fe<15% and silica content of around 0.7%;
- Foundry-grade (typical Cr_2O_3 >46%) which generally needs to be beneficiated to remove talc, silica and clay impurities.
- Chemical-grade (typical Cr_2O_3 44-46%, SiO_2<3.5% Cr/Fe ratio 1.5-2.1)

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

4.2.4 WORLD AND EU MINE PRODUCTION

The world mine production of chromium reached 14,058 kt (in Cr_2O_3 content) as an average over 2016-2020, which is equivalent to 9,610 kt in Cr content (WMD, since 1984 and USGS) (Figure 26 and Figure 27). South Africa is the world's largest chromium ore producer, contributing about 45% of the total world supply. Other important suppliers of chromium ores and concentrates are Kazakhstan (16%), India (11%) and Turkey (10%). Chemical-grade chromite is produced in India, Kazakhstan and South Africa; refractory-grade in Oman and South Africa; and foundry-grade in South Africa and Oman (Roskill 2014).

The EU mine production of chromium is concentrated in Finland, as the small production in Greece terminated in 2012, and is averaged at about 465 kt (Cr_2O_3 content) per year over 2016-2020 (WMD, since 1984).

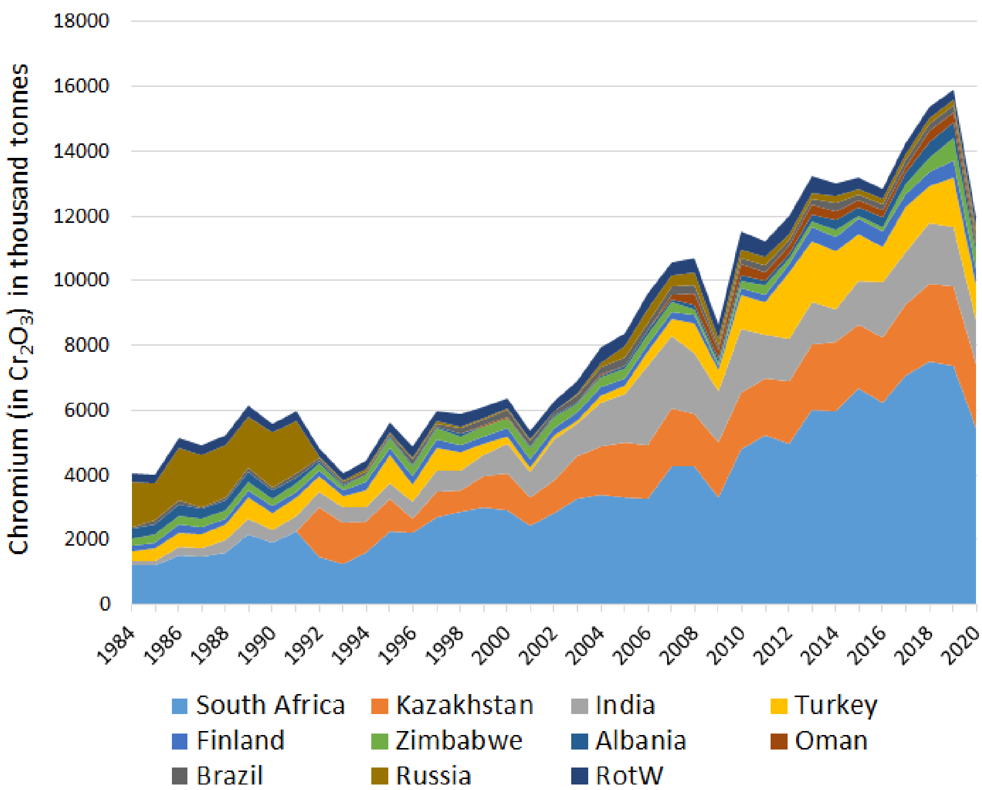

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Figure 26. Global production of chromium (in Cr_2O_3 content) since 1984 according to WMD data (WMD, since 1984).

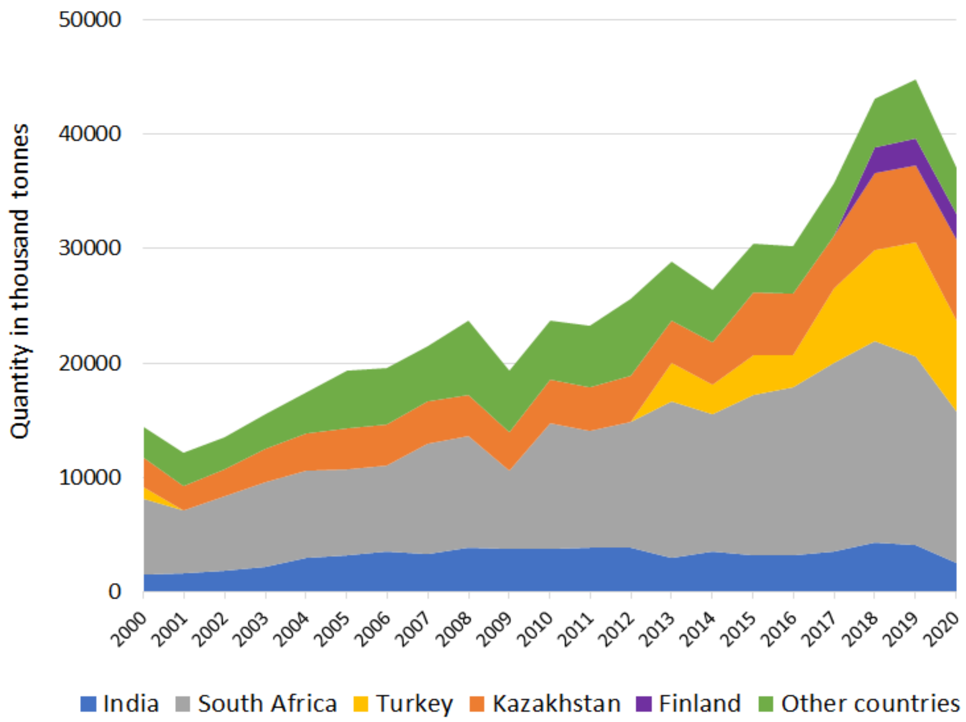

Figure 27. Global production of chromite concentrate since 2000 according to USGS data (USGS, since 2000).

OUTLOOK FOR SUPPLY

The global chromite market is expected to grow by a compound annual growth rate (CAGR) of 4.71% during the period 2022-2026 (Globenewswire, 2022), however there are no available published data concerning the supply increase during the same period. Ferrochromium production is electrical-energy intensive, so constrained electrical power supply and rising costs for electricity in South Africa, which consist the world's larger chromite producer and the second larger ferrochromium producer, could impact on the global FeCr production (USGS, since 2000).

4.3 PRODUCTION OF CHROMIUM BY SECONDARY RESOURCES

There is no specific recycling scheme for pure chromium metal, as the vast majority of chromium is used in the form of alloys. However, stainless steel which accounts for approximatively 70% of chromium's consumption in the EU (BRGM 2017) is very well recycled. The post-consumer functional recycling of stainless steel reaches rates between 80% and 90%, depending on the product (UNEP 2011). In general, the scrap content in the production of stainless steel is estimated at 60%, of which 25% consists of old scrap and 35% of new scrap (BRGM 2017). Stainless steel is commonly recycled in separated flows as its properties will be lost if mixed with common steel scrap.

On the other hand, the detection and sorting of alloy steel products are more complicated, and thus the

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majority of these products ends up in carbon steel (non-functional recycling) (Deloitte 2015). Superalloys (non-ferrous alloys containing chromium) are also recyclable in the same application if the scrap is properly sorted for the production of the same alloy.

According to data provided by the MSA study of chromium, in 2013 the end-of-life recycling input rate (EOL-RIR) in the EU was 21%, the overall functional recycling rate (EOL-RR) was 48%, and the non-functional recycling rate was 24% (Deloitte 2015). These figures are similar to those reported globally in more recent reports (ICDA 2021).

In 2013, the total EU production of crude stainless steel and alloy steel represented around 1,700 kt of chromium content, with an important input of 780 kt of chromium content as scrap (Deloitte, 2015). Specifically, the input from old scrap from recycled end-of-life products was around 380 kt, imports of secondary material represented 90 kt, and 310 kt came from new scrap. About 170 kt of chromium in scrap were generated from the processing of steel in primary forms ("home" scrap), and directly remelted into new steel; 130 kt were generated as "new" scrap from the manufacturing of finished products. The stock accumulated in landfill over the last 20 years is calculated in the MSA study at around 3,000 kt in chromium content (Deloitte 2015).

Other uses, such as leather tanning or pigments, are dissipative and chromium cannot be economically recovered, although various hydrometallurgical processes are known for chromium depollution and decontamination (Dhal 2013).

4.4. PROCESSING OF CHROMITE TO PRODUCE FERROCHROMIUM AND CHROMIUM

Ferrochrome is an alloy of chromium and iron made using metallurgical grade chrome ore. It contains 45% to 75% chromium by weight with much smaller amounts of carbon and silicon which determine the grade or type of alloy. Depending on the level of carbon in the alloy, ferrochrome can be divided into three categories (NRC 1995): high-carbon (HC) ferrochrome (carbon content between 4% and 9%), low- and medium-carbon (LC & MC) ferrochrome (carbon content less than 0.5% for LC and between 0.5% and 4% for MC), and ferrochrome-silico-chrome (FeSiCr).

According to recent data (ICDA 2021), 94.5% of the global ferrochromium alloys production in 2021 comprised high-carbon and charge chrome, 0.2% medium-carbon ferrochrome, and 5.3% low-carbon ferrochrome.

Ferrochrome alloys are produced from metallurgical-grade chromite by smelting a mixture of the ore (in the form of lumpy ore, fines or concentrates), a reductant (e.g. coke) and auxiliary flux materials in an electric arc furnace. AC arc, DC arc (or plasma) furnace technology can be used for the high-temperature reduction (smelting). The smelting process is electrical-energy intensive requiring up to 4,000 kWh per tonne of material weight with the efficiency varying with ore grade, operating conditions, and production process (ICDA 2023).

Depending on the different production routes and the desired carbon content of the ferrochrome, carbon or silicon is used as a reducing agent. For the production of HC FeCr, carbon is added to the process as a reducing agent, predominantly metallurgical coke (with a low phosphorus and sulphur content). The most common modern method of production of HC FeCr with high chromium content is smelting in submerged electric arc furnaces. The basic principle of electric furnace smelting of HC FeCr is to reduce chromium and iron oxides with carbon. For the production of LC FeCr, ferro-silicon-chromium and ferrosilicon are used in a silicothermic

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reduction as reducing agents and raw material. The most commonly used processes to manufacture low carbon ferrochrome are metallo-thermic reductions known as the Duplex (Perrin) or Simplex processes. MC FeCr can be produced by the silico-thermic reduction of chromite ore and concentrates or by the decarburisation of HC FeCr in an oxygen-blown converter. The silico-thermic route is more economic and therefore more important today for producing MC FeCr. This may be because of the low demand for MC FeCr compared to the high demand for HC FeCr. LC FeCr can be produced by the same process.

Chemical grade chrome ore represents 3 to 5% of the global chrome ore output, used by the chrome chemical industry. Chemical-grade chromite ore is processed, together with soda ash (sodium carbonate) by a rotary kiln roasting process to produce sodium chromate. The sodium chromate is then converted into a variety of chromium chemicals such as sodium dichromate, chromic acid and chromium oxide, which are subsequently manufactured into other chromium compounds (such as chromium (III) oxide).

Pure chromium metal is produced primarily through the aluminothermic process by the reduction of chromium (III) oxide and by the electrodeposition process using a wide variety of electrolytes (NRC 1995). Chromium metal standard grades range from 99% to 99.4%.

OTHER CONSIDERATIONS

HEALTH AND SAFETY ISSUES

Chromium may be found in different oxidation states, with Cr^{II}, Cr^{III} and Cr^{VI} as most common compounds. While the first two compounds may be considered relatively harmless, in its sixth oxidation state, chromium becomes a hazardous compound. Exposure to Cr^{VI} through ingestion or inhalation may indeed result in various types of physiological damages: ulcerations (cuts and abrasions of skin, ulcerations of the nasal septum), dermatitis (skin irritation and sensitization), acute respiratory effects (irritation of mucous membranes), carcinogenic effects (e.g. lung cancer), and effects in other organs (e.g. necrosis of kidneys). To prevent any potential risks of exposure to Cr^{VI}, the ILO recommends to suppress dust and mist containing Cr^{VI} as far as possible, e.g. through wet cleaning (ILO, 2011), or adequate ventilation.

Sodium chromate is a substance of very high concern and is listed as entry 22 on REACH ANNEX XIV (List of substances for authorization) due to its mutagenicity, carcinogenicity and toxicity for reproduction. Chromium VI compounds are included in REACh Annex XVII. The placing on the market and use in certain products/applications of these substances is therefore restricted. For example, “cement and cement-containing mixtures shall not be placed on the market, or used, if they contain, when hydrated, more than 2 mg/kg (0.0002 %) soluble chromium VI of the total dry weight of the cement” (ECHA, 2021).
Canada published technical guidelines related to the presence of chromium in drinking water, i.e. a maximum acceptable concentration of 0.05 mg/L (50 µg/L) is established for total chromium in drinking water. (Government of Canada, 2018)

ENVIRONMENTAL ISSUES

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In a life cycle perspective, the environmental impacts of chromium production on a per kilogram basis range among the lowest of the metals sector (out of 63 metals) considering the global warming potential, cumulative energy demand, terrestrial acidification and freshwater eutrophication impact categories. However, when considering the global annual chromium production volume (which is relatively significant compared to other metals), the impacts in terms of global warming potential appear among the highest of the metals sector (11th out of 63) (Nuss and Eckelman, 2014).

From a process perspective, the environmental impacts of chromium production are primarily induced by purification and refining operations, while mining/concentration operations have limited contributions to these impacts (Nuss and Eckelman, 2014).

NORMATIVE REQUIREMENTS

The maximum discharge limit to the aquatic environment in the EU are 1 and 5 mg/l for CrVI and Cr(total), respectively. (Vaiopoulou et al. 2020)

Zimbabwe issued a local regulation related to chromium mining, where this sector is one of the main contributors to the national economy (Mining Technology, 2018). In 2018, the government first introduced a two-week ban, following reports of dangerous and destructive chrome mining operations. The ban was then deleted, "on the condition that chromium mining operations adhere to new regulations […] Chrome miners will … be obliged to rehabilitate land damaged by operations once mines have been exhausted, and mining companies will have to employ managers on permanent contracts to monitor and control mining activities" (Mining Technology, 2018).

RESEARCH AND DEVELOPMENT TRENDS

RESEARCH AND DEVELOPMENT TRENDS FOR LOW-CARBON AND GREEN TECHNOLOGIES

- Deposition of black chromium coating for solar thermal application, Weng Wen et al. 2023

Deposition of black chromium on the substrates provides the coating surface as a medium for converting solar energy into thermal energy. This work focused on coating black chromium onto two different substrate materials; zinc and aluminium plates. The optical properties of the coated substrates were tested and analysed. It was found that with duplex coating application, both the zinc and aluminium substrates exhibited absorptivity with more than 0.85 and emittance lower than 0.24. Crack was barely seen on zinc coated sample, but obvious on aluminium coated sample with average coating thickness of 5.382 µm on zinc coated sample and 8.168 µm on aluminium coated sample. Chemical composition analysis showed that chromium was the major element present in the coating with a smaller amount of oxygen element. The deficiency in the optical property value could be attributed to the lack of black colorization due to the low amount of oxygen in the coating with higher quantity of Cr, CrO and Cr_2O_3.

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- Insight to chromium homeostasis for combating chromium contamination of soil: Phytoaccumulators-based approach (Pandey et al. 2023)

Chromium (Cr) is a naturally occurring, carcinogenic heavy metal that has become a pressing concern in recent decades for environmentalists. Due to high anthropogenic activities, the concentration of Cr has crossed the environmental threshold levels and consequently contaminated soil and water. The high solubility of Cr ions in the groundwater results in its high uptake by the plants leading to phytotoxicity and yield loss. The dearth of efficient and cost-effective treatment methods has resulted in massive chromium pollution. However, some phytoaccumulators capable of accumulating Cr in high amounts in their shoots and then performing their metabolic activity typically have been identified. Chromium bioremediation using phytoaccumulators is very contemplative due to its eco-friendly and cost-effective outcome. These accumulators possess several mechanisms, such as biosorption, reduction, efflux, or bioaccumulation, naturally or acquired to counter the toxicity of chromium. This review focuses on the detoxification mechanism of Cr by the phytoaccumulator species, their responses against Cr toxicity, and the scope for their application in bioremediation.

OTHER RESEARCH AND DEVELOPMENT TRENDS

- CHROMA[4] project:- Mobilization of chromium by organic matter in reduced systems (2022 – 2024, EU)

Long-term pollution mitigation measures require a better understanding of the biogeochemical processes that regulate the behaviour of trace metals, such as chromium, over time. While stable chromium isotopes can be used to effectively assess the element’s biogeochemical and redox cycles, few studies have investigated the ligand-induced chromium mobilisation mechanism. The CHROMA project will investigate whether chromium can be mobilised by organic ligands under various environmental conditions. To this end, it will combine field sampling, isotopic analysis and geochemical modelling. Project results will help reveal more about how organic ligands affect the chromium redox cycle and how anthropogenic activities impact the subsurface environment.

- Cr VI FREE COATING project: Development of an innovative alternative to the use of hexavalent chromium in the aerospace coating[5] (2018, EU)

The project aimed to develop the first green, anticorrosion primer for aircraft structures. Hexavalent chromium has been widely used as an anticorrosive agent in primers applied on structural airframe components. Despite its durability and long-term corrosion resistance, it causes adverse health effects. The EU-funded Cr VI FREE COATING project is developing a water-based primer free of carcinogenic compounds. The first-of-its kind coating will be easily sprayed onto large aerospace parts with a long pot life exceeding 4 hours and with reduced concentrations of volatile organic compounds. Furthermore, researchers are designing droplet tests to reduce the time of primer effectiveness testing from 3,000 to 168 hours.

[4] CORDIS EU research results, https://cordis.europa.eu/project/id/101031974
[5] CORDIS EU research results, https://cordis.europa.eu/project/id/816090

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- An environment-friendly chromium electrodeposition process using additive-laden deep eutectic solvent (Brusas et al. 2023)

The development of safer and more sustainable electrochemical processes has been one of the promising applications of deep eutectic solvents. In this study, a trivalent chromium-ethaline deep eutectic solvent electrolyte with the incorporation of significant plating additives such as water, boric acid, and lithium chloride was developed for chromium electroplating application. The effect of the selected plating additives on the morphology of the chromium deposits was mainly investigated.

- Statistical analysis and profiling of chromium leaching characteristics in Basic Chrome Sulphate (BCS) sludge dumping at Khanchandpur-Rania, district Kanpur Dehat, Uttar Pradesh (India), Kumar et al. 2023[6]

The present investigation has been conducted to study the leaching behaviour of chromium species in immobilised hazardous waste containing Basic Chrome Sulphate (BCS) dumped at Khanchandpur-Rania, Kanpur Dehat district of Uttar Pradesh, India. Results indicated that the concentration of total and TCLP-based Cr and Cr 6+ increased with depth. A similar trend was also observed in total and TCLP-based Cr 3+, total Fe, total Mn and TDS contents, which strongly justified the leaching characteristic of salts increasing with the increasing depth level of the dumpsite.

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