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 **BASED ON THE EU FACTSHEETS 2020**

IRON ORE

AUTHOR(S):

TABLE DES MATIÈRES

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IRON ORE

OVERVIEW

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Iron ore is the source of primary iron for the iron and steel industry. It consists mostly of iron oxides, the primary forms of which are magnetite (Fe_3O_4) and hematite (Fe_2O_3). Iron (chemical symbol Fe, atomic number 26, transition metal group) is a lustrous silver-grey metal with density of 7.87 g/cm^3 and melting point of 1,530°C. Pure iron is rarely used as it is relatively soft (4 in Mohs hardness scale) and oxidises rapidly in air to hydrated iron oxides, commonly known as rust. Iron is commonly used as an alloy with other elements to make thousands of different steel grades and other alloys with a vast range of desirable properties. Iron ore smelting in the presence of a reductant generally yields an alloy of iron and carbon (pig iron) which usually contains 3.5-4.5% carbon along with small amounts of other elements such as silicon, manganese and phosphorus.

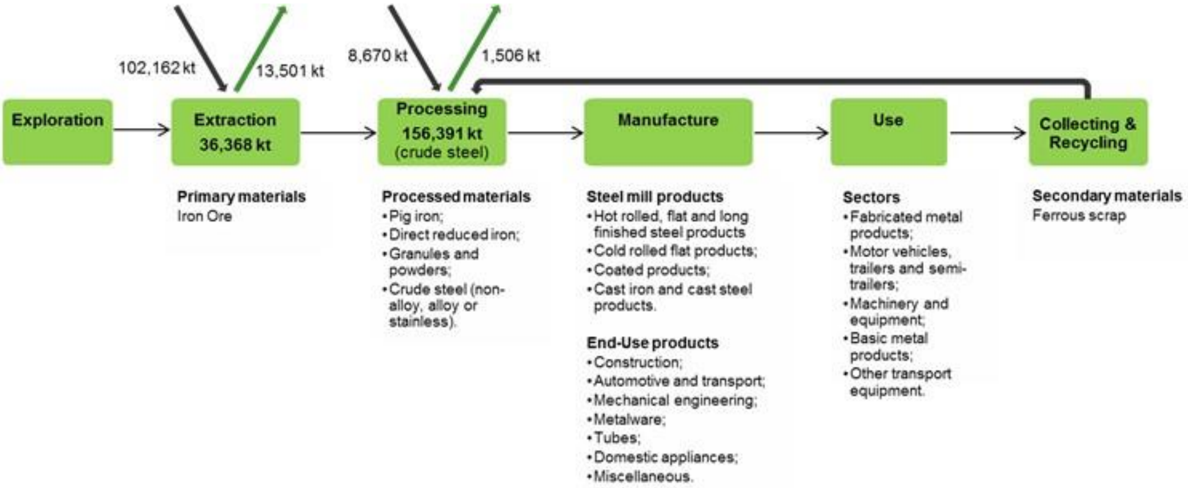

Figure 1. Simplified value chain for iron ore in the EU[1]

Table 1. Iron ore supply and demand (extraction) in metric tonnes, Fe content, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
1,515,358,230	Australia 37% Brazil 18% China 14% India 9% Russia 4% South Africa, Ukraine 3%	76,644,797	5%	Brazil 38% Canada 21% Ukraine 17% Russia 7% South Africa 6% Liberia, Mauritania 3% Norway 2%	**71%**

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

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Table 2. Iron ore supply and demand (processing) in metric tonnes, Fe content, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
1,668,290,348.0	China 52% India 6% Japan 6% USA 5% Russia 4%	150,379,229	9.0%	Russia 43% Ukraine 29% Brazil 11% UK 7%	**5%**

Prices: Until the early 2000s, the price of iron ore was exclusively fixed by annual over-the-counter (OTC) negotiations between producers and steel producers. The explosion of the Chinese steel demand and the resulting tightening of the iron ore supply disturbed the prevailing pricing system, and the spot market emerged in the early 2000s. The massive demand growth driven by the industrialisation of China has had a distinct effect on the iron ore price evolution. The peaks in price evolution are associated with supply deficits incurred in the seaborne market, and the troughs with periods when supply growth eventually exceeded demand growth (Wilson, 2015) (S&P Global, 2019). A strong upward trend is observed from 2005 to mid-2008 when prices surged before collapsing rapidly within one year during the global financial crisis (Löf and Ericsson 2016). Iron ore prices recovered almost to their pre-crisis levels by mid-2011 induced by increased demand from China due to an economic recovery plan to counter the effects of the global financial crisis, mainly based on infrastructure investments, which boosted demand for steel (Le Gleuher, 2019).

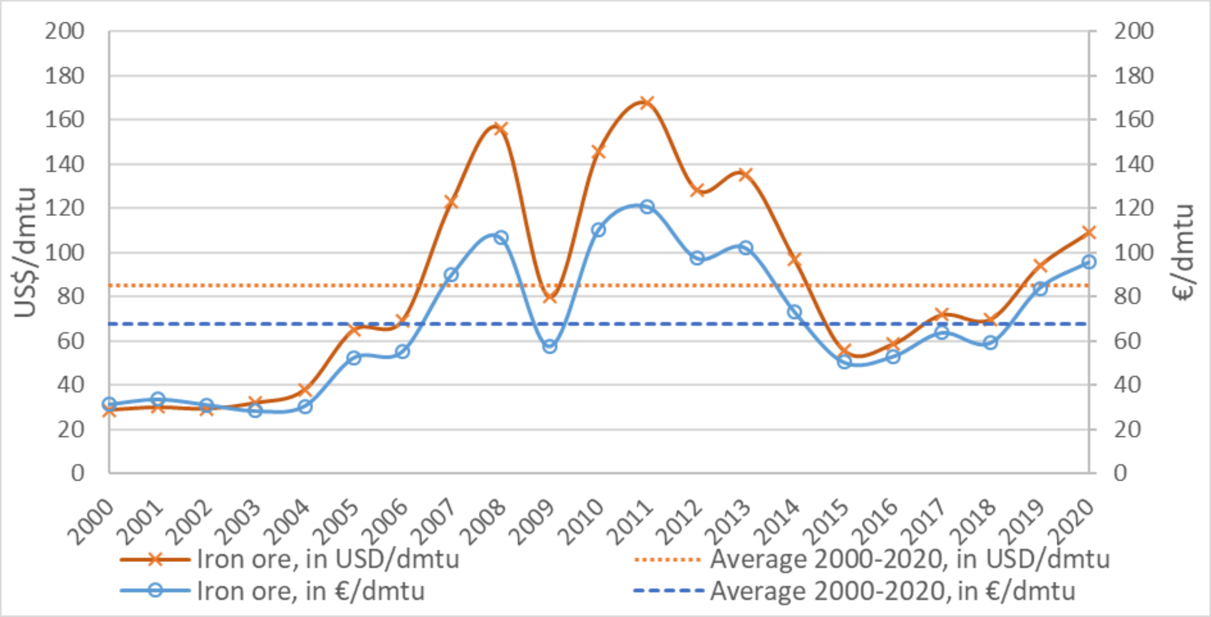

Figure 2. Annual average price of iron ore between 2000 and 2020 (USGS, 2021)[2].

Primary supply:

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[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)

Secondary supply:

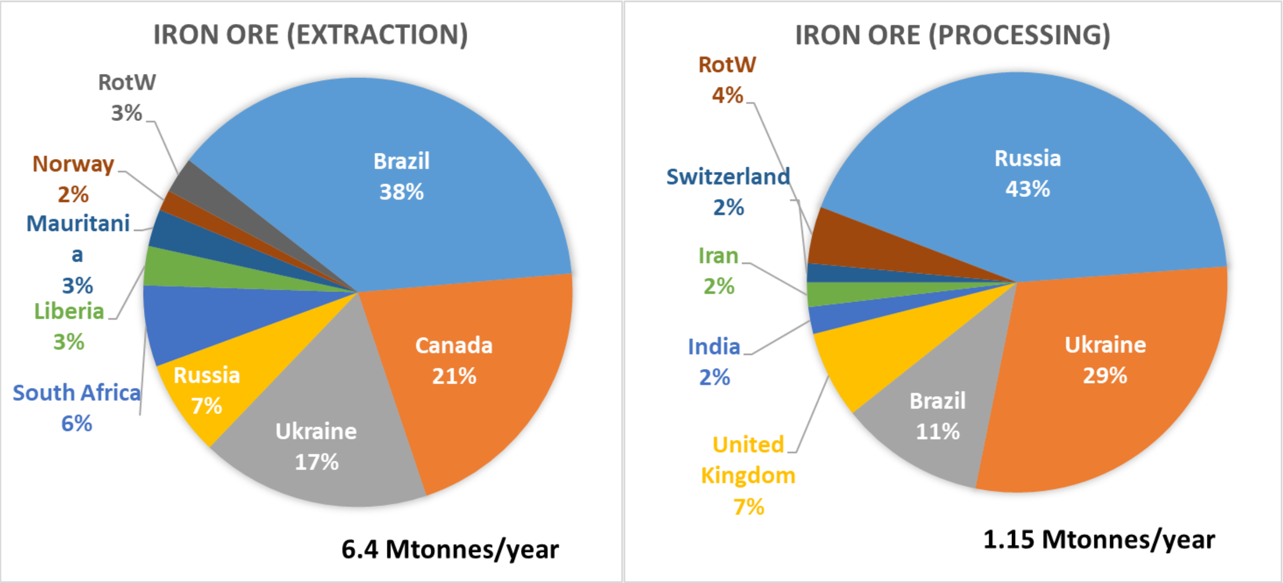

Figure 3. EU sourcing of iron ore (quantity in Fe content)

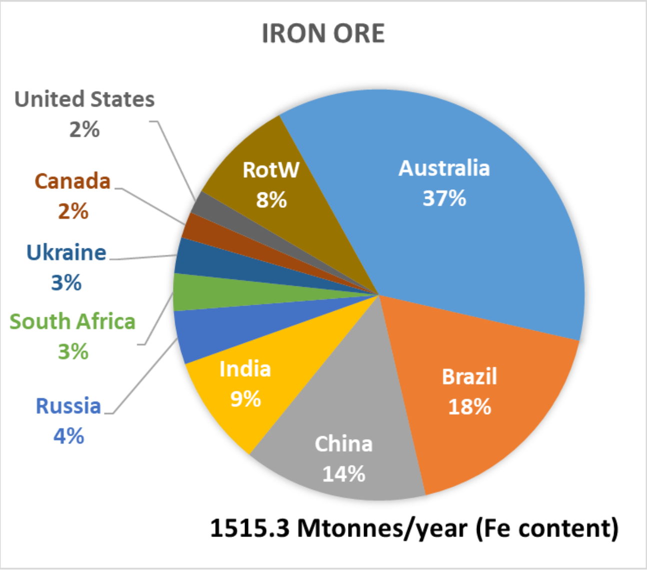

Figure 4. Global mine production (update)

Uses: Iron ore is is the main feedstock raw material for primary steel production and for cast iron production. Approximately 98% of the iron ore shipped worldwide is consumed in iron and steel manufacturing (USGS 2018). The remaining 2% of the total iron ore consumption is used in a range of non-steel applications. Iron is the by far mostly used metal in our society. Steel, which is an alloy of iron, carbon and possibly further elements, is closely linked to many different downstream industrial sectors. The construction sector, which includes buildings and infrastructure, accounts for about 40% of steel demand in Europe (Eurofer 2020). Further significant steel consuming sectors are the transportation, industrial equipment and appliances sectors.

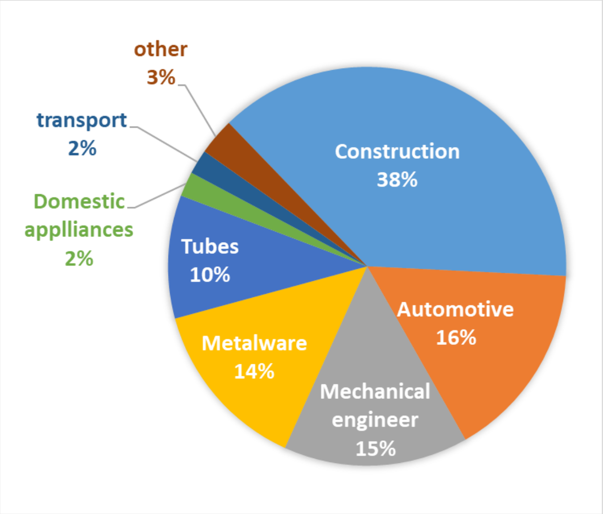

Figure 5: EU uses of iron ore (Steel and cast iron consumption in the EU per steel-using sector) (Eurofer 2020)

Substitution: Substitutes have been identified for the applications of steel in construction, automotive, mechanical engineering and metals products. There are no substitutes for iron ore itself, but steel and iron scrap can to a certain extend and depending on its quality serve as alternative raw materials for iron- and steelmaking.

Table 3. Uses and possible substitutes

Use	Percentage*	Substitutes	Sub share	Cost	Performance
Construction	38 %	Reinforced concrete	30%	Similar or lower costs	Similar
Construction	38 %	Timber	7%	Similar or lower costs	Reduced
Construction	38 %	Masonry	6%	Similar or lower costs	Similar
Construction	38%	Others	4%	Similar or lower costs	Similar
Automotive	16 %	Aluminium	13%	Slightly higher costs (up to 2 times)	Similar
Automotive	16 %	Magnesium - alloy	7%	Very high costs (more than 2 times)	Similar
Automotive	16 %	Carbon fibre composites	5%	Very high costs (more than 2 times)	Similar
Mechanical equipment	15 %	Composites	13%	Very high costs (more than 2 times)	Similar
Mechanical equipment	15 %	Aluminium	13%	Slightly higher costs (up to 2 times)	Similar
Mechanical equipment	15 %	Magnesium	13%	Very high costs (more than 2 times)	Similar
Mechanical equipment	15 %	Titanium	13%	Very high costs (more than 2 times)	Similar
Metalware	14 %	Plastics	10%	Similar or lower costs	Reduced
Metalware	14 %	Silver	10%	Very high costs (more than 2 times)	Similar

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Metalware	14 %	Bronze	10%	Slightly higher costs (up to 2 times)	Similar
Metalware	14 %	Copper	10%	Very high costs (more than 2 times)	Similar
Metalware	14 %	Aluminium	10%	Very high costs (more than 2 times)	Similar

** European end use consumption shares for 2019 according to Rostek et al. (2019) based on Dworak et al. (2021) and WSA (2020)*

Other issues: According to the notifications provided by companies to ECHA in REACH registrations no hazards have been classified for iron ores (ECHA 2022). Iron ore extraction can have detrimental impacts on the quality of the air, the water and on the biological species. An in-depth analysis in Liberia showed degraded water quality because of surface runoff and leachate that are frequently generated from large volume overburden and tailings that are produced during iron ore mining and subsequent processing activities. A life cycle assessment of GHG emissions for iron ore mining and processing in China shows that the mean life-cycle GHG emissions for Chinese iron ore production are 270 kg CO2e/tonne, with a 90 % confidence interval ranging from 210 to 380 kg CO2e/tonne. Iron ore production is key in the economy of several countries: The top three countries with the highest economic share of iron ores exports are Mauritania (54.8 %), Australia (33.9 %), and Brazil (15.9 %). Ukraine and Mongolia accounts for 10.3 % of the overall exports, followed by South Africa (8.1 %).

MARKET ANALYSIS, TRADE AND PRICES

GLOBAL MARKET

Table 4. Iron ore supply and demand (extraction) in metric tonnes, Fe content, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
1,515,358,230	Australia 37% Brazil 18% China 14% India 9% Russia 4% South Africa, Ukraine 3%	76,644,797	5%	Brazil 38% Canada 21% Ukraine 17% Russia 7% South Africa 6% Liberia, Mauritania 3% Norway 2%	**71%**

Table 5. Iron ore supply and demand (processing) in metric tonnes, Fe content, 2016-2020 average

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The main producers of iron ore include Australia (37%), Brazil (18%), China 14%, India 9%, and Russia 4%. The world's top exporters of iron ore (2020) were Australia and Brazil with respectively 75.82 billion euros and 25.24 billion euros ($79.6 billion and $26.5 billion) (OEC, 2022). China is by far the largest importer of iron ore (1342.19 million metric tons-2019 value, World Steel Association, 2021).

The biggest market players and iron ore producers in 2021 were Vale, Rio Tinto, BHP Group and Fortescue Metals Group, each making up 13%, 11%, 10% and 8% of the global production share, consecutively (S&P Global, 2022).

International price reporting agencies such as "The Steel Index and Metal Bulletin" compile spot prices from physical iron ore trading, and after applying a variety of methodologies, come up with various volume-weighted average reference prices (indexes) within a specified data collection window (e.g., daily, weekly or monthly) (Fastmarkets, 2018) . The benchmark prices assessed by agencies are used globally for short-term and spot contracts, as well as a basis for discussing longer-term contractual agreements (in any case less than one year). Iron ore's derivatives market has also developed in the recent years, e.g., the Singapore Mercantile Exchange (SMX) was one of the first exchanges to offer futures contract in 2011 (Fastmarkets, 2018) . Sinter fines and lumps make up the bulk of the seaborne iron ore market and are the products most frequently traded on a spot basis. By contrast, the beneficiated iron ore comprising pellet and concentrate is smaller in terms of both volume and liquidity, and weekly assessed indices are therefore more appropriate (Fastmarkets, 2018).

The COVID-19 pandemic had and still has a significant impact on the iron ore market, with a slowing global economy weighing on iron ore demand. Ongoing COVID outbreaks and a depressed property sector in China have put further pressure on the market (S&P Gobal Market Intelligence, 2022). Increased output from Australia and Brazil alleviates some of the negative effects, but the market is still sluggish. Fitch Solutions forecast iron ore production to grow by 0.8% y-o-y in 2020 compared with 4.7% y-o-y in 2019, as a result of government lockdowns around the world causing operational disruptions (MINING.COM, 2020).

EU TRADE

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

Table 6. Relevant Eurostat CN trade codes for Iron Ore.

Mining		Processing/refining	
CN trade code	title	CN trade code	title
26011100	Iron ores and concentrates, non-agglomerated	7206	Iron and non-alloy steel in ingots or other primary forms (excl. remelting scrap ingots, products obtained by continuous casting and iron of heading 7203)
26011200	Iron ores and concentrates; agglomerated (excluding roasted iron pyrites)	7207	Semi-finished products of iron or non-alloy steel
		7224	Steel, alloy, other than stainless, in ingots or other primary forms, semifinished products of alloy steel other than stainless (excl. waste and scrap in ingot form, and products obtained by continuous casting)
		7218	Stainless steel in ingots or other primary forms (excl. remelting scrap ingots and products obtained by continuous casting); semi-finished products of stainless steel

The listed CN codes that referring to Iron Ore are: 260111-Iron ores and concentrates, non-agglomerated, 260112- Iron ores and concentrates; agglomerated (excluding roasted iron pyrites), 7206- Iron and non-alloy steel in ingots or other primary forms (excl. remelting scrap ingots, products obtained by continuous casting and iron of heading 7203), 7207- Semi-finished products of iron or non-alloy steel, 7224-Steel, alloy, other than stainless, in ingots or other primary forms, semifinished products of alloy steel other than stainless (excl. waste and scrap in ingot form, and products obtained by continuous casting) and 7218-Stainless steel in ingots or other primary forms (excl. remelting scrap ingots and products obtained by continuous casting); semi-finished products of stainless steel.

Figure 6 shows the import and export trend of Iron ores and concentrates, non-agglomerated. EU is net importer of Iron ores and concentrates. EU import showed a decreasing trend with some fluctuations. In 2008, the EU import unexpectedly decreased 54% from 101,122,377 tonnes to 54,707,761 tonnes. The import of

Iron ores and concentrates, non-agglomerated fell during 2019 and 2020 as COVID-19 pandemic happened. EU's export of Iron ores and concentrates increased considerably from 199,987 tonnes in 2000 to 2,578,947 tonnes in 2021.

Figure 7 illustrates the share of import in EU for Iron ores and concentrates, non-agglomerated from various countries. The main import partners of EU are Brazil (49%), Ukraine (12%), Canada (7%), Mauritania (incl. Spanish Sahara from 1977) (7%) and South Africa (5%). Brazil used to be the main supplier during 2000-2021.

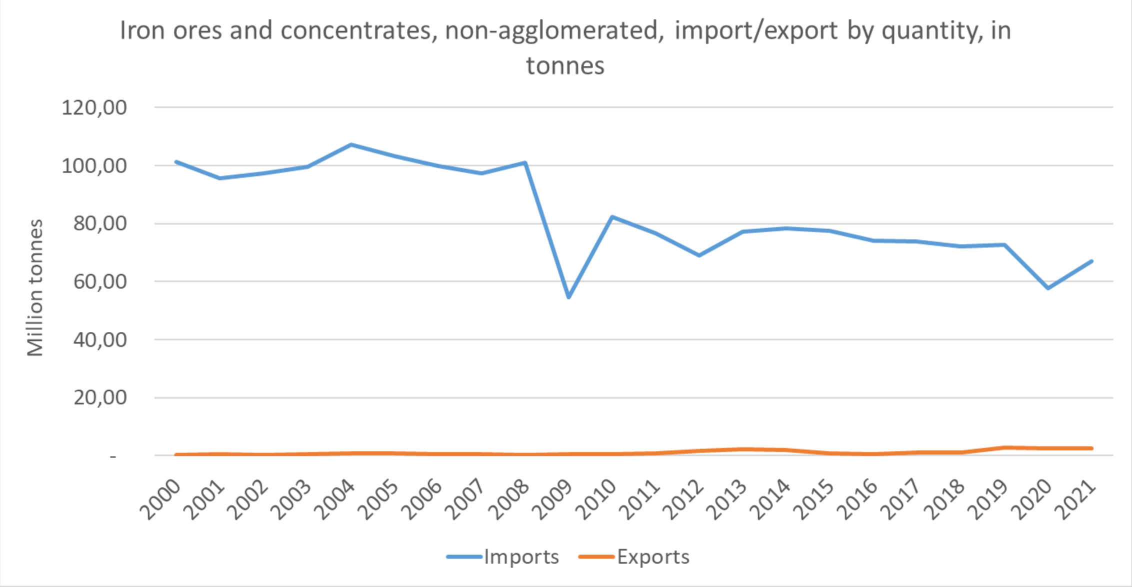

Figure 6. EU trade flows of Iron ores and concentrates, non-agglomerated (CN 260111) from 2000 to 2021 (Eurostat, 2022)

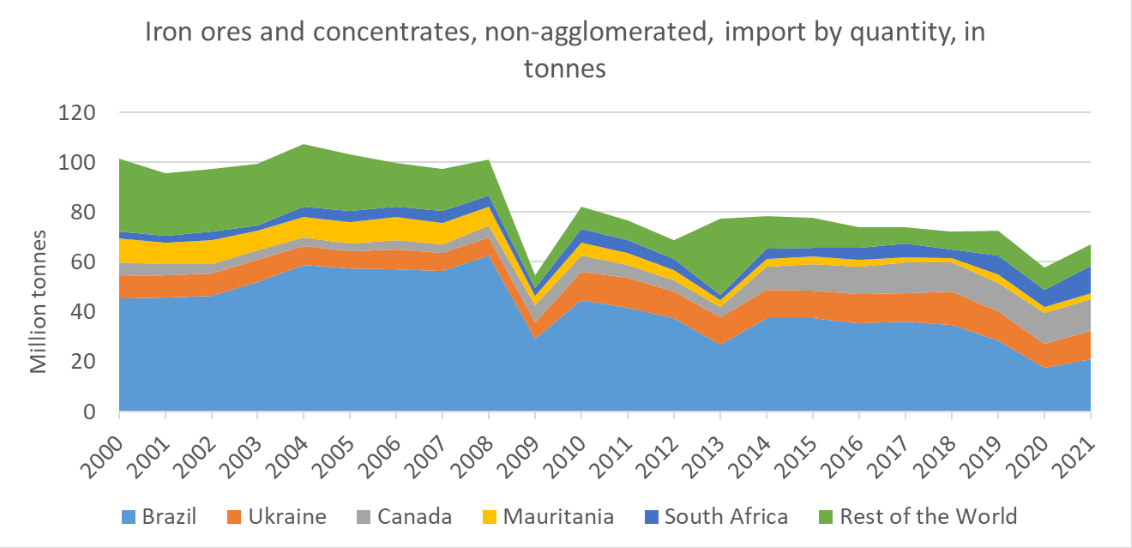

Figure 7. EU imports of Iron ores and concentrates, non-agglomerated (CN 260111) by country from 2000 to 2021 (Eurostat, 2022)

Figure 8 shows the import and export trend of Iron ores and concentrates; agglomerated (excluding roasted iron pyrites). The EU is a net importer of this material in the observed period (2000-2021). The import of Iron

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ores and concentrates; agglomerated declined from 37,275,677 tonnes in 2000 to 20,198,855 tonnes in 2020 and then increased to 26,645,401 tonnes in 2021. The EU exports has been relatively stable compared to the imports and had an increasing trend till 2020 and decreased to 10,286,453 tonnes in 2021.

Figure 9 illustrates the share of import in EU from various countries. The main supplier to EU in the past two decades (2000-2021) was Brazil (32% of share), followed by Canada, Russia, and Ukraine (24%, 16%, and 16%, respectively). The most notable trend is the decreasing of imports from Brazil especially since 2015.

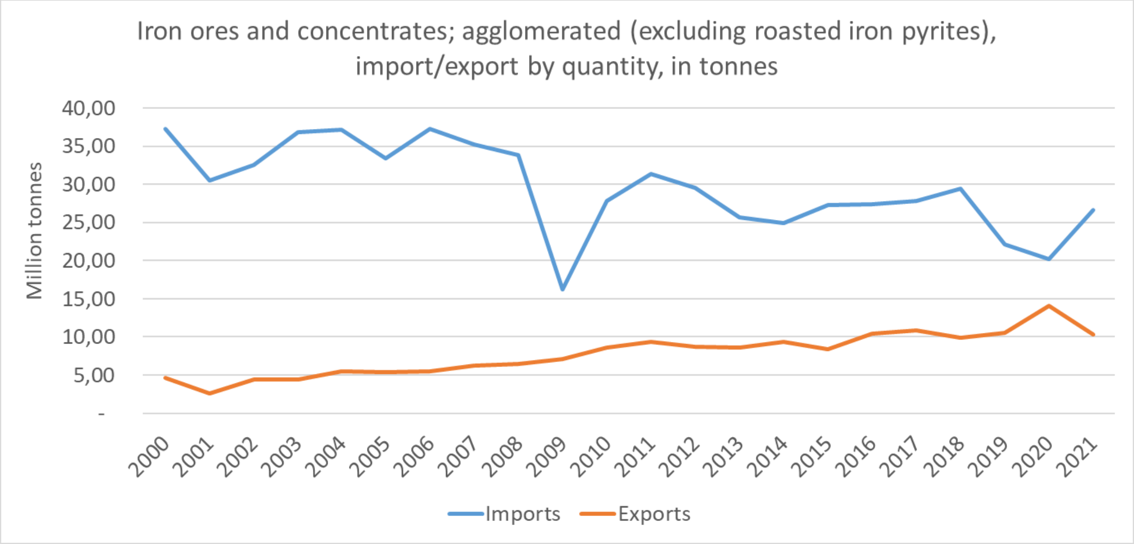

Figure 8. EU Trade flows of Iron ores and concentrates; agglomerated (excluding roasted iron pyrites) (CN 260112) from 2000 to 2021 (Eurostat, 2022)

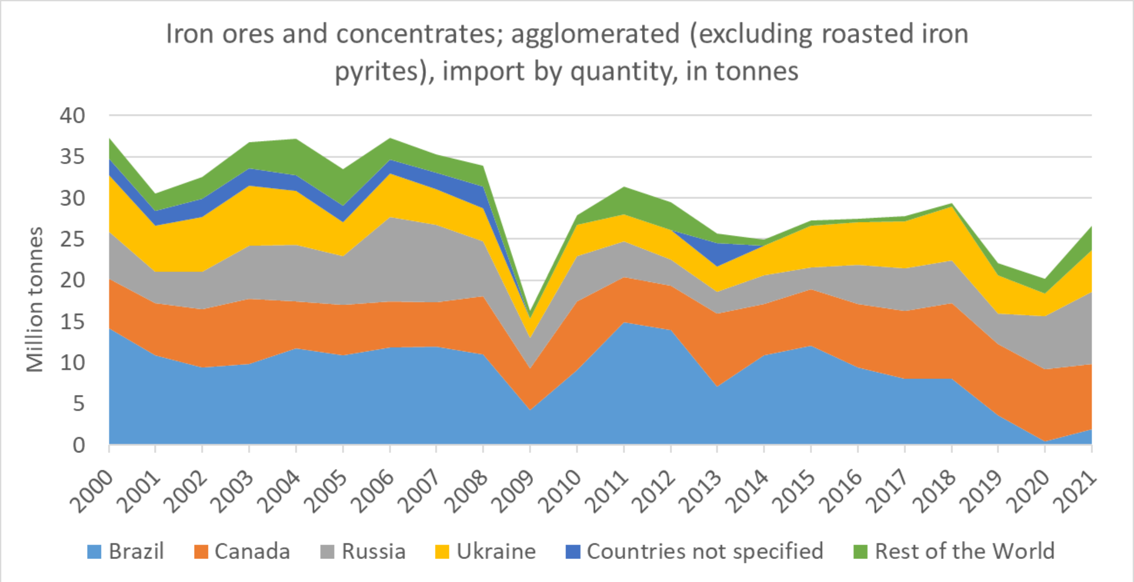

Figure 9. EU imports of Iron ores and concentrates; agglomerated (excluding roasted iron pyrites) (CN 260112) by country from 2000 to 2021 (Eurostat, 2022)

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Until 2008, EU imported little quantity of roasted iron pyrites (up to 550 000 tonnes in 2006) but then it drops to less than 500 tonnes since 2018. Between 2003 and 2008 the imports were mainly from Ukraine (Figure 10 and Figure 11).

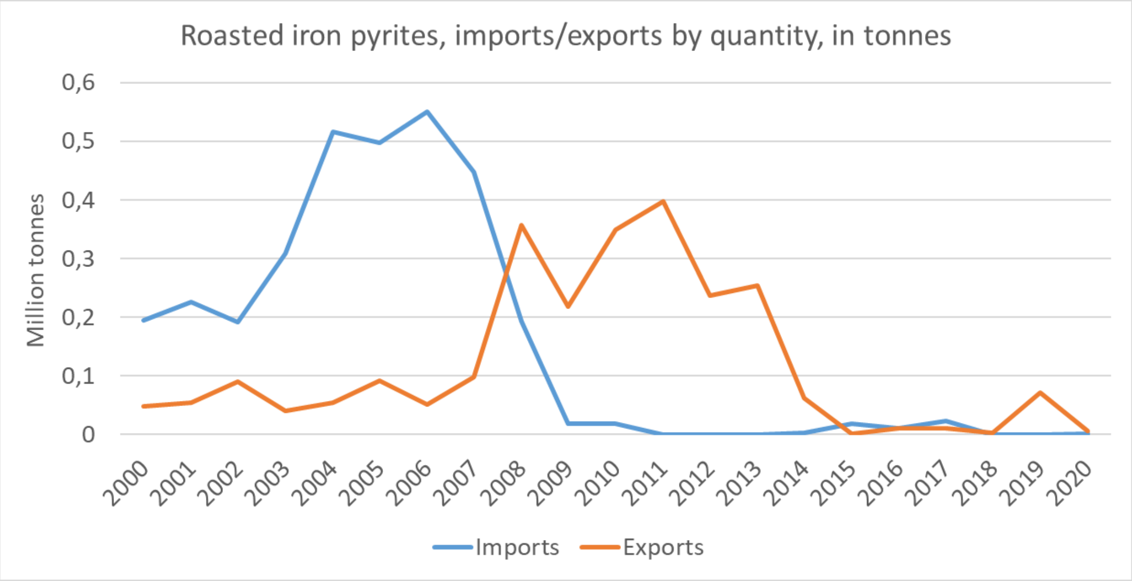

Figure 10. EU Trade flows of Roasted iron pyrites (CN 260120) from 2000 to 2021 (Eurostat, 2022)

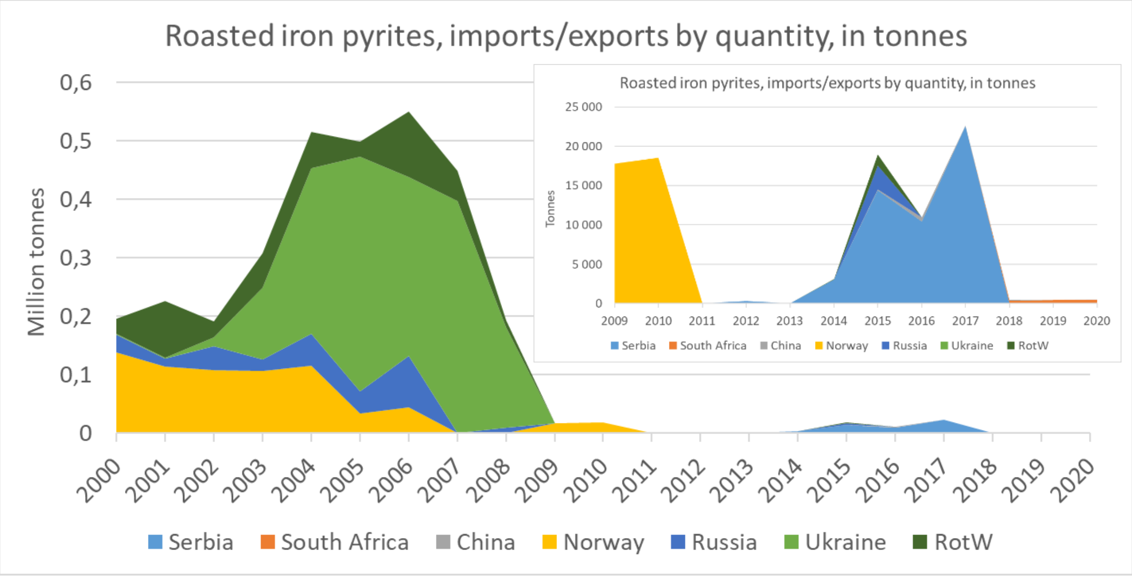

Figure 11. EU imports of Roasted iron pyrites (CN 260120) by country from 2000 to 2021 (Eurostat, 2022)

Figure 12 shows the import and export trend of Iron and non-alloy steel in ingots or other primary forms (excl. remelting scrap ingots, products obtained by continuous casting and iron of heading 7203) over the period from 2000 to 2021. The EU export and import had a relatively same value between 2000 and 2003. Then the export started to increase from 2004. It had some fluctuations with an increasing trend but from 2018 it showed a declining trend and reach to 22,191 tonnes in 2021. The import also had an increasing trend with fluctuations over the years. Furthermore, the import and export of Iron and non-alloy steel in ingots or other primary forms fell during 2019 and 2020 as COVID-19 as pandemic happened.

Figure 13 illustrates the share of Iron and non-alloy steel in ingots or other primary forms from various countries. The main supplier to EU in these 21 years was Russia (30%), Venezuela (19%), Norway (17%), Ukraine (8%) and Brazil (7%). The import from Russia significantly raised since 2006 and Russia was the main supplier of non-alloy steel in ingots or other primary forms in the most years between 2006 and 2021. Another noticeable point is that there was no import from Brazil in some years.

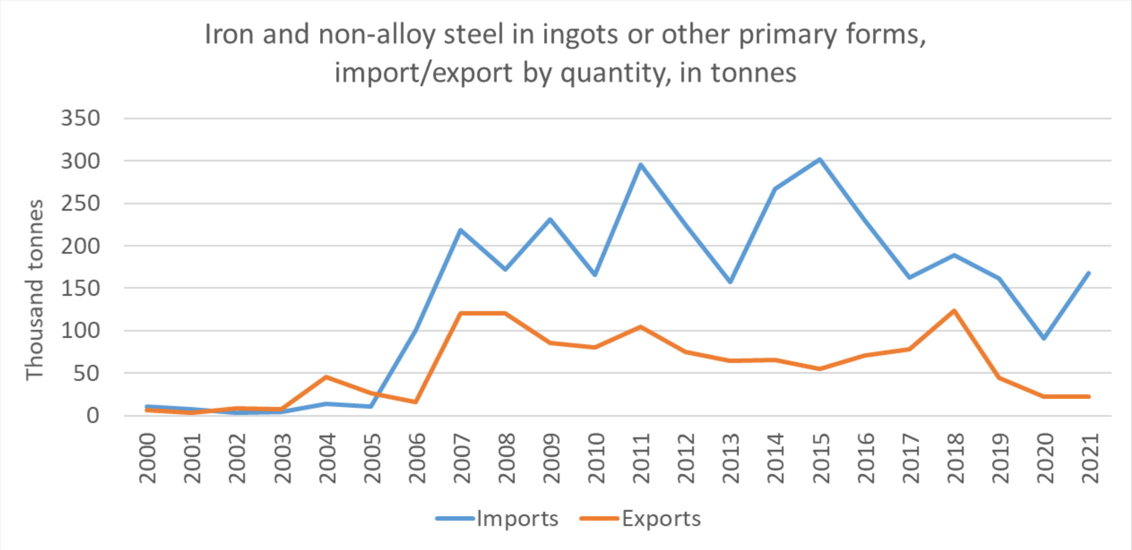

Figure 12. EU Trade flows of Iron and non-alloy steel in ingots or other primary forms (CN 7206) from 2000 to 2021 (Eurostat, 2022)

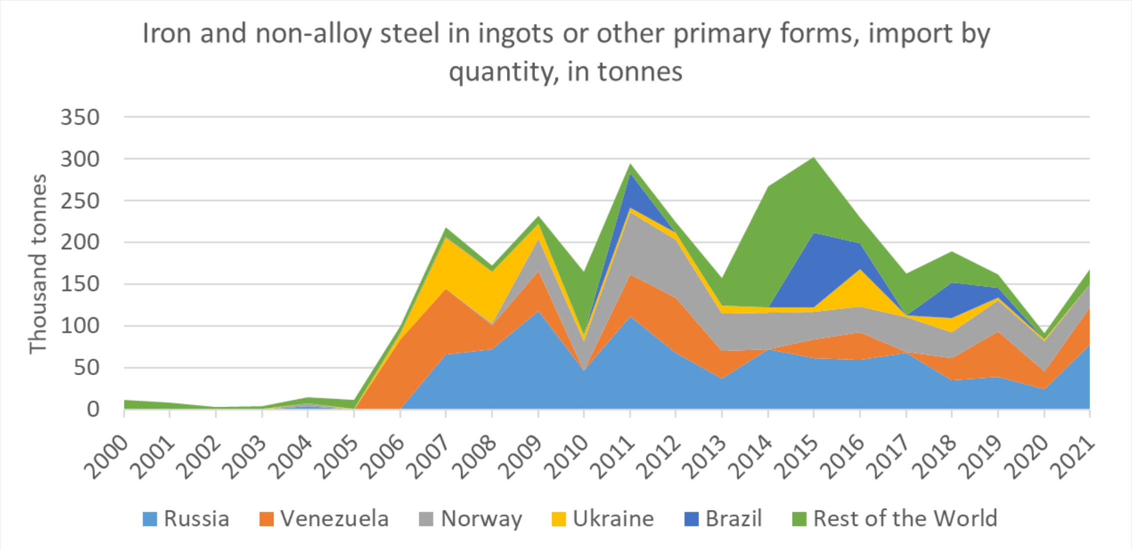

Figure 13. EU imports of Iron and non-alloy steel in ingots or other primary forms (CN 7206) by country from 2000 to 2021 (Eurostat, 2022)

Figure 14 shows the import and export trend of semi-finished products of iron or non-alloy steel during the year 2000-2021. The EU import and export EU in the past two decades (2000-2021) fluctuated rather greatly. The EU import changed from 365,321 tonnes in 2000 to 315,441 tonnes in 2021. The export decreased from 237,917 tonnes in 2000 to 55,317 tonnes in 2021.

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Figure 15 illustrates the share of import in EU for semi-finished products of iron or non-alloy steel from various countries. The UK was the main supplier with the share of 82% during all the years (2000-2021). Other import partners were Indonesia, Ukraine and U.S, all with around with a share of 2%.

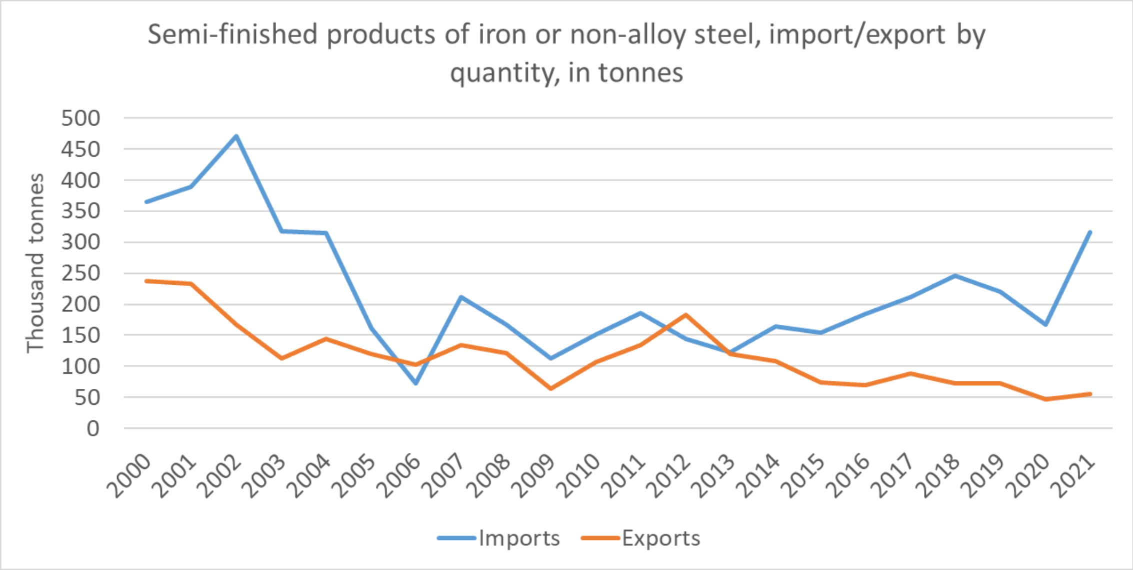

Figure 14. EU Trade flows of semi-finished products of iron or non-alloy steel (CN 7207) from 2000 to 2021 (Eurostat, 2022)

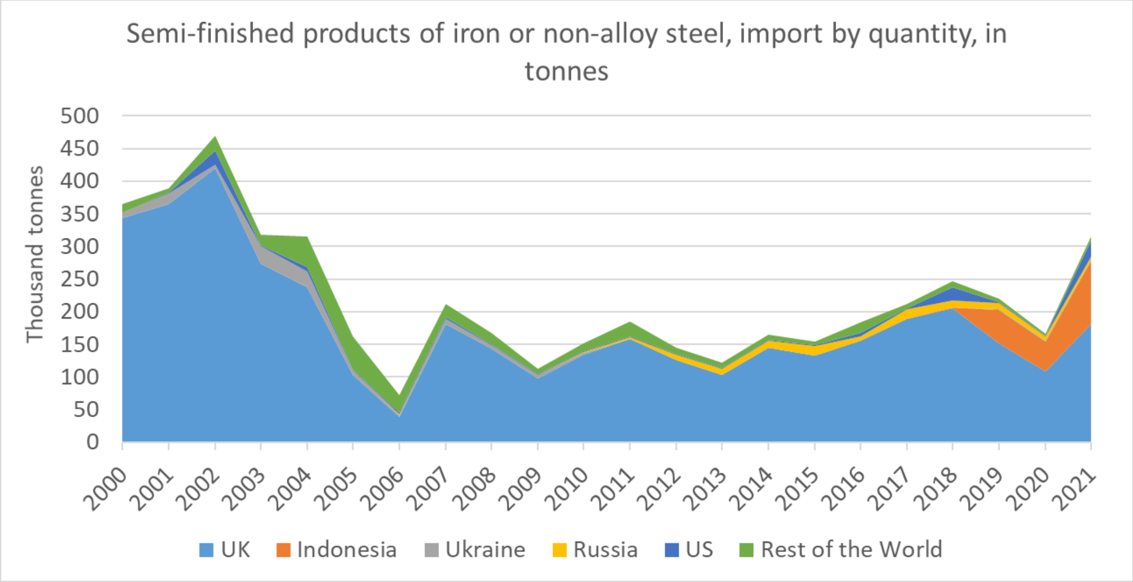

Figure 15. EU imports of Articles of semi-finished products of iron or non-alloy steel (CN 7207) by country from 2000 to 2021 (Eurostat, 2022)

Figure 16 presents the import and export trend of steel, alloy, other than stainless, in ingots or other primary forms, semifinished products of alloy steel other than stainless (excl. waste and scrap in ingot form, and products obtained by continuous casting). During the year 2000-2021, the EU import and export of steel, alloy, other than stainless, in ingots or other primary forms, semifinished products of alloy steel other than stainless,

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showed relatively great fluctuations. For the most years, the export shoed the lower amount, sitting at an average of 163,509 tonnes/year.

Figure 17 illustrates the share of steel, alloy, other than stainless, in ingots or other primary forms, semifinished products of alloy steel other than stainless (excl. waste and scrap in ingot form, and products obtained by continuous casting) from various countries. The import of steel, alloy, other than stainless, in ingots or other primary forms, semifinished products of alloy steel other than stainless to EU in the past two decades (2000-2021) fluctuated rather greatly. The main supplier to EU in the past two decades (2000-2021) was Russia (44% of share), followed by UK, Ukraine, Brazil and Turkey (13%, 11%, 11%, and 10%, respectively).

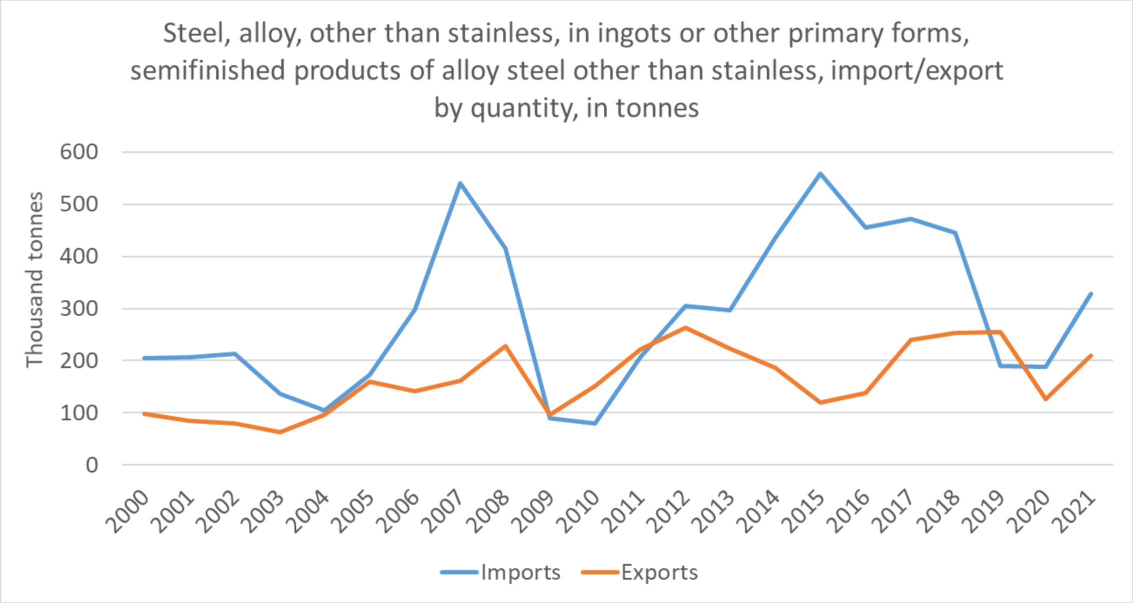

Figure 16. EU Trade flows of steel, alloy, other than stainless, in ingots or other primary forms, semifinished products of alloy steel other than stainless (CN 7224) from 2000 to 2021 (Eurostat, 2022)

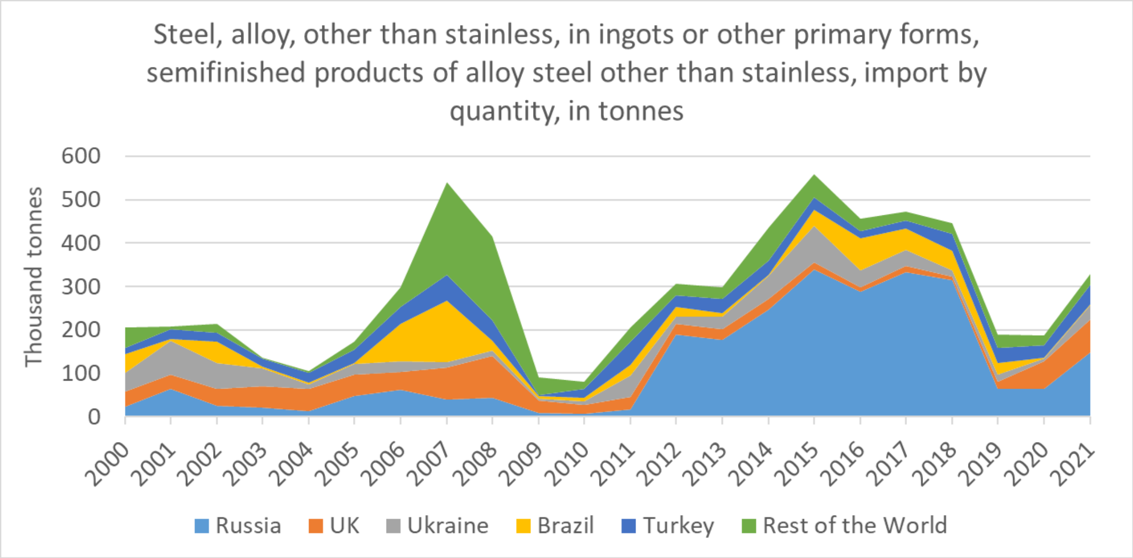

Figure 17. EU imports of steel, alloy, other than stainless, in ingots or other primary forms, semifinished products of alloy steel other than stainless (CN 7224) by country from 2000 to 2021 (Eurostat, 2022)

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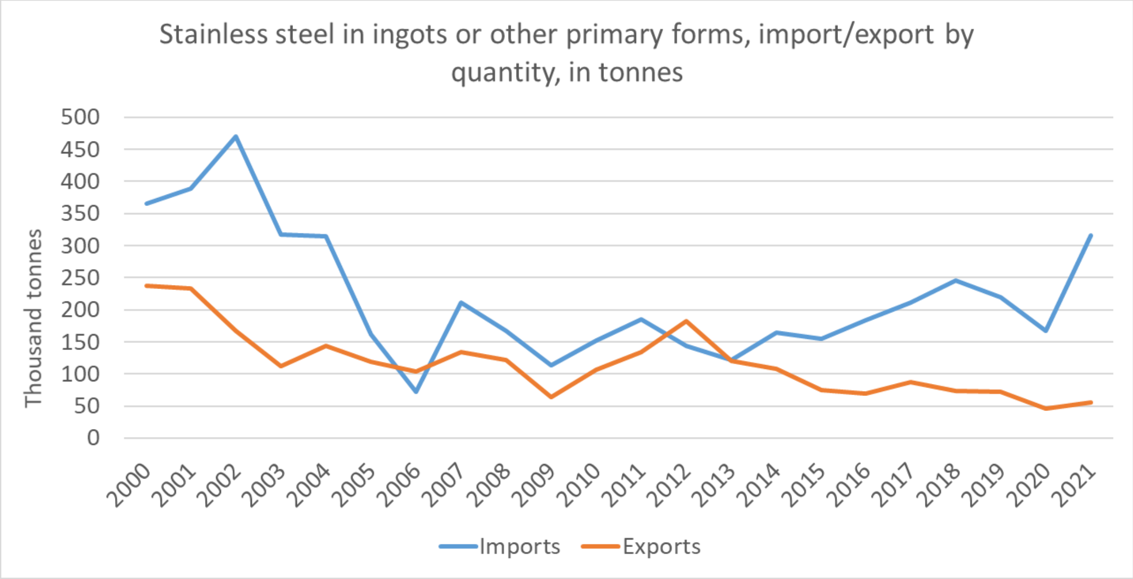

Figure 18. EU Trade flows of stainless steel in ingots or other primary forms (CN 7218) from 2000 to 2021 (Eurostat, 2022)

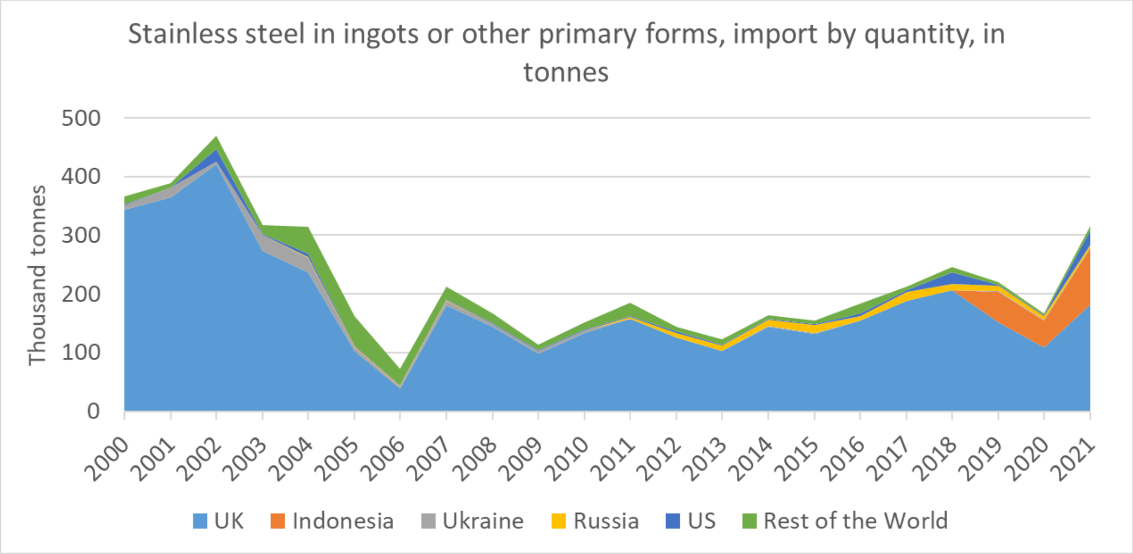

Figure 19. EU imports of stainless steel in ingots or other primary forms (CN 7218) by country from 2000 to 2021 (Eurostat, 2022)

PRICE AND PRICE VOLATILITY

Until the early 2000s, the price of iron ore was exclusively fixed by annual over-the-counter (OTC) negotiations between producers and steel producers. The explosion of the Chinese steel demand and the resulting tightening of the iron ore supply disturbed the prevailing pricing system, and the spot market emerged in the early 2000s. Chinese steel producers, in view of the steady growth of steel production in China, faced supply difficulties in the conventional market dominated by non-Chinese companies, and they turned to iron ore from India marking the beginning of a more flexible and transparent parallel spot market. The annual price-fixing system eventually collapsed in 2010, and BHP, Vale and Rio Tinto put in place a system of quarterly price-fixing closer to the prices recorded on spot markets, which were much higher than the annual reference prices fixed in 2008. Iron ore prices have since experienced significant volatility, and most of the iron ore trade continues to use long-term contracts (Le Gleuher, 2019).

Multiple factors are of importance for iron ore prices. Iron ore is a variable commodity having specific physical and metallurgical properties affecting its price (e.g., Fe content, physical form) and premiums and discounts are applied to account for quality differences. For example, higher iron grade achieves a higher price, while lump ores and pellets that can be charged directly into the blast furnace attract a premium in comparison to fines requiring sintering prior to use. The profit margin that steelmakers are achieving drives the relative preference for different ore types, i.e., when profit margins are high, steelmakers prefer to use high-purity ores to maximise their blast furnace yield. It also depends on market availability and circumstances (e.g. ore used in the direct-reduction process to make direct-reduced iron (DRI) needs to be of much higher grade than that fed into a blast furnace), constraints derived from the end-use applications of steel (e.g. higher-grade flat steel products require higher-quality raw material inputs with lower impurities), and environmental considerations (e.g. lower-grade ores with higher fractions of impurities such as silica and alumina require increased consumption of coke, which can raise emissions) (Fastmarkets, 2018) .

The massive demand growth driven by the industrialisation of China has had a distinct effect on the iron ore price evolution. The peaks in price evolution are associated with supply deficits incurred in the seaborne market, and the troughs with periods when supply growth eventually exceeded demand growth (Wilson, 2015) (S&P Global, 2019). A strong upward trend is observed from 2005 to mid-2008 when prices surged before collapsing rapidly within one year during the global financial crisis (Löf and Ericsson 2016). Iron ore prices recovered almost to their pre-crisis levels by mid-2011 induced by increased demand from China due to an economic recovery plan to counter the effects of the global financial crisis, mainly based on infrastructure investments, which boosted demand for steel (Le Gleuher, 2019). Since the end of 2013, iron ore prices declined significantly and were below the average price by 2015 due to the fast capacity expansion, particularly from the three largest producers, i.e., Vale, Rio Tinto and BHP Billiton (Löf & Ericsson, 2016). In 2019, the prices rose sharply due to a supply deficit after supply disruptions coupled with strong steel demand in China. For most of June 2020, iron ore prices traded above USD 100 per tonne for the first time since August 2019. This is due to a sharp expansion in steel production in China alongside tightness in supply (S&P Global, 2020).

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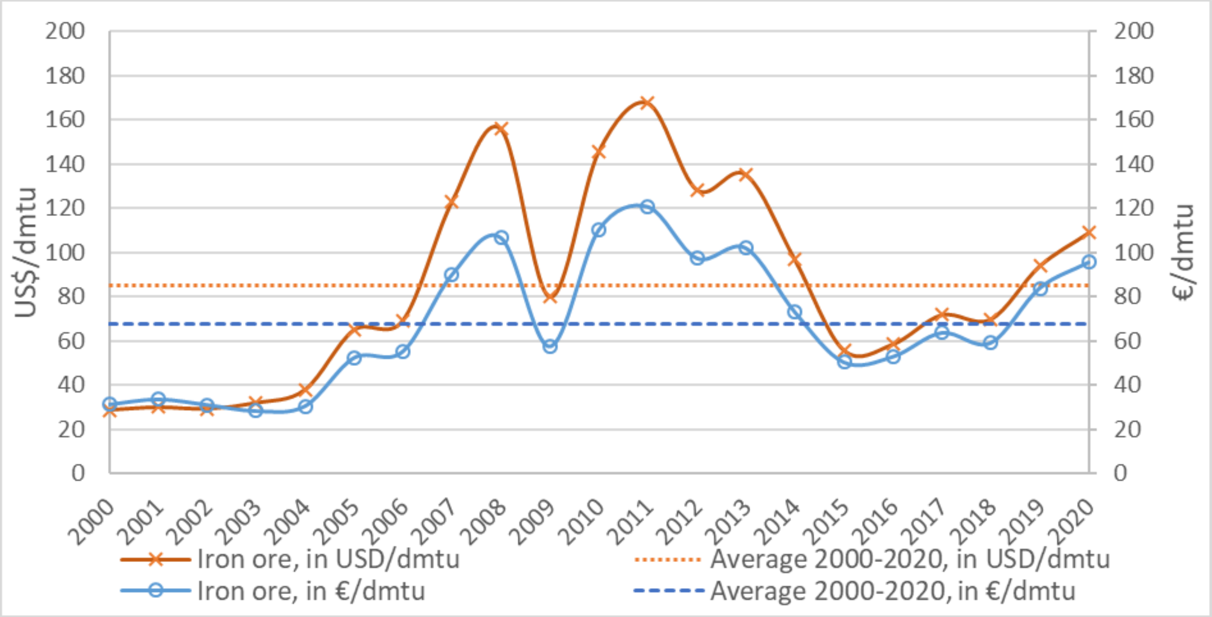

Figure 20. Annual average price of iron ore between 2000 and 2020, in US$/dmtu and €/dmtu[3]. Dash lines indicates average price for 2000-2020 (Statista, 2022).

OUTLOOK FOR SUPPLY AND DEMAND

Iron and steel production is the largest metals sector in volume as steel is an omnipresent and indispensable material across the economy. With no perfect substitutes currently on the horizon, the underlying demand for steel is expected to remain robust. Demand for steel is expected to continue rising in the future, as demand for goods and services increases with economic and population growth. In the IEA's Stated Policies Scenario, global end-use demand for steel is expected to reach 2.1 gigatonnes by 2050, a nearly 40% increase from end-use demand in 2019 (IEA, 2020) . A report by the OECD (OECD, 2019) provides a quantitative outlook for steel demand by 2060. In the baseline scenario, assuming a four-fold increase in world GDP, global steel production is projected to roughly increase by 1.8 times up to 2060 in comparison to 2017.

Steel demand growth will be partially decoupled from GDP growth due to a decrease of material intensity in the global economy. In case of improved efficiency of the steel-intensive industrial sectors in China and India, the report projects a 17% overall lower demand for steel in comparison with the baseline scenario, and the majority of the reduction will be met through decreased primary steel production. In general, secondary production is projected to grow faster than production from iron ore. In 2060, the share of world steel production from secondary sources will range between 39% and 43%, whereas in 2017 was 28% (OECD, 2019).

Fitch Solutions projects that global iron-ore production is expected to accelerate between 2022 and 2026, after stagnating somewhat over the past five years. It is forecasted that global iron-ore mine output will grow

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[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)

by an average 2.7% over the period, compared with a -1.3% growth rate over 2017 to 2021 (Arnoldi, 2022). The agency says that supply growth will be driven by Brazil and Australia, since Vale, in Brazil, has made aggressive expansion commitments, while BHP Billiton, Rio Tinto and Fortescue, in Australia, plan on using currently buoyant profits to increase production. Looking ahead, Fitch Solutions expects lower prices to eventually drag on production growth rates. It forecasts a yearly iron-ore production growth rate average of 1.1% over 2026 to 2030 (Arnoldi, 2022).

DEMAND

EU DEMAND AND CONSUMPTION

Annual average worldwide consumption of iron ore is estimated at 2,217 Mtonnes and EU consumption is estimated at 127 Mtonnes for 2017-2020 (Worldsteel, 2022).

For steel, the consumption is estimated at 1,749 Mtonnes worldwide and at 148 Mtonnes for EU for 2017-2020.

Iron ore extraction stage EU consumption is presented by HS codes CN 26011100 - Non-agglomerated iron ores and concentrates (excl. roasted iron pyrites), CN 26011200 - Agglomerated iron ores and concentrates (excl. roasted iron pyrites) and 26012000 - Roasted iron pyrites. Import and export data is extracted from Eurostat Comext (2022). Production data is extracted from WMD (2022).

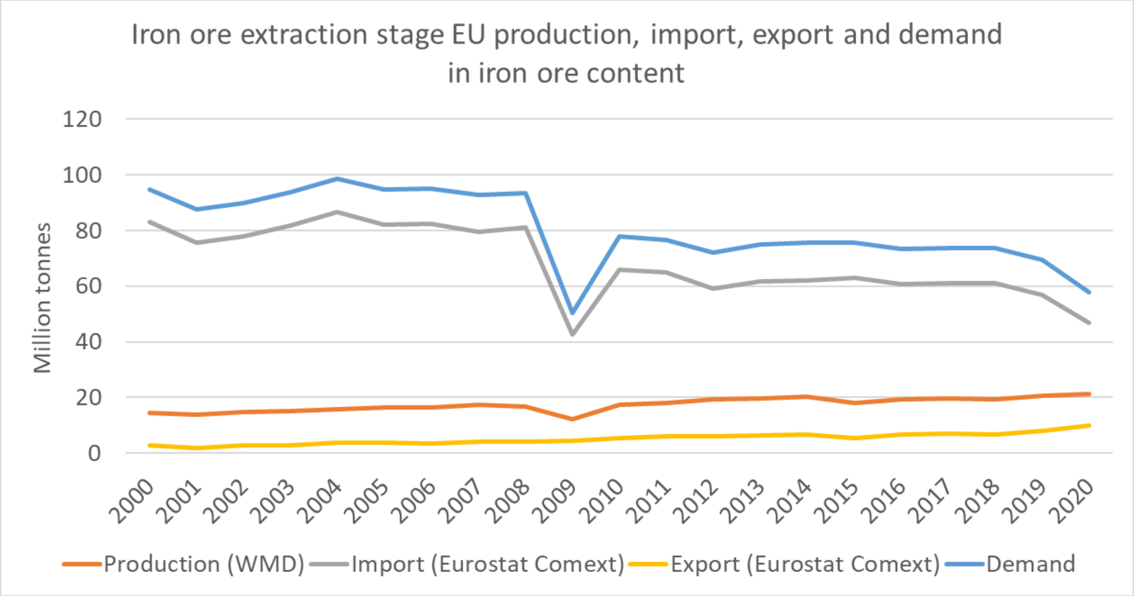

Figure 21. Iron ore (CN 26011100, CN 26011200, CN 26012000) extraction stage apparent EU consumption. Production data is available from WMD (2022). Consumption is calculated in Iron ore content (EU production+import-export).

Iron ore processing stage (crude steel) EU consumption is presented by HS codes CN 7206 - Iron and non-alloy steel in ingots or other primary forms (excl. remelting scrap ingots, products obtained by continuous casting and iron of heading 7203), CN 7207 - Semi-finished products of iron or non-alloy steel, CN 7218 - Stainless steel in ingots or other primary forms (excl. remelting scrap ingots and products obtained by continuous casting); semi-finished products of stainless steel and CN 7224 - Steel, alloy, other than stainless, in ingots or other primary forms, semi-finished products of alloy steel other than stainless (excl. waste and scrap in ingot form, and products obtained by continuous casting). Import and export data is extracted from Eurostat Comext (2022). Production data is extracted from BGS (2022) (Crude steel convert to Fe content (93-94%)).

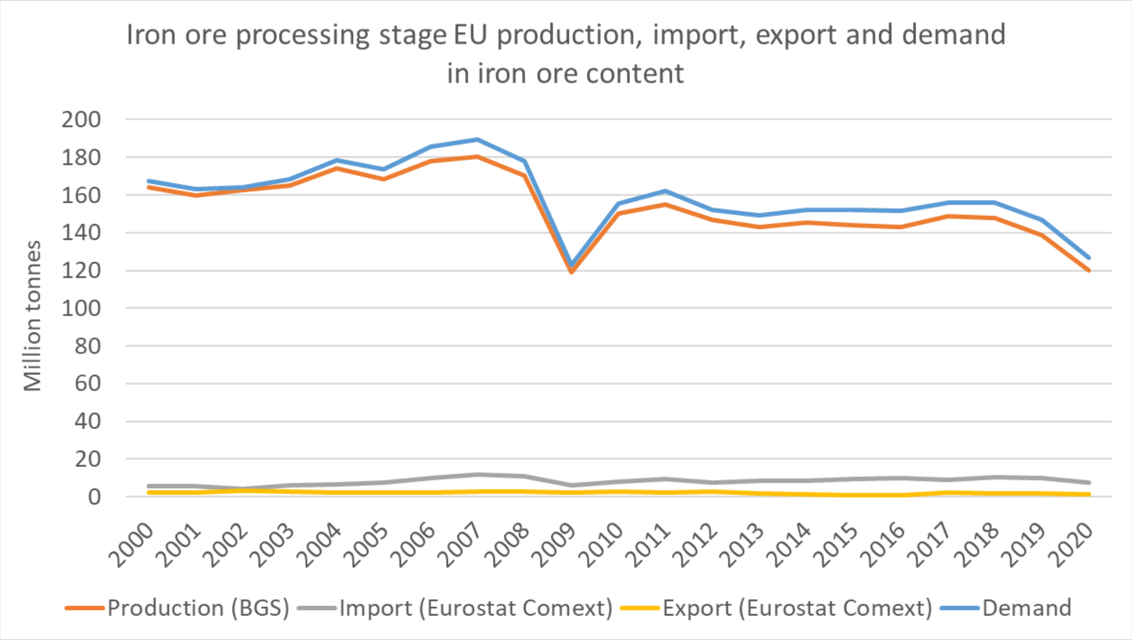

Figure 22. Iron ore (CN 7206, CN 7207, CN 7218, CN 7224) processing stage (crude steel) apparent EU consumption. Production data is available from BGS (2022). Consumption is calculated in iron ore content (EU production+import-export).

Average import reliance of iron ore at extraction stage is 77% and at processing stage 5% for 2016-2020.

GLOBAL AND EU USES AND END-USES

Iron ore is is the main feedstock raw material for primary steel production and for cast iron production. Approximately 98% of the iron ore shipped worldwide is consumed in iron and steel manufacturing (USGS 2018). The remaining 2% of the total iron ore consumption is used in a range of non-steel applications. The steel, iron and other applications are described below.

Iron is the by far mostly used metal in our society. Steel, which is an alloy of iron, carbon and possibly further elements, is closely linked to many different downstream industrial sectors. The construction sector, which includes buildings and infrastructure, accounts for about 40% of steel demand in Europe (Eurofer 2020). Further significant steel consuming sectors are the transportation, industrial equipment and appliances sectors. For both Europe and the world, the use structure changed only slightly within the past decade. The relevant industry sectors and their 2- and 4-digit NACE codes are summarised in Table 7 and visualized in Figure 24.

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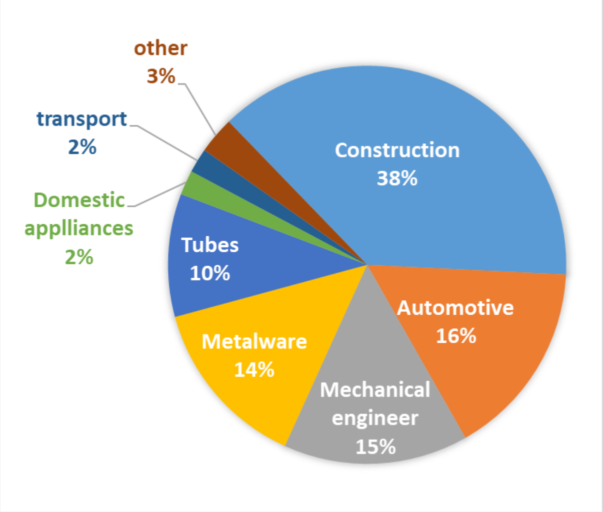

Figure 23. Steel and cast iron consumption in the EU per steel-using sector (Eurofer 2020)

Table 7. Iron ore applications, 2-digit and examples of associated 4-digit NACE sectors, and value-added per sector for 2018 (*for 2014) (Eurostat 2021).

Applications	2-digit NACE sector	Value added of NACE 2 sector (M€)	4-digit CPA
Steel in Construction	C25 - Manufacture of fabricated metal products, except machinery and equipment	183,016	C2511 - Manufacture of metal structures and parts of structures
Steel in Automotive	C29 - Manufacture of motor vehicles, trailers and semi-trailers	234,941	C2920 - Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semi-trailers
Steel in Mechanical Engineering	C28 - Manufacture of machinery and equipment n.e.c.	200,030*	C2811 - Manufacture of engines and turbines, except aircraft, vehicle and cycle engines
Steel in metalware	C25 - Manufacture of fabricated metal products, except machinery and equipment	183,016	C2571 - Manufacture of cutlery
Steel in tubes	C24 - Manufacture of basic metal	71,391	C2420 - Manufacture of tubes, pipes, hollow profiles and related fittings, of steel
Steel in domestic appliances	C28 - Manufacture of machinery and equipment n.e.c.	200,030*	C2821 - Manufacture of ovens, furnaces and furnace burners
Steel in other transport	C30 - Manufacture of other transport equipment	49,098*	C3011 - Building of ships and floating structures

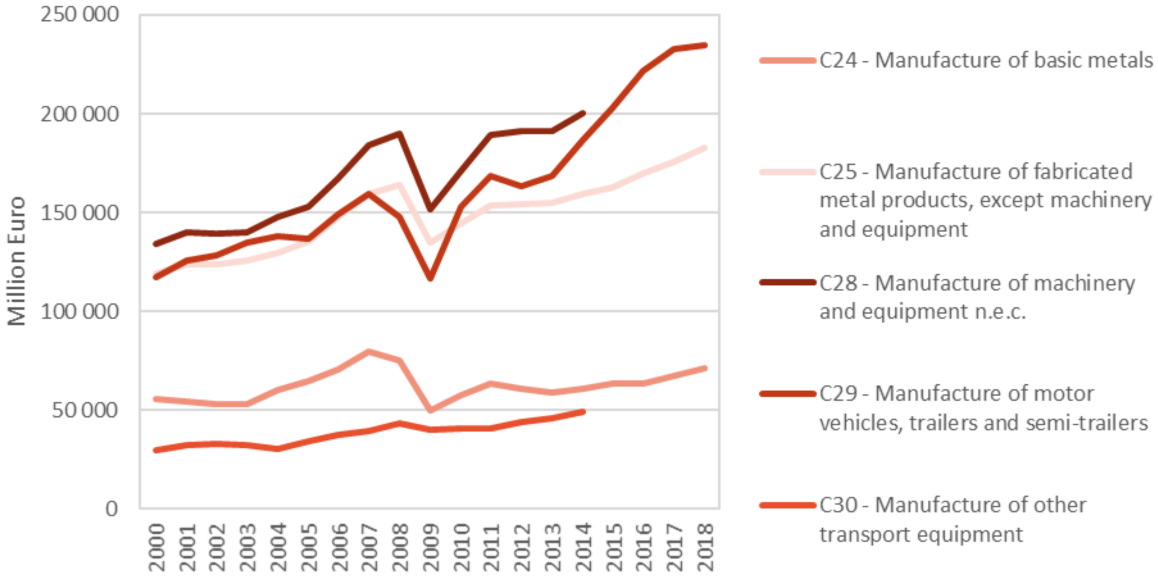

Figure 24. Value added per 2-digit NACE sector over time (Eurostat, 2021).

APPLICATIONS OF IRON ORE

Iron ore is used for steel production, cast iron production and in other forms not directly related to steel and iron. In the following, for each of these categories the specific applications are described.

STEEL APPLICATIONS

Steel is ubiquitous in everyday life and it is impossible to make an exhaustive list of steel applications. A selection of the main end-uses of steel is presented below (WorldSteel 2019; EUROFER 2019).

CONSTRUCTION

More than half of the steel produced worldwide goes into steel buildings and infrastructure. The possibilities for using steel in buildings are manifold: in structural sections of the building frame, in reinforcing bars in concrete, in sheet products in roofs and claddings for exterior walls. Likewise, steel is found in many non-structural applications such as heating and cooling equipment and interior ducting. Internal fixtures and fittings such as rails and stairs are also made of steel as well as a variety of other construction materials, such as bolts, nails, and screws. Besides, steel is used widely in the construction of major infrastructures including roads, bridges, tunnels, railways, ports and airports in the form of rebar sections, plates and rail track.

AUTOMOTIVE AND OTHER TRANSPORTATION

Steel is used in all motor vehicles. It is found in the body structure, panels, doors, engine, gears, wheels, tyres and many more. Advanced high-strength steels are used in all new vehicles, which enables them to be lighter by 25% to 39% compared to conventional steel. Other typical applications in the transport sector include ships and shipping containers, trains and rail cars as well as aircraft. Including automotive, 14.9 % of the steel produced worldwide in 2019 was used in the transport sector (IEA 2020).

TOOLS AND MACHINERY

The use of steel in mechanical and electrical equipment reaches from heavy equipment (cranes, bulldozers, drills and scaffolding used in construction) and tools used by the manufacturing sector, to small household tools.

DOMESTIC APPLIANCES

A variety of applications ranging from fridges to washing machines and other smaller equipment belong to the domestic appliances.

METAL PRODUCTS

Numerous products of everyday use such as cutlery, cookware, office furniture, radiators, packaging and others are made of steel.

ENERGY AND UTILITIES

Steel is indispensable in the production, distribution and storage of energy such as in high voltage pylons, in wind turbines as well as in nuclear, thermal and hydroelectric plants. Pipes and tubes made of steel are used in the energy sector for the transport of oil and natural gas, some of them made of special high-purity grades that withstand corrosion. Ships carrying liquefied natural gas cooled to below -160° C use low-temperature special steels, designed to withstand extreme cold without getting brittle or fragile. In the utilities sector (fuel, water and power), over 50% of the steel used is in underground pipelines to distribute water to and from housing, and to distribute gas.

ELECTRICAL

Electrical steel with special magnetic properties is the core material for every electric motor today. It is also essential for the engines of electric or hybrid vehicles.

CAST IRON

Besides steel, pig iron has many applications in the manufacture of ferrous castings. In particular, foundry pig iron is suitable for grey iron castings made in cupola furnaces used in general engineering, machine tools and parts for the automotive industry. High purity pig iron constitutes the principal ferrous feedstock material for foundries producing ductile iron castings for high quality automotive, engineering and energy casting components.

OTHER IRON ORE APPLICATIONS

Beside steel- and ironmaking, iron ore has a variety of minor applications such as ballast, cement clinker production, coal washing, crushed road base material, fertilizer, dense media separation, iron oxide pigments, ferrite magnets, oil and gas well drilling, radiation shielding, water treatment, and other specialty applications (USGS 2018).

SUBSTITUTION

Substitutes have been identified for the applications of steel in construction, automotive, mechanical engineering and metals products. These are described within this chapter and summed up in Table 8. There are no substitutes for iron ore itself, but steel and iron scrap can to a certain extend and depending on its quality serve as alternative raw materials for iron- and steelmaking.

Table 8. Substitution options for iron ore by application.

Use	Percentage*	Substitutes	Sub share	Cost	Performance
Construction	38 %	Reinforced concrete	30%	Similar or lower costs	Similar
Construction	38 %	Timber	7%	Similar or lower costs	Reduced
Construction	38 %	Masonry	6%	Similar or lower costs	Similar
Construction	38%	Others	4%	Similar or lower costs	Similar
Automotive	16 %	Aluminium	13%	Slightly higher costs (up to 2 times)	Similar
Automotive	16 %	Magnesium - alloy	7%	Very high costs (more than 2 times)	Similar
Automotive	16 %	Carbon fibre composites	5%	Very high costs (more than 2 times)	Similar
Mechanical equipment	15 %	Composites	13%	Very high costs (more than 2 times)	Similar
Mechanical equipment	15 %	Aluminium	13%	Slightly higher costs (up to 2 times)	Similar
Mechanical equipment	15 %	Magnesium	13%	Very high costs (more than 2 times)	Similar
Mechanical equipment	15 %	Titanium	13%	Very high costs (more than 2 times)	Similar
Metalware	14 %	Plastics	10%	Similar or lower costs	Reduced
Metalware	14 %	Silver	10%	Very high costs (more than 2 times)	Similar
Metalware	14 %	Bronze	10%	Slightly higher costs (up to 2 times)	Similar
Metalware	14 %	Copper	10%	Very high costs (more than 2 times)	Similar
Metalware	14 %	Aluminium	10%	Very high costs (more than 2 times)	Similar

** European end use consumption shares for 2019 according to Rostek et al. (2019) based on Dworak et al. (2021) and WSA (2020)*

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CONSTRUCTION

Substitutes for steel used in construction sector include reinforced concrete, timber, masonry and other construction products that are often used for construction purposes. These alternative materials have in some applications similar performance to steel or used for the same purposes (AISC 2018; The Construction Index 2012), except for wood for which the substitution performance is assessed in literature from reduced (DG ENV 2010) to adequate (Graedel et al. 2015). Cost is considered equal or in some cases lower for all alternative materials.

AUTOMOTIVE

Potential substitutes for the use of steel in automotive include aluminium, magnesium and carbon fibre composites. Aluminium is considered the principal substitute (Graedel et al. 2015). All of the identified alternatives have comparable performance as steel, but the cost is higher, especially for magnesium and composites (McKinsey 2014; General Motors 2012; Liao 2017).

MECHANICAL EQUIPMENT

Substitutes for steel used in mechanical engineering include composites, aluminium, magnesium and titanium. The performance is assessed as similar, but the cost of the potential substitutes is higher, especially for titanium, carbon fibre composites and magnesium (Rao et al. 2018; Mouritz 2012). Titanium could be an effective substitute for stainless steel in products such as medical devices, in marine applications and aircraft applications (see Titanium factsheet). Fibre-reinforced polymers are considered the primary substitutes in machinery (Graedel et al. 2015).

APPLIANCES AND METAL GOODS

Steel in appliances and metal goods could be substituted by a variety of materials including plastics, silver, bronze, copper and aluminium. The different substitutes have different characteristics and performance to steel (European Commission 2017). Aluminium is again considered as the main substitute in metal goods (Graedel et al. 2015).

SUPPLY

EU SUPPLY CHAIN

The iron flows through the EU in the year 2015 are shown in Figure 25.

The average annual amount of extracted and processed iron oxides in EU during the period 2016-2020 was 171,474 kt in terms of Fe content. A small share of these amount, about 20,000 kt in terms of Fe content, corresponds to mined iron oxides, while the rest amount corresponds to the processing of crude steel (with an average Fe metallic content around 93-94 wt.%). Sweden is the major iron ore producer in EU (18,200 ktonnes in terms of Fe content produced in EU), while minor production is taking place also in Austria and

Germany. The average annual imported iron oxide amount in EU in 2016-2020 was 79,300 kt (Fe content) mainly imported from Brazil, Ukraine and Canada. During the same period, around 31,600 kt (Fe content) were exported. China, Bahrain, Singapore, United Kingdom, Morocco and United States were the main export destination countries (Eurostat, 2021). According to Eurofer data, about the 56% of EU steel was made from scrap in 2020 (Eurofer, 2020). The recycling rate is even higher in EU in case of specific iron products such as: (a) packaging steel (recycling rate exceeded 84% in 2019) (APEAL, 2021), (b) stainless steel (recycling rate exceeds 90% according to 2015 data) (circulareconomy.europa.eu, 2020).

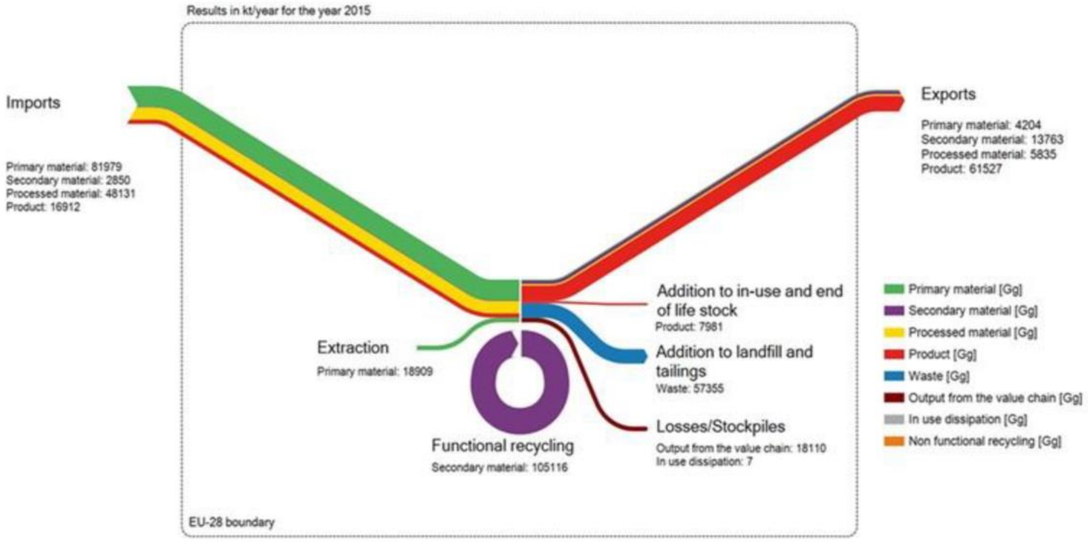

Figure 25. Simplified MSA of iron flows in the EU in 2015 (Passarini et al. 2018).

EU SOURCING OF IRON ORE

In Sweden, which is by far the leading EU iron ore producer, the iron mine activities are taking place in the Kiruna district of northern Sweden. Underground iron ore mines are operated by Luossavaara-Kiirunavaara AB (LKAB) at Kiruna (magnetite) and Malmberget (magnetite and hematite), operating at a depth of more than 1 km (LKAB 2018). In 2015, the Kiruna Mine was the largest underground iron ore mine in the world in terms of the value of production (USGS, since 2000). The ore is extracted using the sub-level caving technique which, after drilling and blasting, utilises gravity to get the ore to fall into underlying production tunnels. Apart from underground mines, iron ore is also extracted in the open-cast mines at Leveäniemi and Gruvberget in the same district (LKAB 2018).

Kirunairon, a newly founded company aims to the exploitation of so far non-exploited iron deposits in Kiruna area. The company is planning the production of an iron ore with high-added value specifications such as: high iron content >69 wt% composed by magnetite, low impurities and fine grained that can reduce the energy processing.

The company targets to the exploitation of Paljasjärvi deposit which is considered as the largest undeveloped magnetite orebody in Sweden. Paljasjärvi is the second most intense magnetic feature in Norrbotten, only sitting behind Kiirunavaara owned by LKAB. The evaluation of the deposit through research drillings is under

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progress. The mined ore is expected to transferred to Narvik, Norway, Luleå, Sweden or Skibotn, Norway harbors through a buried pipeline to avoid national parks and Natura 2000 areas (Kirunairon, 2021).

In Austria, iron ore is mined from the Erzberg open-pit mine operated by VA Erzberg GmbH and located in Eisenerz (Styria), which contains the largest siderite deposit in the world. According to Eurostat data (Eurostat, 2021) iron ores with Fe content around 974 ktonnes were extracted in Austria in 2020. The output of the Erzberg mine supplies Voestalpine Stahl GmbH's steel plants in Donawitz and Linz (USGS, since 2000) (VA Erzberg 2019).

According to Eurostat data (Eurostat, 2021) iron ores with Fe content around 95 ktonnes were extracted in Germany in 2020. Barbara Erzbergbau GmbH mines iron ore at the Wohlverwahrt-Nammen mine in Porta Westfalica, North Rhine-Westphalia, where only low-grade iron ore is produced (around 15% Fe content) which finds use as construction additive (USGS, since 2000) (Barbara Erzbergbau 2019).

EU SOURCING OF CRUDE STEEL

The steel industry is an essential contributor to the EU economy. It directly employs 314,000 people and supports more than 2 million indirect jobs jobs in the associated value chains (EUROFER 2019a). In 2018, the EU industry generated around EUR 148,000 million of Gross Value Added. Steel is produced in about 500 sites including primary steelmaking in Blast Furnace/Basic Oxygen Furnace integrated steelmaking, secondary steelmaking in Electric Arc Furnaces, and fabrication of steel mill products.

According to the latest available data of the European Steel Association (EUROFER 2019c), in 2018 the EU produced 160,100 ktonnes of crude steel across 22 Member States, accounting for 9% of the worldwide production. The share of the BF/BOF route stood at 58.3% of the total crude steel output in 2018, and the remainder (41.7%) was produced through the EAF route. In 2018, carbon steel accounted for 78.6% of the total EU2790 crude steel production, alloy steel for 17%, and stainless steel for 4.4%. The net import reliance for crude steel is 4% as a percentage of apparent consumption.

SUPPLY FROM PRIMARY MATERIALS

GEOLOGY, RESOURCES AND RESERVES OF IRON ORE

GEOLOGICAL OCCURRENCE

Iron is the second most abundant metal in the Earth's crust (after aluminium). The average concentration in the continental crust is 6.71% FeOT91, and in the upper crust is 5.04% FeOT (R. L. Rudnick and Gao 2014). Iron forms several common minerals including hematite (Fe_2O_3), magnetite (Fe_3O_4), goethite ($FeO(OH)nH_2O$), limonite ($2Fe_2O_3.3H_2O$), siderite ($FeCO_3$) and pyrite (FeS_2). It is also present in many rock-forming minerals, including mica, garnet, amphibole, pyroxene and olivine (FOREGS 2006). The principal iron ores for iron making are hematite (70% Fe content) and magnetite (72% Fe content).

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Despite its abundance in the Earth's crust, only a small part of iron is concentrated in rich deposits. The grade of iron ore deposits varies from 20% to 30% for poorer sources to as much as 60% to 70% for the higher-grade deposits (Comtois and Slack 2016).

Iron ore deposits occur mainly in iron-rich sedimentary rocks known as banded iron formations (BIF). The BIF-hosted iron ore deposits represent the most extensive iron ore resources worldwide and most of the high-grade concentrations of iron ore currently mined. Major BIF-hosted deposits with average ore grade above 60% iron occur in Australia (Hamersley province), Brazil (Quadrilatero Ferrifero and Carajas deposits) and India (Noamundi deposit). Iron ore deposit types also include the volcanic-associated massive sulphide deposits which predominantly consist of iron sulphide in the form of pyrite. With increasing magnetite content, these ores become massive oxide ores of magnetite and/or hematite. Typical examples of such deposits include the Savage River in Tasmania, Fosladen in Norway and Kiruna in Sweden.

Iron ores vary considerably in iron content. On average the iron content of Chinese iron ores is 30-40%, whereas the Fe content of iron ores originating from Australia and Brazilia is above 60%. The iron content of iron ores extracted in Sweden ranges from 45% to 53%.

Concerning iron ore deposits in the EU, the apatite-iron oxide Kiruna-type deposit at the Kiruna district in northern Sweden is mainly composed of apatite-bearing magnetite and accounts for about 90% of EU iron ore production. According to data published by the Fennoscandian Mineral Deposits database (FODD 2017), at the end of the year 2017 the iron ore resources and reserves (including active and closed mines, as well as not exploited deposits and all reporting codes of mineral resources and reserves) of the Kiruna-type deposit amounted to 3,100 million tonnes of ore, of which the iron ore reserves are 1,200 million tonnes of ore.

GLOBAL RESOURCES AND RESERVES

The United States Geological Survey (USGS, since 2000) estimate that world resources of iron ore are greater than 800 billion tons containing more than 230 billion tons of iron. The world iron ore reserves are estimated by USGS at about 180,000 million tonnes, containing 84,000 million tonnes of iron. The world's largest iron reserves are located in Australia (29%), Brazil (20%) and Russia (17%). The breakdown per counties is given in the Table 9.

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

Country	Iron ore Reserves (million tonnes)	Iron content (million tonnes)
Australia	51,000	25,000
Brazil	34,000	15,000
Russia	25,000	14,000
China	20,000	6,900
India	5,000	3,400
Ukraine	6,500	2,300
Canada	6,000	2,300
Iran	2,700	1,500
Kazakhstan	2,500	900

Peru	2,600	1,500
Russia	25,000	14,000
South Africa	1,000	670
United States	3,000	1000
Sweden	1,300	600
Turkey	130	38
Other countries	18,000	9,500
World total	180,000	85,000

EU RESOURCES AND RESERVES

The most abundant iron ore resources and reserves in the EU are located in Sweden. At the end of 2018, the mineral resources of the operating mines of LKAB are reported in accordance to the FRB standard to 1,440 million tonnes at an average iron grade of 41.8%, whereas the mineral reserves (not included in resources) to 1,151 million tonnes at an average iron grade of 43.7% (LKAB 2019). Minerals4EU (2019) compiled resources and reserve data for other countries in Europe (see Table 10 and Table 11). Collected data they cannot be summed as they are partial and they do not use the same reporting code.

Table 10. Iron ore resources data in the EU

Country	Reporting code	Quantity (Mt of iron ore)	Grade (% Fe)	Classification	Reporting date	Source
Finland	None	327.7	27.85	HistoricEstimate	12/2017	(FODD 2017)
	NI 43-101	190	30	Measured	12/2017	(FODD 2017), (Minerals4EU)
		12	26	Indicated		
		62	32	Inferred		
Greece	USGS	7	45 (Fe_2O_3)	Measured	11/2014	(Minerals4EU)
		5	NA	Inferred		
	None	10	40-45 (Fe_2O_3)	Historic Estimate		
Hungary	Russian classification	0	NA	A	11/2014	(Minerals4EU)
		1.75	24.4	B		
		23.84	24.4	C1		
		11.92	24.1	C2		
Lithuania	State reportingcode	61.69 (million m^3)	NA	Indicated (preliminary explored)	01/2015	(Minerals4EU)
	None	58.73	NA	Inferred (prognostic)		
Portugal	None	790.65	38.25	Historic Estimates	11/2014	(Minerals4EU)
Slovakia	None	4.02	33.81	Verified (Z1)	11/2014	(Minerals4EU)
		12.9	33.94	Probably (Z2)		

		3.62	34.97	Anticipated (Z3)		
		51.75	30.19	Sub-economic		
Spain	None	282	NA	Identified	12/2014	(Minerals4EU)
		155.4	NA	Indicated		
		480	NA	Inferred		
Sweden	FRB	181	42.1	Measured	12/2018	(LKAB 2019)
	NI 43-101	770.43	35.72	Total Resources		
	None	795.16	34.89	Historic Estimate		

Table 11. Iron Ore reserves data in the EU

Country	Reporting code	Quantity (Mt of iron ore)	Grade (% Fe)	Classification	Reporting date	Source
Italy	None	3.5	NA	Estimated	03/2015	(Minerals4EU)
Romania	UNFC	57	NA	Probable (121)	11/2014	(Minerals4EU)
Slovakia	None	4.02	34	Verified (Z1)	11/2014	(Minerals4EU)
		12.9	34	Probable (Z2)		
Sweden	JORC	29.1	34.46	Total Reserves	12/2017	(FODD 2017)
Sweden	NI 43-101	70.4	42.33	Total Reserves	12/2017	(FODD 2017)
Sweden	NI 43-101	94.5	25.72	Total Reserves	12/2017	(FODD 2017)
Sweden	FRB	1,057	43.94	Proven	12/2018	(LKAB 2019)
		94	40.53	Probable		

EXPLORATION AND NEW MINE DEVELOPMENT PROJECTS IN THE EU

Exploration and new mine development projects having iron ore as the main commodity are located in Sweden, Finland and Spain with varying degrees of development and undertaken studies (S&P Global 2019d). The more advanced ones are the Kiruna project in Sweden with JORC-compliant total resource estimate at 395,000 ktonnes (40.1% Fe) (Hannans Reward Ltd 2019), the Kallak project in Sweden with total resources estimated at 152,000 ktonnes (27.2% Fe) (Beowulf Mining plc 2019), and the Hannukainen iron-(copper-gold) project in Finland with 221,000 ktonnes of total resources at 32.2% Fe (GTK 2019)(Hannukainen Mining 2019).

MINING OF IRON ORE

Extraction of iron ore is undertaken mostly through surface mining as many deposits are situated near the surface. The extracted iron ore is hauled to the beneficiation plant, where the direct-shipping ores, i.e. those with sufficiently high Fe content (at least 55-58% Fe) undergoes only crushing and screening to produce iron ore lump and sinter feed fines. For lower-grade ores, additional beneficiation is required to remove impurities and achieve sufficient iron content before use in ironmaking. Iron oxide minerals are separated from the gangue through grinding and gravity separation, magnetic separation (for magnetite) or flotation. According to background data by S&P Global (2019d), it is estimated in 2017 the iron ore production consisted of 55% fines, 25% concentrates, and 21% lump ore.

Following separation, agglomeration is required for fine and very fine iron ore concentrates into pellets capable of being transported over long distances and fed directly into the blast furnace. Alternatively, the fine iron ore concentrates can be mixed with residues and additives to produce iron-rich sinters (i.e. semi-fused and solidified lumps of iron oxide) prior to being charged to the blast furnace; the sintering plant is often located adjacent to the blast furnace.

WORLD AND EU MINE PRODUCTION OF IRON ORE

The global production iron ore expressed in Fe content since 1984 according to WMD, can be seen in Figure 26 (WMD, since 1984). World production of iron ore since 2000 can be seen in Figure 27 expressed in ore quantity (USGS, since 2000). Australia, Brazil, China and India are the most important iron producers. Their average annual production in the period 2016-2020 was: 894 Mt, 422 Mt, 351 Mt and 207 Mt, respectively. Sweden consists a significant producer in Europe with >36 Mt of crude iron ore in the same period.

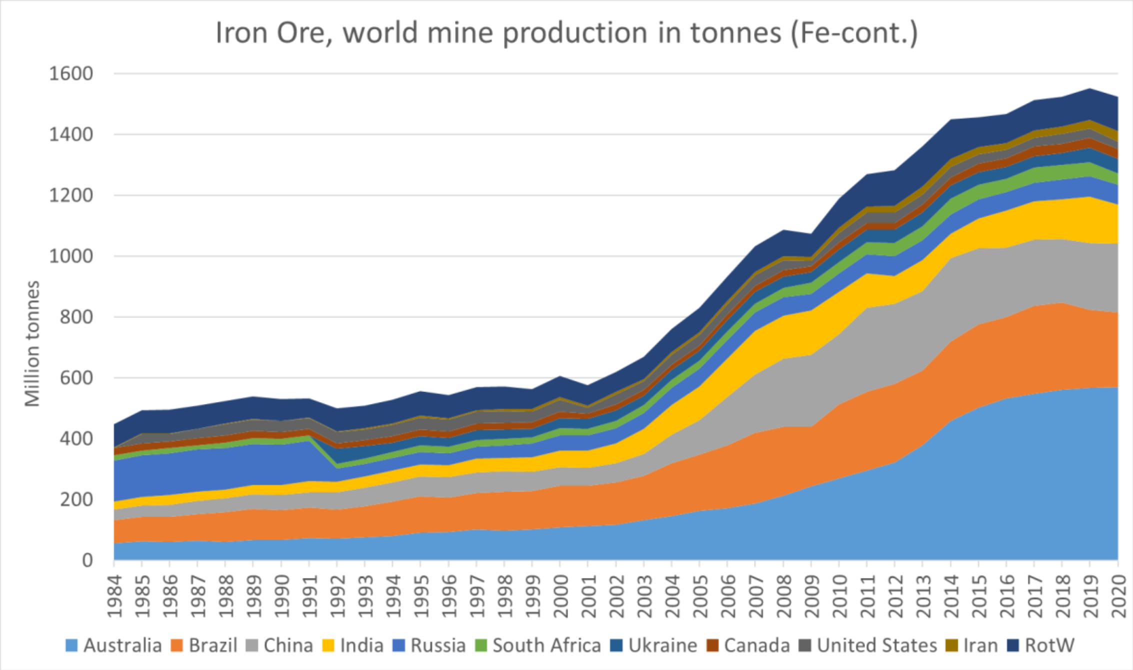

Figure 26. Annual production of iron ore expressed in iron content since 1984 according to WMD data (WMD, since 1984).

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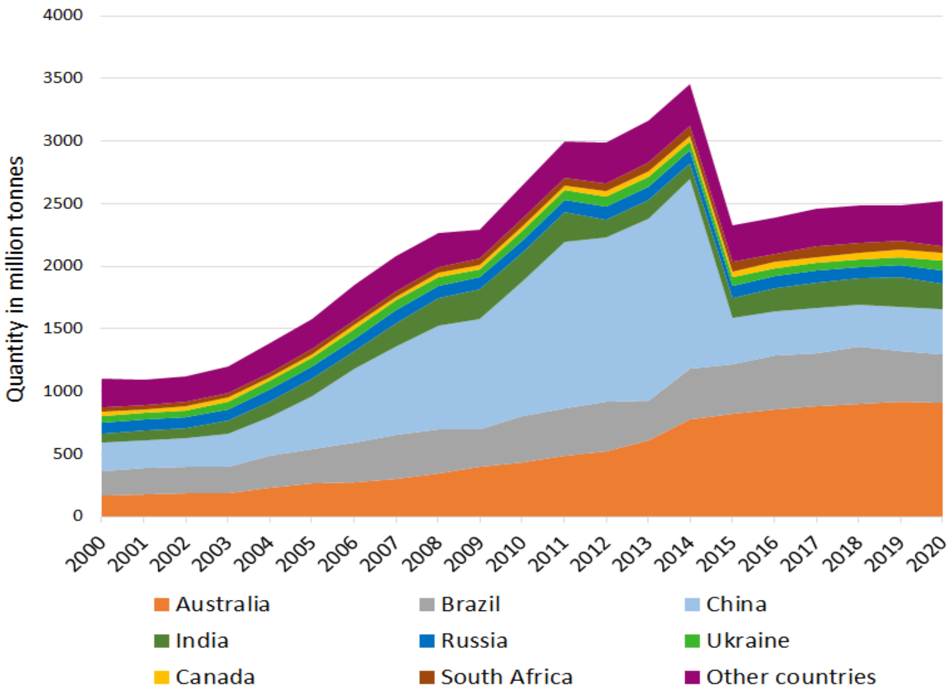

Figure 27. Annual production of iron ore since 2000 according to USGS data (USGS, since 2000).

OUTLOOK FOR SUPPLY

According to Fitch forecast, global iron ore production growth will accelerate over 2022-2026, after stagnating during the previous five years, with an annual rate between 1 and 4.5% (Figure 4). More specifically, the iron ore production situation in the 3 most important producer countries (Australia, Brazil and China) is expected to be the following (Fitchsolutions, 2022; mining.com, 2022):

The iron ore production grow in Australia will be low at an annual average of 0.4% over 2022-2026. The significant slowdown compared to the previous five years is attributed to the launch of the limited new sources of supply from new projects available. The annual amount increase will be just 19.3 million tonnes compared in 2026 compared to 2022 levels.

The iron ore production in Brazil is expected to increase significantly at annual average rate of 2.6% from 2022-2026 from 409.6 Mt this year to 473.5 Mt in 2026. The increase of productivity will be favoured by the low operating cost, the Brazil's high-quality iron ore and new infrastructures in the mining places. Furthermore, after the huge environmental disaster by the collapse of the Brumadinho dam, the mining is expected to be continued under more reasonable basis. Large companies such as Vale will be subjected to governmental control. In December 2020, The Samarco joint venture, owned by BHP and Vale, restarted. Production is initially aimed at 26% of its 30.5mnt capacity with a 60% nameplate utilisation target set for 2026.

China will invest heavily in overseas mines in order to improve security of iron ore import supply. Guinea will be an important beneficiary of this trend via the Simandou project. In Mainland China, iron ore production will rise once again in the next three to four years.

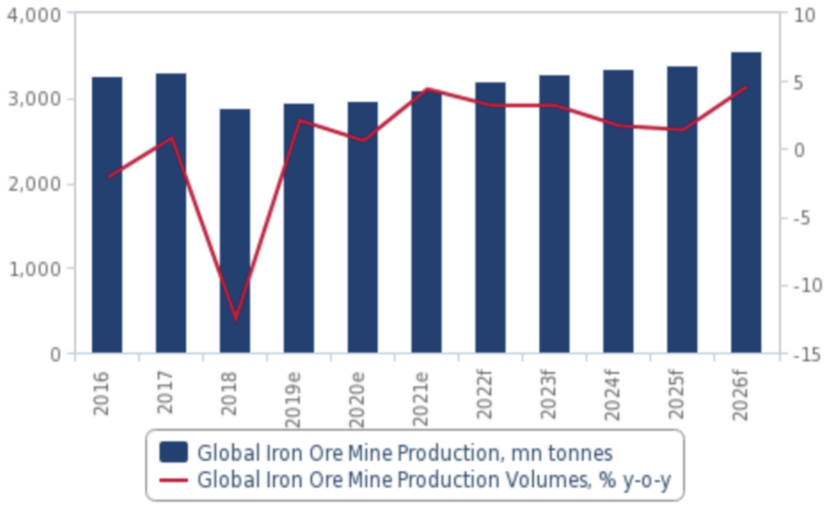

Figure 28. Forecast of the amount of the global iron ore production and the respective increase growth until 2026 (Fitchsolutions, 2022; mining.com, 2022).

Despite the above-mentioned data, it is uncertain whether the iron ore productivity be affected by the variation of its price. According to various organizations, among them the World bank, the Commonwealth Bank of Australia and the Fitch, the iron ore price is expected to significantly decreased in short term (from 129 $/tonne in 2022 to 83 $/tonne in 2024) and further in medium term (to 62$/tonne after 2024) (GMK, 2023).

The usage of iron scrap in respect to primarily produced steel is expected to become more and more crucial until 2050. The iron scrap amount is expected to exceed the 30% of the total produced steel amount after 2040 globally (Figure 29) (BHP, 2022).

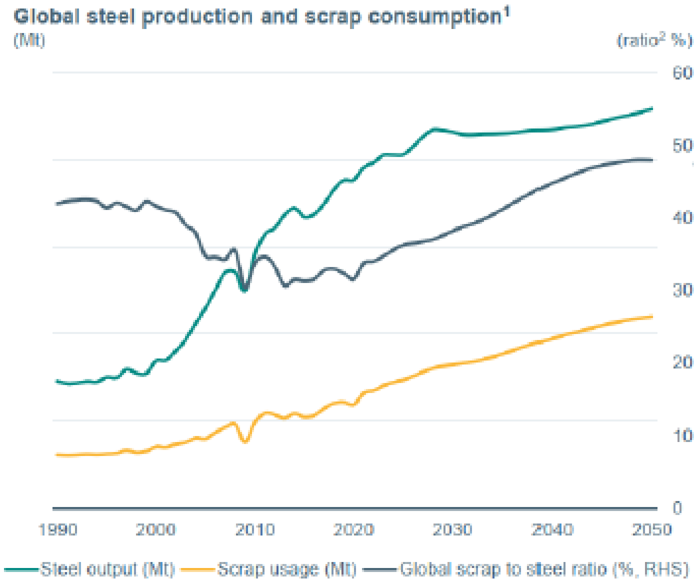

Figure 29. Forecast of iron scrap usage to primary steel production ratio until 2050 (BHP, 2022).

SUPPLY FROM SECONDARY MATERIALS/RECYCLING

The recycling of steel and ferrous alloys has a crucial importance on the environmental protection and the sustainable development of the mining/metallurgical sector. It has been estimated that using steel scrap in the production process (circulareconomy.europa.eu):

- Reduces CO_2 emissions by 58%
- Saves 72% of the energy needed for primary production (i.e., 4,697 kWh per tonne)
- Saves 1.4 tonnes of iron ore, 0.8 tonnes of coal, 0.3 tonnes of limestone and additives, and 1.67 tonnes of CO_2

The recycling rate of steel and specific steel products in EU is referred in paragraph. Figure 30 displays the amount of the recycled steel scrap in EU in 2015 (circulareconomy.europa.eu).

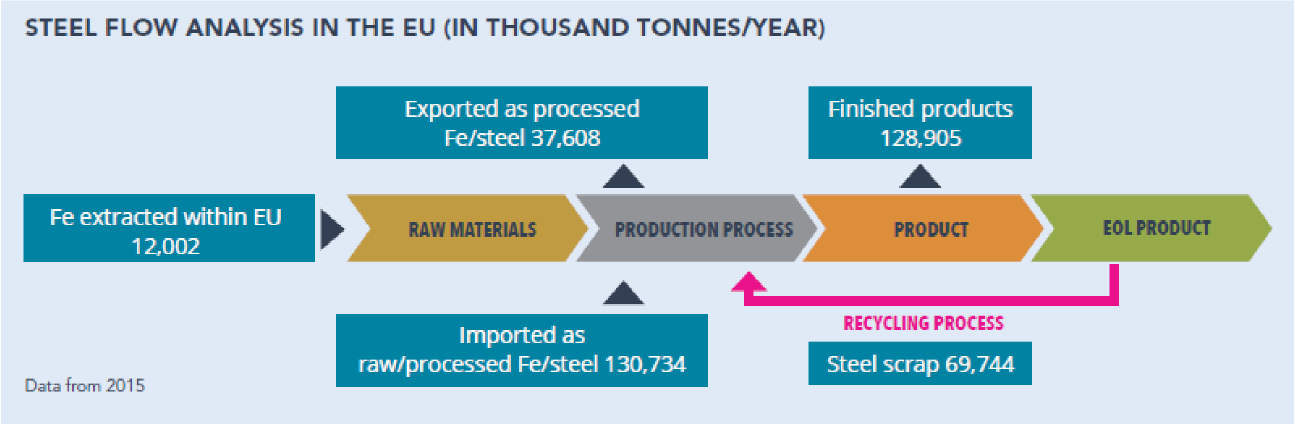

Figure 30. Steel flow analysis in EU displaying the amount of the recycled steel scrap (data referred in 2015) (circulareconomy.europa.eu).

Steel is 100% recyclable and has a potentially infinite life cycle without loss of properties. The World Steel Association reports that about 630,000 ktonnes of ferrous scrap is recycled every year, making steel the most recycled material in the world by volume (WorldSteel 2019a).

The recycling process of steel is well established globally, and it is an integral part of steel manufacturing. Steel recycling reduces the demand for primary ore, and at the same time offers substantial environmental benefits and savings in raw material inputs. In particular, steel production from scrap requires a lower amount of energy in comparison to production from iron ore decreasing by about half the generation of CO2 emissions. At the same time, every tonne of steel scrap used in steelmaking offsets the consumption of around 1,400 kilogram of iron ore, 740 kilogram of coal and 120 kilogram of limestone required by the integrated steelmaking route (WorldSteel 2017) (WorldSteel 2016).

The average lifetime of steel in different applications and products is another factor to be taken into consideration when examining secondary supply sources. The average life expectancy of steel goods ranges from 35 to 40 years. In construction, the largest consumer of steel, steel will not be available for recovery for several decades, as the average lifetime of steel is above 60 years (Allwood 2016). As most steel products

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remain in use for decades before they can be recycled, there is not enough ferrous scrap available to meet current levels of demand for steel products by using the EAF steelmaking route only. The projections of increasing demand imply that primary steel production will continue to play an essential role in the future and, therefore, demand will be met through a complementary and interdependent use of the BF/BOF and EAF production routes (EUROFER 2015)(EUROFER 2019c)(Worldsteel 2018).

In the EU, ferrous scrap plays a vital role in steel making. Approximately 42% of the crude steel output in 2018 was produced by the EAF route that uses up to 100% ferrous scrap, while globally the share of electric arc furnaces in steel production is about 28% (UNEP 2013) (Worldsteel 2019d).

POST-CONSUMER RECYCLING (OLD SCRAP)

Recycling of post-consumer products is enhanced as steel is used in large amounts in easily recoverable applications (e.g. vehicles). Also, due to its magnetic properties (except some stainless steel types), it is easy to separate and recover steel from waste streams. According to (UNEP 2011), the end-of-life functional recycling rate (EOL-RR) for iron and steel is high, estimated to range from 70% to 90%.

Recycling rates from simple products, such as packaging, construction and vehicles is high (above 85%) but for more complex products (for instance electronics) is lower at around 50% (WorldSteel 2019c). Ferrous scrap originates from different alloys, which changed their composition and increased in number over time to accommodate the latest requirements from technology innovation. This, in turn, influences the recycling process, especially from complex products such as electronics which currently include over 50 different elements in their composition. Apart from the complex product composition, inefficient collection rates are also responsible for the lower recycling rate of electronic EOL products. Moreover, the recovery of steel and other metals from waste electrical and electronic equipment often poses significant challenges to metallurgy if the products are not designed for recyclability and disassembling. In case steel is recycled together with other metals, it is substantially downgraded and in some cases might not be functionally recycled at all (UNEP 2011). By sector, global steel recovery rates are estimated at 85% for construction, 90% for automotive, 90% for machinery, and 50% for electrical and domestic appliances (Allwood 2016).

A notable end-of-life recycling performance for iron and steel is shown for the EU. According to the datasets developed by the MSA study of iron (Table 12), of the total amount of old scrap generated at end-of-life in the EU in 2015 (108,000 kt), about 81,000 ktonnes were collected for recycling, resulting in EOL-RR (i.e. the fraction that is recycled at the end of the material's life cycle) of 75%. If exports are accounted for (EU is a net-exporter of ferrous scrap and waste), the EOL-RR95 decreases to 62%. As regards the end-of-life recycling input rate (EOL-RIR), which measures the quantity of end-of-life scrap (i.e. 'old scrap') contained within the total amount of metal available to manufacturers (which would also include primary metal and 'new scrap'), the input from secondary materials accounted for 31% of the EU metal supply in 2015.

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Table 12. Material flows relevant to the EOL-RIR96 of steel in 2015. (Wyns, Khandekar, and Robson 2018)

MSA Flow	Value (kt)
B.1.1 Production of primary material as the main product in EU sent to processing in EU	12,625
B.1.2 Production of primary material as a by-product in EU sent to processing in EU	0
C.1.3 Imports to the EU of primary material	81,979
C.1.4 Imports to the EU of secondary material	2,850
D.1.3 Imports to the EU of processed material	48,131
E.1.6 Products at end-of-life in EU collected for treatment	108,075
F.1.1 Exports from the EU of manufactured products at end-of-life	0
F.1.2 Imports to the EU of manufactured products at end-of-life	0
G.1.1 Production of secondary material from post-consumer functional recycling in the EU sent to processing in the EU	66,894
G.1.2 Production of secondary material from post-consumer functional recycling in the EU sent for manufacturing in the EU	0

INDUSTRIAL RECYCLING (NEW SCRAP)

A quarter of the finished steel made each year (including half of all sheet steel) is never fabricated into a product but is cut off in manufacturing. This represents a significant amount of new scrap available for recycling. In 2008, more than half of the ferrous scrap recycled came from the manufacturing process rather than end-of-life products (European Commission 2018c).

STEELMAKING

Steel is produced via two routes:

- The integrated steelmaking process (BF/BOF), in which iron ores are first converted to iron metal utilising the blast furnace (BF) and then iron is converted to steel in the basic oxygen furnace (BOF);
- The electric arc furnace (EAF) process.

The key difference is the type of raw materials they consume. The BF/BOF route uses as raw materials iron ore, coal (mainly in the form of metallurgical coke), limestone and iron and steel scrap while the EAF route uses mainly iron and steel scrap and electric power to melt the scrap. Electric arc furnaces can be charged by up to 100% ferrous scrap feedstock. The BF/BOF route is the most utilised steelmaking technology worldwide. According to data published by the World Steel Association (WorldSteel 2019c), in 2017 71.4% of global crude steel output was produced in oxygen-blown converters which transform pig iron into steel, and 27.9% in electric arc furnaces. In the EU, the share of the EAF production is higher. In 2018, 40.3% of steel output came from electric arc furnaces and 59.3% from the BF/BOF route. Another steelmaking technology, the open-hearth furnace (OHF), contributes to less than 1% of global steel output and is no longer utilised in Europe.

The OHF process is very energy-intensive and is in decline, on account of its environmental and economic disadvantages.

BLAST FURNACE-BASIC OXYGEN FURNACE INTEGRATED STEELMAKING (BF/BOF)

The blast furnace is the central operational unit in ironmaking in which iron-bearing oxide ores are reduced to elemental iron, also called ‘hot metal’ or ‘pig iron’. The main reducing agent in a blast furnace is coal in the form of metallurgical coke; coke also partly acts as an energy carrier for sustaining the processes within the metallurgical reactor. The blast furnace is a counter-current gas/solids reactor in which the descending column of feed materials (coke, iron ore and fluxes/additives) reacts with the ascending hot gases (IIMA 2019).

Modern high-performance blast furnaces require physical and metallurgical preparation of the charge. Pelletizing and sintering are the two types of iron ore preparation generally applied. The load of the blast furnace is charged from the top consisting of alternate layers of coke and a mixture of sinter and/or pellets, lump ore and fluxes such as limestone to collect impurities. Air which is heated to about 1200°C, is blown into the furnace through nozzles in the lower section (World Coal Association 2019). The hot blast provides the necessary oxygen to burn the coke and form carbon monoxide, which is the basic reductant for the iron oxides, as well as generates heat to melt the iron. In the furnace, the iron ore is progressively reduced, and molten iron is collected at the bottom of the furnace. The majority of impurities present in the ore and fuel are removed from the melt as a separate liquid by-product called slag, also collected at the bottom of the furnace, floating on top of the molten iron. The process is continuous with raw materials being regularly charged to the top of the furnace and molten iron and slag being tapped from the bottom of the furnace at regular intervals (IIMA 2019).

Part of pig iron can be cast into ingots or rapidly solidify to form granules (granulated pig iron). However, the vast majority of pig iron produced from the blast furnace is consumed within integrated steelmaking complexes where molten iron (hot metal) from the blast furnace is transferred directly to the basic oxygen furnace.

The process converts iron into steel using pure oxygen to oxidise carbon and the unwanted impurities in molten iron. Typically, the carbon content is lowered from around 4% to less than 1%. The necessary energy is obtained from the exothermal oxidation reactions; ferrous scrap is added to the converter in order to cool the process, which can be as much as 30% of the furnace charge (Worldsteel 2018). Upstream ladle desulphurisation of the hot metal and downstream ladle metallurgy of the molten steel are applied in order to refine molten steel and achieve the required quality; in particular, the former is applied when needed (depending on the ore grade) and the latter is a necessary step for targeting the desired steel composition. Ferrous slag is also generated from the added fluxes and the energy of the process, at an average rate of 400 kg per tonne of crude steel (WorldSteel 2019c). Molten steel is then cast either into ingots or by means of continuous casting into billets, blooms and slabs (semi-finished products). Nowadays, ingots are not common anymore and are used only for some specific/niche applications. In 2017, continuously cast semis (billets, blooms, and slabs) accounted for 96.3% of the world steel output, ingots for 3.5%, whereas the remainder (0.2%) was delivered in liquid form for castings (WorldSteel 2019c).

On average, the integrated steelmaking route uses 1,370 kilogram of iron ore, 780 kilogram of coal, 270 kilogram of limestone, and 125 kilogram of ferrous scrap to produce 1,000 kilogram of crude steel (WorldSteel 2019c).

ELECTRIC ARC FURNACE (EAF) STEELMAKING

The principal material input for the EAF is iron and steel scrap, which may be comprised of scrap from inside the steelworks, cut-offs from iron and steel product manufacturers and post-consumer scrap. The electric arc furnace can be charged with 100% steel scrap. Depending on the plant configuration and on the availability and quality of ferrous scrap, other sources of metallic iron such as direct reduced iron (DRI), pig iron or hot metal can be used in the EAF route too. As in the BF/BOF, a slag is formed by the addition of fluxing agents (limestone and/or dolomite) to refine and condition the steel composition and also to form a protective layer separating the liquid steel from the external atmosphere. In the EAF, around 170 kilogram of slag is produced per tonne of crude steel (BGS 2019). The downstream casting process is the same for all the steel production routes.

On average, the EAF route uses approximately 710 kilogram of ferrous scrap, varying amounts of iron sources (i.e. metallics, DRI, hot metal, and granulated iron) corresponding to 586 kilogram of iron ore, 150 kilogram of coal, 88 kilogram of limestone and 2.3 gigajoule of electricity to produce 1,000 kilogram of crude steel (BGS 2019).

OTHER IRONMAKING PROCESSES

An alternative process of ironmaking is the direct reduction of iron ore oxides in solid-state, i.e. without melting as in blast furnace, with natural gas, hydrogen or coal as reducing agents. Direct reduced iron (DRI), also called sponge iron, is mainly used as feedstock in electric arc furnaces. Hot Briquetted Iron (HBI) is a form of DRI which is briquetted at elevated temperature to form dense briquettes which can be transported and handled efficiently and safely. Because there is no separation of iron from gangue in the reduction facility, high-grade ores must be used (>67% iron and a low gangue content; commonly DRI-pellets grades are commercialised, but the supply is limited). Global DRI output accounts for about 0.7% of total iron production (average 2012-2016).

Another process is the production of nodular pig iron which contains much less manganese, sulphur and phosphorus content and is almost exclusively used in foundries and castings.

WORLD AND EU PRODUCTION OF STEEL AND PIG IRON

The average annual global production of pig iron during the period 2016-2020 was 1.234 million tonnes according to USGS (USGS, since 2000) (Figure 31). China is by far the larger pig iron producer with about 777 million tonnes per year. Japan and India are following with 75 and 68 million tonnes, respectively. In EU, Germany is the larger producer with an annual amount of 26 million tonnes. According to Eurostat data, EU was the second largest producer of crude steel after China, with an annual average production of about 151 million tonnes during 2016-2020. Germany, Italy, France, Spain and Poland were the major producers of crude

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steel in EU in 2020 with produced amounts of: 35.7 Mt, 20.4 Mt, 11.5 Mt, 11 Mt and 7.8 Mt, respectively (Eurostat, 2021).

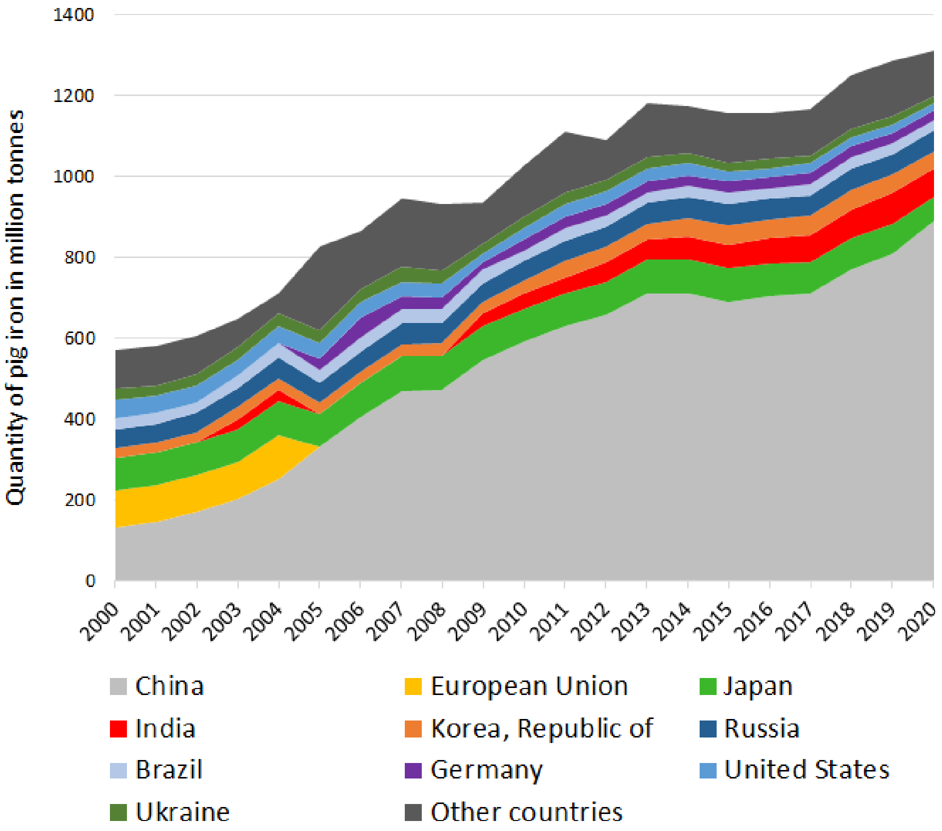

Figure 31. Annual production of pig iron since 2000 according to USGS data (USGS, since 2000).

OTHER CONSIDERATIONS

HEALTH AND SAFETY ISSUES

According to the notifications provided by companies to ECHA in REACH registrations no hazards have been classified for iron ores (ECHA 2022).

According to (IFA 2022), the limit value of iron ore is reported only for Latvia and is estimated 4 mg/m^3 for 8 hours of exposure. According to (OSHA 2022) the exposure limit for iron[4] is 10mg/m^3.

Different lung diseases including lung cancer are the major occupational diseases among mining workers exposed to iron ore dust. However, health hazards that arise due to exposures to the ore dust vary due to the ores' variable compositions in different mines. Iron ore dust-exposed workers need to be examined

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[4] Values are provided for iron oxide fume, not specifically for iron ore

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periodically to determine early symptoms. Routine environmental monitoring and chemical composition evaluation of iron-ore dust are also recommended. (Banerjee et al 2006).

It was found that in Western Australia, where iron ore operations involve an integrated system of seven mines, that high levels of dust were compromising the health and the lifestyle of the mine workers (Reuters 2021).

ENVIRONMENTAL ISSUES

Iron ore extraction can have detrimental impacts on the quality of the air, the water and on the biological species. An in-depth analysis in Liberia showed degraded water quality because of surface runoff and leachate that are frequently generated from large volume overburden and tailings that are produced during iron ore mining and subsequent processing activities. As most of the mines in the country use overburden as backfilling material for mined out areas, ground water contamination may also result from leaching activities. Iron ore tailings may contain large amount of SiO_2, Si, Fe_2O_3, Fe_3O_4, Fe (OH), and traces of Hg, Se, Cu, Pb, Zn, As, Mn etc. that are harmful to humans, even at low levels. The investigation of water quality from China Union Iron Ore Mine of Liberia revealed a potential of surface and ground water pollution by iron ore mining. (Gleekia 2016).

A life cycle assessment of GHG emissions for iron ore mining and processing in China shows that the mean life-cycle GHG emissions for Chinese iron ore production are 270 kg CO2e/tonne, with a 90 % confidence interval ranging from 210 to 380 kg CO2e/tonne. The two largest contributors to overall GHG emissions are agglomeration (60 %) and ore processing (23 %). Iron content (ore grade) varies from 15 % to 60 % and is the largest contributor (40 %) to the uncertainty of the results. The depletion of rich ore deposits will result in increased exploitation of lower grade ores with the concomitant increase in energy consumption and GHG emissions (Gan et al. 2018).

NORMATIVE REQUIREMENTS

(Sai Global 2013) developed a Guide to standards on iron ore mining, defining main Australian standards and certification on the extraction of iron ore.

The Initiative for Responsible Mining and Sourcing (IRMA 2021) issued a set of Standard for responsible mining processing, intended to apply to a range of minerals – including iron ore. The IRMA Standard is intended to be applicable to sites where smelting, refining or other forms of mineral processing and extractive metallurgy are carried out.

SOCIO-ECONOMIC AND ETHICAL ISSUES

ECONOMIC IMPORTANCE OF IRON ORE FOR EXPORTING COUNTRIES

Table 13 lists the countries for which the economic value of exports of Iron ore represents more than 0.1 % in the total value of their exports.

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Table 13: Countries with highest economic shares of IRON ORE exports in their total exports

Country	Export value (Million USD)	Share in total exports (%)
Mauritania	3 267	54.8 %
Australia	342 036	33.9 %
Brazil	280 815	15.9 %
Ukraine	65 870	10.3 %
Mongolia	9 241	10.3 %
South Africa	121 321	8.1 %
Lao People's Dem Rep	7 165	3.4 %
Peru	56 260	3.2 %
Chile	94 677	2.7 %
Sweden	189 845	2.5 %
Oman	44 591	2.1 %
Canada	501 463	1.6 %
India	394 814	1.1 %
Russian Federation	492 314	0.8 %
Malaysia	299 230	0.4 %
Philippines	74 620	0.3 %
Turkey	225 214	0.2 %
Kenya	6 751	0.2 %
Fiji	815	0.2 %
Pakistan	28 795	0.1 %
Norway	161 687	0.1 %
China	3 362 302	0.1 %
USA	1 753 137	0.1 %

Source: COMTRADE (2022), based on data for 2021

The top three countries with the highest economic share of iron ores exports are Mauritania (54.8 %), Australia (33.9 %), and Brazil (15.9 %). Ukraine and Mongolia accounts for 10.3 % of the overall exports, followed by South Africa (8.1 %). A few countries have overall exports share above 1%, namely Lao People's Democratic Republic (3.4 %), Peru (3.2 %), Chile (2.7 %), Sweden (2.5 %), Oman (2.1 %), Canada (1.6 %) and India (1.1 %).

Iron ore is the base metal used to make steel – and steel is the most used alloy in the world. According to the World Steel Association (WSA), steel demand is expected to grow by 1% to 2% per year over the next decade (ABCDust 2022).

SOCIAL AND ETHICAL ASPECTS

While the iron mining and processing industry creates jobs and incomes, in countries such as Brazil, for those communities living along a mining railway, adverse impacts normally outweigh any benefit (News Mongabay 2022). The Carajás Railroad runs 892 kilometres, from the world's largest open-pit iron ore mine to the port of Ponta da Madeira on Brazil's Atlantic coast, contributing to record 24 billion USD profit in 2021. However, "many people have died on this railroad, killed by the trains," as reported by a resident of the community of

Auzilândia in Brazil's Maranhão state. In addition to this, other residents reported of strong and permanent headaches due to the rail noises or suffered structural damages to their houses for the construction of the railway (News Mongabay 2022).

A similar study on the livelihood impacts of iron ore mining-induced land change in Sierra Leone demonstrated that the establishment of industrial iron ore mines in 2011 resulted in gradual urban land expansion (average of 7.5 %) and exponential population growth (600 %) in search of employment through 2018. Notwithstanding, the negative livelihood impacts of iron ore mining on agricultural productivity and forest products was far higher than the positive impacts. (Wilson et al 2022)

RESEARCH AND DEVELOPMENT TRENDS

RESEARCH AND DEVELOPMENT TRENDS FOR LOW-CARBON AND GREEN TECHNOLOGIES

- Decarbonization of iron and steel production

Researchers explore approaches and potential decarbonization paths of the global iron and steel industry: fuel switching to low-C hydrogen, solid biomass, zero-carbon electricity substitution, and retrofit with carbon capture and storage (CCS) (Fan et al. 2021, Draxler et al. 2021).

OTHER RESEARCH AND DEVELOPMENT TRENDS

- Experimental study on melt and flow characteristics and pore structure of iron ore (Ji et al, 2022)[5]

The liquid phase formed during the sintering of iron ore greatly influences the quality of the sintered ore. This paper aims to study the melt and flow characteristics of iron ore and analyse the variation law of pore structure with fluidity of iron ore during sintering. First, the melt characteristic and liquid phase flow index of five iron ores and their mixtures were investigated, with the mixed ores performing best. A method for measuring the flow characteristic was developed to study mixed iron ores with different alkalinity. This measurement method allowed the simultaneous acquisition of flow velocity, characteristic temperature and bottom curvature to comprehensively assess the flow characteristic. Finally, the effect of the flow characteristic on the pore structure and distribution of sintered ores was investigated by X-ray computed tomography. The results showed that improving the fluidity of the sintered ores would promote the diffusion and overflow of pores.

- Livelihood impacts of iron ore mining-induced land change in Sierra Leone: A time series analysis (Wilson et al. 2022)[6]

This study explores the role of industrial iron ore mining on land change and local livelihoods in the Tonkolili mineral rich region of North-eastern Sierra Leone. The study integrates time series of land use and land cover (LULC), statistical modelling, and qualitative analytical framework to provide a comprehensive assessment of livelihood response to iron ore mining induced land change over an 8-year period (2010–2018). Results of the

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[5] https://www.sciencedirect.com/science/article/pii/S0009250922007692

[6] https://www.sciencedirect.com/science/article/abs/pii/S0143622822000844

study demonstrated that the establishment of industrial iron ore mines in 2011 resulted in gradual urban land expansion (average of 7.5%) and exponential population growth (600%) in search of employment through 2018.

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