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Cost allocation and incentive mechanisms for environmental protection in the iron ore / steel supply chain

Summarised results for decision makers in the industry

Based on reports by

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Section I 1.5 and Section III 2.1

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Abstract: Cost allocation and incentive mechanisms for environmental protection in the iron ore / steel supply chain

The research project "Cost allocation and incentive mechanisms for the environment, climate protection and resource conservation along global supply chains" (project number 3722 14 101 0) commissioned by the German Environment Agency investigated (dis)incentives for and barriers to the implementation of environmental measures as well as the exchange of information between different actors along selected global supply chains. The project focused on five supply chains from raw material to the end product that represent key sectors of the German industry with a high potential for environmental and human rights risks: cotton-readymade garments; tin – tin solder; natural rubber – car tyres; coffee – coffee for consumption; iron ore – quality steel for automotive industry. It aimed to provide guidance to business and policy makers to facilitate the practical implementation of effective environmental upgrade measures along these global supply chains and to allocate the distribution of the resulting cost and benefits more equitably. This report consolidates the research findings for the iron ore/steel supply chain. It is a compilation of texts already published in other reports with the purpose of informing decision makers in the iron and steel industry.

Kurzbeschreibung: Kostenverteilungs- und Anreizmechanismen für den Umweltschutz in der Eisen/Stahl-Lieferkette

Das vom Umweltbundesamt in Auftrag gegebene Forschungsprojekt „Kostenallokation und Anreizmechanismen für Umwelt-, Klima- und Ressourcenschutz entlang globaler Lieferketten" (Forschungskennzahl 3722 14 101 0) analysierte (Fehl-)Anreize und Barrieren für die Umsetzung von Umweltschutzmaßnahmen sowie den Informationsaustausch zwischen verschiedenen Akteur*innen entlang ausgewählter globaler Lieferketten. Das Projekt konzentrierte sich auf fünf Lieferketten, die Schlüsselsektoren der deutschen Industrie mit einem hohen Potenzial für Umwelt- und Menschenrechtsrisiken darstellen und betrachtet diese vom Rohstoff bis zum Endprodukt: Baumwolle – Konfektionsware, Zinn – Lötzinn, Naturkautschuk / Autoreifen, Kaffee – Konsumkaffee, Eisenerz – Qualitätsstahl für die Automobilindustrie. Das Projekt soll Unternehmen und politischen Entscheidungsträger*innen als Orientierungshilfe dienen, um die praktische Umsetzung wirksamer Umweltschutzmaßnahmen entlang der globalen Lieferketten zu erleichtern die daraus resultierenden Kosten und Nutzen gleichmäßiger zu verteilen. Dieser Bericht fasst die Forschungsergebnisse für die Eisenerz/Stahl-Lieferkette zusammen. Der Bericht ist Zusammenstellung von Texten, die bereits in anderen Forschungsberichten veröffentlicht wurden, mit dem Ziel Entscheidungsträger*innen in der Eisen- und Stahlbranche zu informieren.

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1 Introduction and background of the research project

The research project "Cost allocation and incentive mechanisms for the environment, climate protection and resource conservation along global supply chains", commissioned by the German Environment Agency, investigates (dis)incentives for and barriers to the implementation of environmental upgrading activities as well as the exchange of information between different actors along selected global supply chains. The report addresses the issue that the implementation of environmental upgrading activities is often accompanied by significant costs (both financially and in terms of resources and expenditure). Observations from the research conducted in the project confirm that these costs are often unevenly distributed among the actors involved in the setting of global supply chains - the costs are often higher for the less powerful and financially weak suppliers, while the benefits from the implementation of environmental protection measures (e.g. improved reputation) are focused to a greater extent on more powerful and financially stronger, larger purchasing companies. This can hinder the effective implementation of environmental and climate protection as well as cooperation between supply chain actors. For this reason, the report is intended to provide guidance to businesses and policy makers to facilitate the practical implementation of environmental upgrading activities along global supply chains and to improve the distribution of cost and benefits in the process.

The project focuses on global supply chains from raw material to the end product that represent key sectors of the German economy with a high potential for adverse environmental impacts. We analyse the following five supply chains:

- Cotton and the manufacturing of cotton-based ready-made garments
- Tin and tin solder for the manufacturing of electronics
- Natural rubber and car tyres for the automotive industry
- Coffee for retail and consumer brands
- Iron ore and quality steel for the automotive industry

Building on the findings this report will synthesise the overall project findings, ultimately resulting in a roadmap combining seven instruments that appear most promising to more equitably distribute costs and benefits and thus support the effective implementation of environmental upgrading activities in the global **iron ore/steel supply chain.** These instruments were chosen based on a qualitative assessment of all materials collected throughout the project implementation – consisting of an extensive literature review, workshops and interviews with practitioners and various industry experts. They were mentioned repeatedly as being the most promising approaches to environmental upgrading, cost-benefit sharing and cooperation between different stakeholders along global supply chains. Some are already in use, while most are not yet used or still in pilot phases in the analysed supply chains.

Chapter 2 contains a supply chain profile for the iron ore/steel industry. By focusing on the market design, e. g. market structures, pricing mechanisms, power structures in the value chain and barriers for mainstreaming environment protection in the supply chain, this chapter lays the ground for the analysis of how to promote sustainable supply chain management (SSCM) in the industry. Chapter 3 maps the main environmental impacts in the iron ore/steel supply chain and provides an overview of the SSCM instruments already in use by steel producers and their suppliers or that are currently emerging. Chapter 4 presents a roadmap for the introduction of SSCM instruments that can deliver meaningful incentives to reduce GHG emissions along the iron ore/steel supply chain at all stages. The roadmap was created in close collaboration with a multinational mining company and is additionally backed by research, interviews with other industry representatives and workshops.

By considering SSCM instruments and related incentive mechanisms that go beyond current practice, the report aims to support industrial actors as well as those who regulate, finance or otherwise support these sectors in furthering an equitable distribution of costs and benefits, supporting the effective implementation of environmental upgrade activities along global supply chains.

2 Supply chain profile for iron ore/steel

This chapter is an excerpt of the report "Cost allocation and incentive mechanisms for environmental, climate protection and resource conservation along global supply chains - Analysis of the cotton, tin, natural rubber, coffee and iron ore supply chains" (Strasser et al. 2024). The supply chain profile for the iron ore/steel supply chain contains background information on the commodities, an explanation of the market structure, the functioning of the value chain, pricing mechanisms and power relationships, an indication of how the industry addresses its environmental impacts as well as an outlook on market, consumer and technology trends that will likely shape the future composition and functioning of the value chain. The chapter ends with lining out selected institutional incentive mechanisms and barriers for environmental upgrading of the iron ore/steel supply chain.

2.1 Background

Iron ore is by far the most commonly mined metal in the world with a large part of globally mined iron ore being processed into steel and steel products (Mallinger und Mergili 2022; U.S. Geological Survey 2023a). Together, iron and the steel made from it are essential materials in the engineering and construction industry. Worldwide, more than 6 million people work in the steel industry and 49.3 million are employed in jobs indirectly connected to it.[1] Iron ore mining and iron and steel production are associated with a variety of negative environmental and social impacts (see Table 1). These include, for example, the large amount of CO_2 emissions generated by the steel industry, which is responsible for 30% of total industrial emissions in Germany (IEA 2020; Bookhagen et al. 2022; Harpprecht et al. 2022).

Iron has played a crucial role in the history of mankind and has been used in the form of tools since 1200 BC (Küblböck et al. 2022). Forms of steel have been made of iron since the 11th century BC and it has been produced industrially and in larger quantities since the 1850s, when it contributed heavily to processes of industrialisation. While steel production was historically concentrated in Great Britain and later in the U.S. and Germany, the new possibilities of worldwide transport, communication and cooperation, as well as industrial development in Asia since the Second World War, led to a shift in production capacity and a globalisation of the industry (Allen 1979; World Steel Association n.d.). Since the middle of the 20th century, the production and use of iron and steel has increased considerably (Mallinger and Mergili 2022). Over the past 20 years, the production of iron has nearly tripled, from just over 1 billion tonnes in 2000 (Kerkow et al. 2012) to 2.6 billion tonnes in 2022 (U.S. Geological Survey 2023a). Steel production increased tenfold between 1950 and 2021 (World Steel Association 2022).

While the last iron ore mine in Germany closed down in 1987 (Kerkow et al. 2012), Germany is still the largest steel producer in the EU and was the world's seventh largest producer of raw/crude steel in 2021 after China, India, Japan, the U.S., Russia and South Korea (World Steel Association 2023). 27% of crude steel produced in the EU in 2022 (with the EU having a share of 7.2 % of global production) came from Germany (EUROFER 2023). In order to meet the needs of the domestic steel industry, Germany imports iron ore, pig iron and additional steel products. Iron and steel combined therefore ranked 9th among Germany's imports in 2021 (OEC 2023b). Steel is particularly important for the German construction and automotive industry, which consumed 35% and 26% of German steel consumption in 2019, respectively (Bookhagen et al. 2022). Globally, patterns are similar, with the remaining steel mainly used for machinery, metal goods and tubes (DERA 2019). Iron and steel account for more than 60% of the material used in

[1] In the EU, 2.5 Mio. people are directly or indirectly employed in the steel industry. In 2021, 308,000 of which 81,500 people are working in Germany, were directly employed in the industry (Bookhagen et al. 2022).

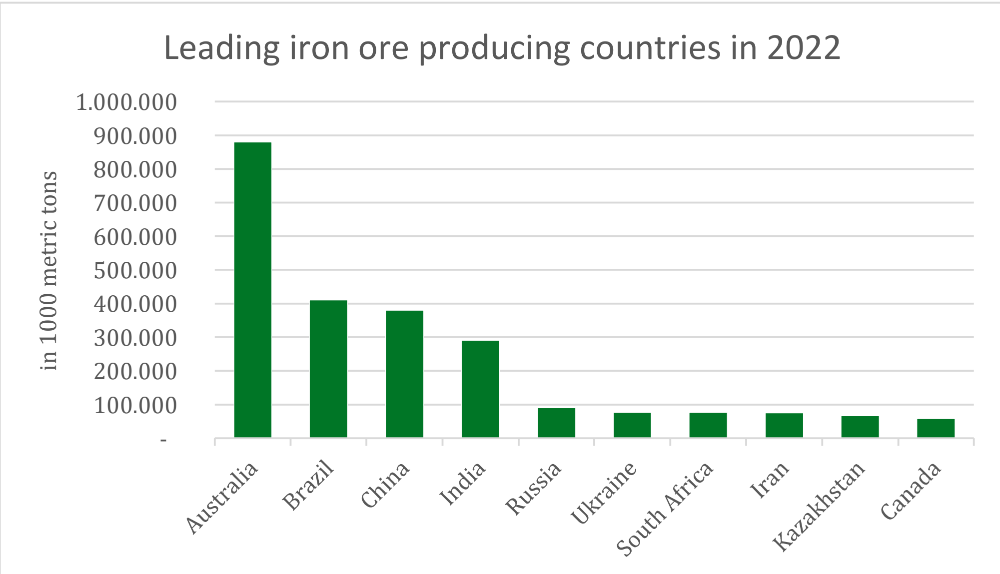
car manufacturing, as they are used not only for the body, but also for the chassis, transmission, wheels, suspension and brakes. Production facilities also rely on steel, which is used in robots, conveyors and tools (Kerkow et al. 2012; Weiss et al. 2022). Given the automotive industry's high reliance on suppliers of steel and steel products, the following profile focuses on the supply chain for steel sheets used in the automotive industry as an iron ore-based commodity.

2.2 Market structure

The various sectors involved in the iron ore/steel supply chain are highly concentrated, both with regard to the mining of iron ore as a raw materials and the processing into pig iron and steel (Küblböck et al. 2022).

Iron ore is mainly mined in large-scale mining (LSM) structures dominated by large global corporations. Similarly, iron ore production is highly concentrated geographically. In 2022, the four market leaders Vale, Rio Tinto, BHP Biliton and Fortescue Metals Group alone accounted for 80% of worldwide production (Global Times 2021; Küblböck et al. 2022)

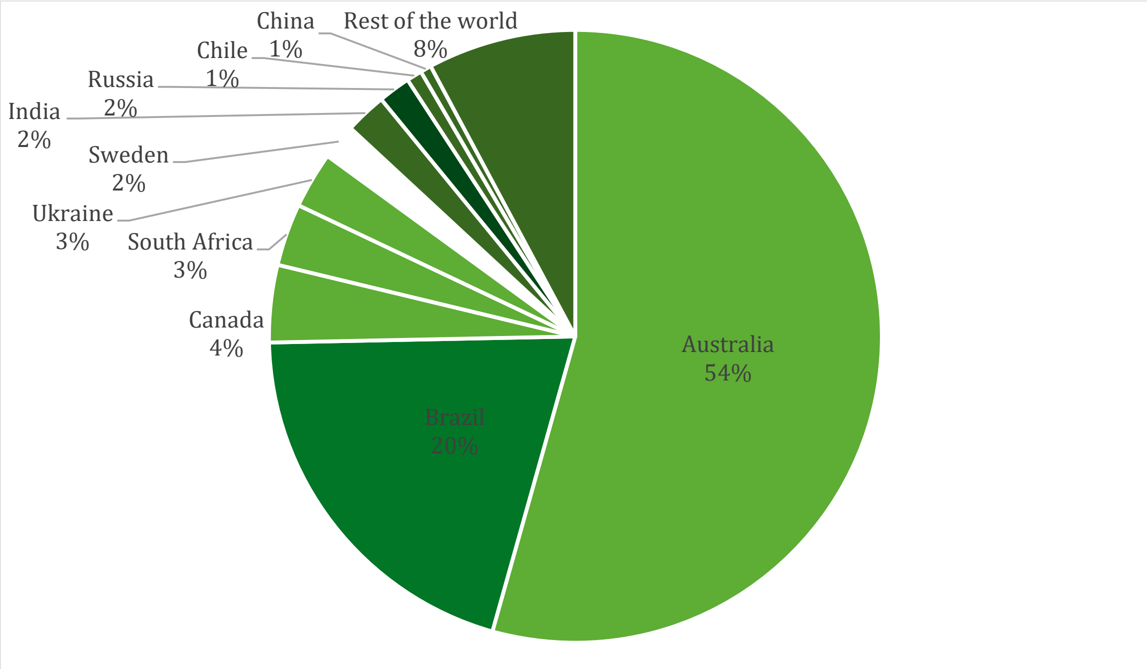
Figure 1: Global iron ore production 2022, by country



Source: Own graph based on data from U.S. Geological Survey 2023a

Geographically, Australia, Brazil, China and India were the biggest producers of iron ore, accounting for 75% of global production (DERA 2019; U.S. Geological Survey 2023a) (see Figure 1. As shown in Figure 2, exports are led by far by Australia and Brazil as China and India retain most of their iron ore production for domestic steelmaking (OECD 2023b).

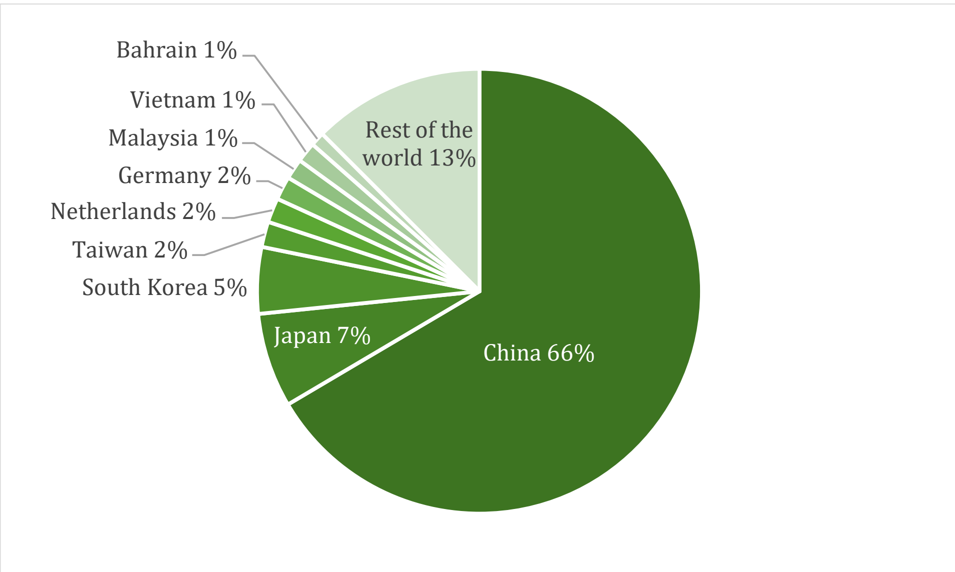
Figure 2: Leading iron ore exporters in terms of value in 2021, by country



Source: adelphi, based on information from OEC (2023b)

Germany is entirely dependent on the import of iron ore. In 2021, Germany imported just under 40 million tonnes of iron ore worth $3.7 billion, mainly from South Africa (27.1%), Canada (23.1%) and Brazil (18.8%), followed by Sweden and Russia. This makes Germany the 6th largest consumer market for iron ore in the world after China, Japan, South Korea, Taiwan and the Netherlands (Destatis 2022; OEC 2023d) (see Figure 3). Overall, however, Germany's share of total global consumption in 2021 was only 1.7%, as China alone accounted for 66% of global iron ore imports worth $146 billion, while Japan and South Korea imported a further 11%. The iron ore market is thus heavily dominated by a few Asian countries (OEC 2023c).

Figure 3: Leading iron ore importers in terms of value in 2021, by country



Source: adelphi, based on information from OEC (2023b)

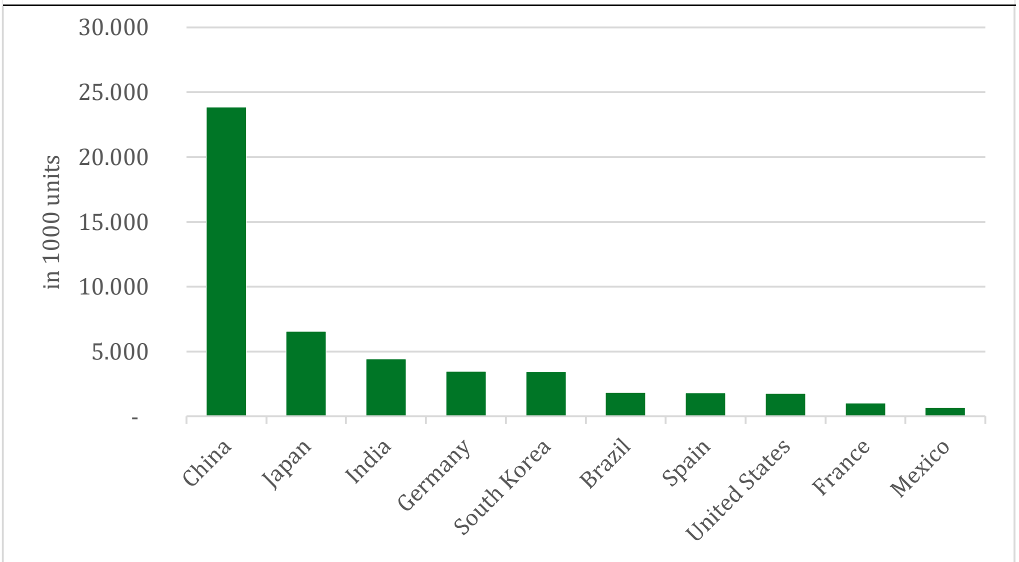
Market dominance is even more pronounced for pig iron and steel. In 2022, more than 60% of global pig iron was produced in China, followed by India, Japan and Russia with much smaller quantities of four to six percent each (U.S. Geological Survey 2023a) (see Figure 3). In comparison to iron ore and steel, world trade in pig iron is rather small, as it is largely produced by steelmakers as an intermediary product in steel production or as a supplement to the use of scrap steel. The steel industry therefore usually only buys pig iron on the market to compensate for possible discrepancies between its own production and the quantities required for steel production (Schlemme et al. 2019). Therefore, the following profile will focus on iron ore as the main input material for steel production.

In terms of steel production, China is again the market leader with a share of more than 50% of global steel production. It is followed by India (6.1%), Japan (4.9%) and the US (4.4%) (U.S. Geological Survey 2023a). Germany produced around 40 million tons of crude steel in 2021, making it the eight largest steel producer in the world and the largest in the EU (EU27) (Wirtschaftsvereinigung Stahl 2022). The three biggest steel producers in Germany are Thyssenkrupp, ArcelorMittal und the Salzgitter AG (BMWK n.d.). In 2021, global steel exports were led by China, Japan, Russia and South Korea, followed by Germany (23.9 million tonnes), which is at the same time the third largest importer of steel after the U.S. and China, importing 23.3 million tonnes of steel in 2021 (World Steel Association 2022). German steel exports go mainly to EU countries (80%) (Wirtschaftsvereinigung Stahl 2022), while an industry expert stated in an interview that imports to Germany also come mainly from European countries such as Italy, the Netherlands, France and Belgium. This is supported by figures from EUROFER on market supply to European consumers of hot-rolled flat steel products and cold-rolled steel sheets – both of which are important for automotive production: in 2022, more than 75% of the EU market supply of hot-rolled flat products came from European suppliers, while for cold-rolled sheet about 68% of EU demand could be met by European deliveries. For both product types, therefore, only 25 to 30% each was covered by imports from third countries (EUROFER 2023).

Since the German trade balance in steel is almost even, Germany does not appear in the list of the largest net exporters and importers of steel. Indirect exports, however, are much higher. For example, 28.1 million tonnes of rolled steel were exported as a component of cars and machinery (Wirtschaftsvereinigung Stahl 2022).

As these number already suggest, the automotive industry is one of the most important consumers of steel products – on average, 900kg of steel is used in a vehicle (World Steel Association o.J.). Globally, automotive production is dominated by companies from China, Japan, India, South Kora, Germany. Chinese production was higher than those of the following five combined (Statista 2023b) (see Figure 4).

Figure 4: Leading car producers in 2022, by country



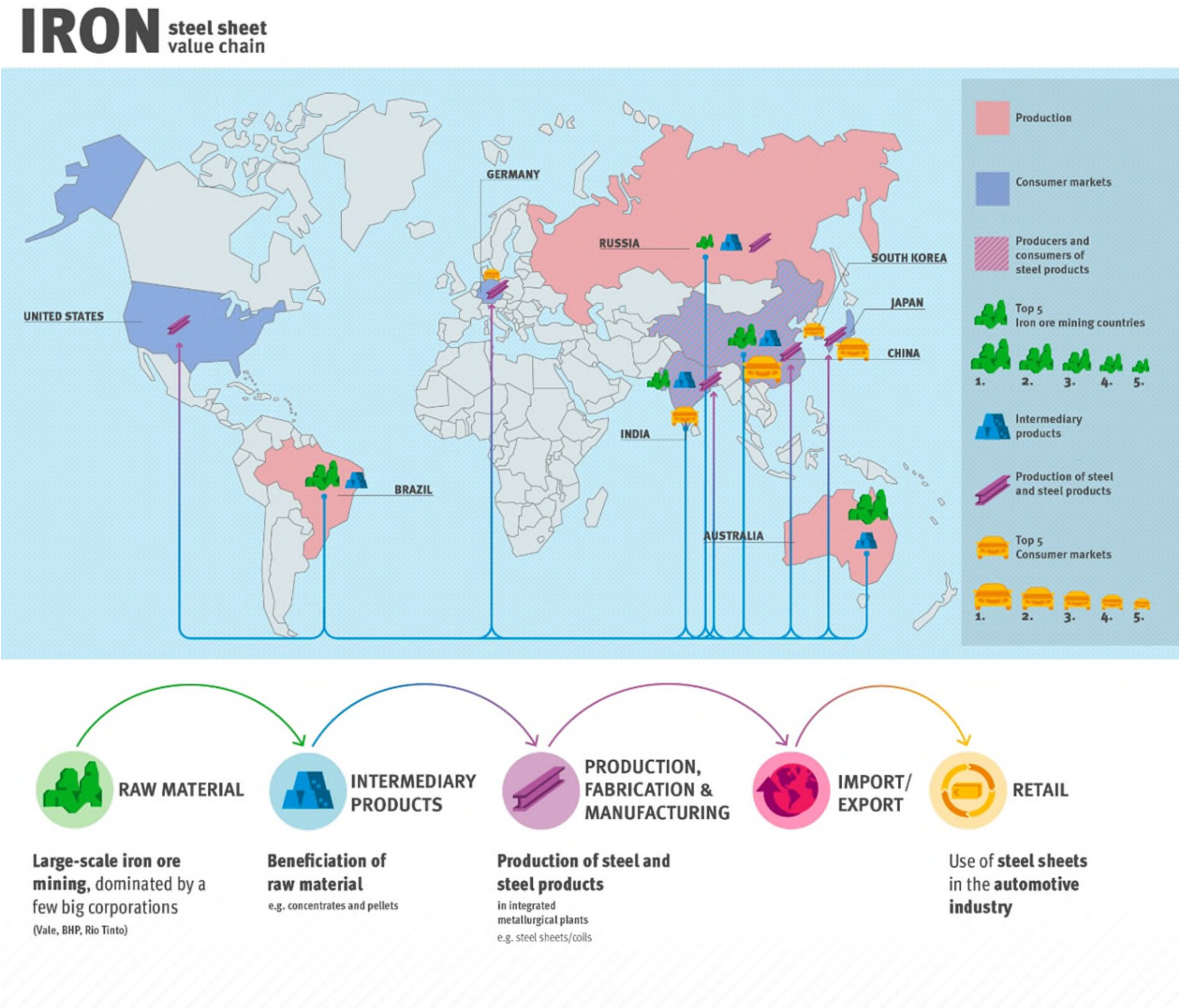
Source: adelphi, based on information from OEC (2023b)

Leading car manufactures include Toyota (11.5%) Volkswagen (6.7%), Honda (5.4%), Hyundai (5.2%) and Nissan (4%), followed by the German brands BMW (3.1%) and Mercedes-Benz (2.9%) (Statista 2023c). In the EU, the automotive industry accounts for 17% of European steel consumption. Germany is the biggest European producer of cars with 42 car factories located in that country (31 in France, 23 in Italy, 17 in Spain). Germany's car exports, worth 92€ billion, account for 59% of total European exports (Grigorenko 2023). In 2022, the three biggest German car manufacturers Volkswagen, BMW and Mercedes-Benz had a revenue of 279.2€, 150.0€ and 142.6€ billion respectively (Statista 2023b).

2.3 The iron ore/steel value chain

Since the maritime transport of bulk commodities such as iron ore has become common, the international iron and steel value chain has become increasingly globalised, with mining companies supplying steelmakers all over the world. But it is particularly China's and other Asian countries' industrial development and growing importance in the iron and steel market that has led to an increase in the trade of iron ore (Küblböck et al. 2022). The iron ore-steel value chain comprises a number of steps, such as the extraction of the mineral, the beneficiation of the raw material, transportation and/or export/import, the production of crude steel and the finalisation of diverse steel products through refinement like steel sheets that are being used in the automotive industry. Figure 5 displays a simplified typical value chain from iron ore mining to the consumption of steel sheets in the automotive industry. Depending on the product and the individual value chain, the production process can include a varying number of suppliers (between automotive OEM and steel maker there can be intermediate suppliers/producers of components), but compared to other metallic raw materials, the iron ore-steel supply chain is relatively short, as confirmed by several experts in interviews. This is mainly due to the fact that large mining or steel companies often combine different processing steps (see section 2.2).

Figure 5: Selected key structures and processes of the iron ore/steel value chain



Source: Own illustration.

The main input materials used for the production of steel today are coking coal, iron ore and steel scrap. There are two main methods for the production of steel that are based on these materials. Steel production via the blast furnace-basic oxygen furnace (BF-BOF)[2] technique dominates global production, accounting for 71.5% in the year 2022. The second method is based on steel production in electric arc furnaces (EAF)[3] and made up 28.2% of global steelmaking in 2022 (World Steel Association 2023). Similarly, in Germany, around 70% of steel

[2] The production of steel in the blast furnace (BF) uses coking coal as a reducing agent to extract oxygen from the ore, resulting in the production of pig iron. This method is usually paired with basic oxygen furnaces (BOF) in which the melted pig iron is further purified through the injection of oxygen and subsequently receives secondary metallurgic treatment, e.g. the adjustment of its chemical composition and the adding of certain properties which give the crude steel its final quality (Külbböck et al. 2022; Hannah and Fan 2021; Stahlinstitut VDEh 2023). This process is also referred to as the primary steel production process, which uses iron ore as the main input material. In addition to iron ore, steel scrap usually accounts for 15-25% of the feedstock (IEA 2020).

[3] Steel production in EAFs mostly relies on the use of scrap steel (scrap-based EAF). Additionally, directly reduced iron (DRI) is used, resulting in the so-called DRI-EAF route. In the process, oxygen is removed by blowing hot gases (carbon monoxide and hydrogen) through the material to produce directly reduced iron (DRI) or so-called sponge iron (tec-science n.d.). Due to the use of gas as a reducing agent, the process takes place at lower temperatures so that the iron ore in the DR plant is reduced in a solid state. DRI therefore still contains a lot of foreign material from the ore (the gangue or slag), and must be melted to form steel which is then carried out in an EAF, where the DRI may be mixed with a varying amount of steel scrap, as far as the product quality considerations allow for it (IEA 2020; BMWK n.d.; Hannah and Fan 2021).

was produced via the BF-BOF route and the remaining 30% via the electric steel route in 2022 (Wirtschaftsvereinigung Stahl 2022). Steelmaking that is based on iron ore accounts for around 70% of global crude steel production, while the rest is obtained from steel scrap (IEA 2020).

As described in Section 2.2, international iron ore production is concentrated in only a few countries. The great majority of iron ore is mined in LSM[4]. While some of the ore is exported directly to Europe and Germany (in the form of lumps or fines), part of it is directly processed by the mining company itself or a separate processing company before it is purchased by steelmakers or traders. If this is the case, the beneficiation usually takes place in the country of origin or in regional proximity. Whether the ore is beneficiated before being sold depends mainly on its quality. Direct-shipping ores (DSO) with between 55% and 65% Fe (iron) content are usually exported directly. Lower quality ore is often processed/beneficiated by the mining company to increase its iron content, thus achieving iron ore concentrates which in turn may be used directly or further processed into pellets (Hannah and Fan 2021). Mining companies therefore usually offer a diverse portfolio of intermediary iron ore products of different qualities (measured by Fe content and impurities). The higher prices that can be obtained for products with higher Fe content (higher grade) and lower impurity levels often make beneficiation economically worthwhile for mining companies (Kim et al. 2022).

After beneficiation, iron products marketed in the form of pig iron, concentrates or pellets are sold to traders, steel service centres (SSCs), producers of intermediary products or directly to steelmakers – with the iron ore products usually being exported as part of these process steps. As suggested by the experts interviewed for this study, reasons to sell to traders include the lack of capacity or means of smaller mining companies to store the raw material and handle the complex sales process including contracts, shipment and discharge of the material. While direct contracts with mining companies are often preferred, interviews with industry experts suggest that a small share (maximum: small double-digit share) of iron ore is bought from traders for the European market. Steelmakers then metallurgically process the material using various refining processes, which usually take place in large integrated steelworks complexes (Kerkow et al. 2012; Weiss et al. 2022).

Depending on their steelmaking process, steelmakers purchase different iron ore products which may lead to slightly different supply chains. For the BF-BOF route, iron ore lumps or natural fines are usually used, which are agglomerated into sinter. Less common is the use of certain concentrates or pellets (Küblböck et al. 2022; Wirtschaftsvereinigung Stahl 2022). In the DRI-EAF production route, direct reduction (DR) plants are usually fed with pellets or, more rarely, with high quality lump or pig iron (Hannah and Fan 2021; Stahlinstitut VDEh 2023). As the production of DRI requires higher quality materials with lower levels of impurities (Hannah and Fan 2021; BMWK n.d.), one reason that limits the global share of direct reduction in the production of steel is the supply of high-grade material (Stahlinstitut VDEh 2023; BMWK n.d.). The main difference from steelmaking in blast furnaces is that DR plants use natural gas instead of carbon (coal) as a reducing agent to remove oxygen from the ore. For this reason, most DR plants are located in the Middle East, where natural gas is cheap (Hannah and Fan 2021; BMWK n.d.). In Germany there is only one production site for DRI at the moment (Wirtschaftsvereinigung Stahl 2022).

[4] As indicated in reports and confirmed by expert interviews, the share of ASM in iron ore mining is very small and does not contribute significantly to the steel supply chain of the automotive sector. Data on ASM production is not available, but the high capital investment in infrastructure required to mine iron ore and the fact that iron ore is a bulk commodity and the associated economies of scale give the large companies advantages over the ASM. Prices for iron ore would have to be much higher for the ASM to be profitable, according to experts in interviews. Only in countries where there is a closed local/domestic loop with no exports is there a small market for high-grade ore from ASM (ILO 1999).

The liquid crude steel is finally cast, usually in a process of continuous casting, and turned into slabs, billets or blooms that are then rolled into steel sheets or other long steel products (beams, reinforcing steel, wire, tubes), either in separate processes or in casting rolling mills. Sheets and wire are usually rolled up into coils for transport (Küblböck et al. 2022; Stahlinstitut VDEh 2023; tec-science n.d.).

The production processes in the iron ore-steel supply chain are associated with **negative environmental impacts** as well as social problems and challenges, including human rights violations (e.g. land grabbing and forced resettlement, health related problems, destruction of natural livelihoods) all along the supply chain, from iron ore mining to the production of steel and steel products. Table 1 shows those environmental impacts that are common in the supply chain and therefore relevant for the industry. This does not mean that every impact listed will occur in every iron ore-steel supply chain.

Table 1: Main environmental impacts in the iron ore-steel value chain

Supply chain segments	Environmental impacts
Mining & beneficiation	Depletion of water reserves and deteriorating groundwater reserves through mine dewatering and high water use for flotation beneficiation
	Deforestation and loss of biodiversity/danger to ecosystems through land use for mines and related infrastructure
	Contamination of water through the release of acid mine drainage and waste water (containing heavy metals and industrial refuse) through mine dewatering and the possible leakage from tailing ponds or breach of tailing dams
	Air and environmental pollution resulting from metal and rock dust emissions caused by blasting and open transportation
	Fragmentation of ecosystems by infrastructure created for transport purposes
Refining processes & steel production	High water consumption: risk of water scarcity and conflicts of use between agriculture/drinking water and steel production
	Very high GHG emissions resulting from high energy consumption and the use of non-renewable energy sources
	Air pollution from metal dust

Source: adelphi, based on information from Kerkow et al. 2012; Baeten et al. 2018; Groneweg 2020; Weiss et al. 2022; ENCORE n.d., and expert interviewsIn the case of the steel products for the automotive industry, i.e. the focus of this study (focus product: coils), there are different trading channels between the steel producer and steel customer: steel producers sell their products either directly to automotive manufacturers, who for example produce components for the car body from coils in their own stamping plants, to SSCs[5] or manufacturers of components for the automotive industry, who produce customised materials or specific car body parts. Steel producers can also sell their products to intermediaries who market the coils worldwide without adding any value. While no detailed figures are available on which trade route is most widely used in the German automotive industry, EUROFER provides some interesting data on

[5] Steel service centres function as intermediaries between producers and end users of steel (and other materials) and can be a relevant actor in the automotive industry. SSCs procure large quantities of steel from steel mills and provide processing, inventory management and distribution services. SSCs mostly follow Just-in-Time models that aim at supplying end users with material in customised quantities, forms and timing to align it to production schedules and increase efficiency and reduce inventory costs. As of 2018, almost two thirds of SSCs were located in the Asia Pacific region while Europe accounted for around 15% of SSCs (Grand View Reseach 2023; Tata Steel Downstream Products Limited n.d.).

the European market: as of 2023, 53.8% of all EU strip mill products are sold directly to end-users (of which 21.1% goes to the automotive industry), 36.7% to SSCs and 9.5% to merchants (EUROFER 2023).[6] Although the iron ore-steel value chain has a global reach, trade inside the value chain often follows regional patterns, with related value-adding steps of the chain being conducted in neighbouring countries/regions inside East Asia, South-East Asia or Europe or domestically (OECD 2017). Transportation costs as well as regional trade agreements help explain this regional approach, which was also confirmed by various expert interviews. This also applies to steel sheets/coils which are mostly traded regionally, with European steel products being supplied to European car manufacturers, often remaining in the same country. Rare, high-value products are more often exported globally (OECD 2017).

2.4 Pricing

Prices in the iron ore-steel supply chain are influenced by a variety of factors, particularly at the raw material level, where the cost of iron ore and coal, energy costs, labour costs, technological developments and also political decisions such as trade agreements, restrictions or tariffs play an important role. In later stages, prices are more often negotiated directly between buyers and suppliers, with the aim of covering production costs and making some profit. Price negotiations are part of a broader framework of purchasing practices that are highly contested between buyers and suppliers, as discussed in Section 2.5. The following chapter therefore focuses mainly on commodity-level pricing mechanisms; prices for steel products are only briefly examined.

The specific pricing system for iron ore has undergone significant changes over the past 20 years; for about 40 years, prices were set in long-term contracts negotiated behind closed doors between buyers and sellers and then presented to the public as a result. Since the mid-2000s, however, there has been a tendency to set prices on the basis of benchmarks that track spot market prices (Hannah and Fan 2021; Kim et al. 2022). Due to the increasing instability and fluctuation of prices and the resulting higher price risk in long-term contracts, the financial crisis of 2008 as well as the rapidly increasing demand for iron ore in China, from 2010 onwards contracts started to be largely based on these indices (see box on the next page). Mining companies such as Vale and BHP, who wanted to close the gap between prices in long-term contracts and spot market prices to achieve much higher margins, played an important role in this system change (Hume and Sanderson 2016; Treadgold 2020). As a result, the producer-pricing regime slowly began to disappear. The resulting intense price competition between producers further contributed to the volatility of the market. Since then, price volatility has remained much higher than in the decades preceding the financial crisis, again changing drastically with the outbreak of the COVID-19 pandemic and the beginning of the Russian war against Ukraine (Jégourel 2020; Hall 2020; Kim et al. 2022). As shown by the fluctuations of the last two decades and confirmed by industry experts in interviews, the most important factor influencing iron ore prices is the dynamics of global supply and demand.

[6] These figures only give an incomplete picture of the trade in steel plate for the automotive industry, as the automotive sector is only one of the customer industries for strip steel products and steel plate is only one of several categories of strip steel products.

Because large companies can more easily withstand increased price fluctuations and make investments in the infrastructure needed to mine iron ore, fluctuating price trends contribute to their dominance in the iron ore industry (Global Times 2021; Kim et al. 2022). The so called "big four", Vale, Rio Tinto, BHP Billiton and Fortescue Metals Group, account for 80% of market share, a power that is also reflected in price setting mechanisms. World market prices and prices that steel producers have to pay are thus heavily dependent on these big players (Kerkow et al. 2012).

While the impact of spot market prices on price discovery described above is a global phenomenon, it is mainly the Chinese steel industry that actually trades iron ore on spot markets (Hannah and Fan 2021) (see box on this page). As suggested by research and verified in interviews with industry experts, European steelmakers typically still negotiate contracts directly with their suppliers, thereby avoiding some of the insecurity that price fluctuation on spot markets causes (Kerkow et al. 2012). This is especially true for higher-quality material. This is partly due to the fact that market price dynamics in the iron and steel supply chain differ in complexity depending on the quality of the material that is traded, the steel production route available as well as regional value drivers. As demand for the diverse iron ore products depends to a large degree on the available production capacities, sellers try to sell to customers that have a special need of the product they are offering, e.g. sellers of high-grade iron will look for steelmakers that use DRI as an input material (Hannah and Fan 2021). Due to these dynamics, iron ore that goes to European markets is usually traded via direct longer-term contracts and only a small share is traded on spot markets.

The increase of price volatility in recent decades has also led to companies increasingly wanting to hedge against price risks through investment in iron ore derivatives. As a result, more financial investors have entered the iron ore market. Today, iron ore is also traded on futures markets. The Chinese Dalian Commodity Exchange, on which iron ore futures have been listed since 2013, is now the most important iron ore financial derivatives trading market worldwide. Due to the steadily growing volume of iron ore traded on futures markets, the influence of trader's bids on

Benchmark indices in the trade of iron ore

Since the breakdown of long-term contracts in 2010, prices on the iron ore market are informed by indices based on spot market sales which are set by independent benchmarking companies such as Platts, Argusmedia and Metal Bulletin (Kim et al. 2022).

The **Platts Iron Ore Index (IODEX)** by S&P Global Commodity has been the primary benchmark for global prices of iron ore. It is used by steelmakers, traders and mining companies for spot market contracts and also serves as a reference/basis for long-term contracts. In the past, the index exclusively assessed the prices of 62% standard ore. However, as this one grade could not reflect the wide variety of iron ore products on the market, different indices were developed for different qualities of ore, each referencing a variety of similar products to index-based specifications where the product's quality is determined either by the natural grade of the ore or is the result of its processing. Today IODEX publishes indices on high- and low-grade ore (e.g. 58% Fe, 65% Fe), as well as for a number of products such as pellets. Qualitative differences in products that exceed these general specifications are priced by trading partners with surcharges or discounts (Fastmarkets 2018; Jégourel 2020; S&P Global Commodity NaN).

For the most common products such as fines and lump, which make up the bulk of the seaborne iron ore market, prices are determined on a daily basis, while for beneficiated products (e.g. concentrates, pellets) weekly indices are published (Fastmarkets 2018).

future price levels is also increasing, which could exacerbate price volatility in the future (Küblböck et al. 2022).

Even though the European and German market work rather differently from the Chinese one, the latter is a central factor influencing the global price development for iron ore/steel. In particular, broader developments such as the recent increase in demand for high-grade iron ore (> 63.5% Fe), accompanied by fluctuations in domestic production capacity in China, as well as the increasing focus on reducing CO_2 emissions, are having an impact on the European market. As supply and demand are the main drivers of iron ore prices, recent lower than expected growth in China, for example, has led to a decline in world iron ore prices (Hannah und Fan 2021; OECD 2022a).

While the trading of iron ore and iron ore products has undergone a major shift to trading on spot markets, the steel market and its downstream industries have not evolved in the same way. This is mainly due to the diversity of finished and semi-finished steel products used in different industries, which makes managing price risk much more difficult. Moreover, there are in fact several segmented regional steel markets due to the limited global integration of the market, including transport costs and the existence of regional trade agreements (RTA) (see section 2.3). This structure hinders one-off trade, e.g. in the foreign exchange markets (OECD 2017; Jégourel 2020).

Pricing mechanisms in China

The pricing mechanisms in China, an important player in the iron ore and steel market, differ drastically from other markets, mainly due to stronger state intervention and political influence. For example, the three largest steel producers in China (China Baowu Steel Group Corp, Hebei Iron and Steel, and Jiangsu Shagang Group) are state-owned enterprises (Steinlein et al. 2022).

These particular characteristics are also reflected in the significant price differences for steel that have been observed in the past. For example, unlike many other countries around the world, China continues to buy cheap coking coal from Russia even after the unlawful attack on Ukraine, which leads to a significant price advantage in steel production. The OECD predicts that the price differences in steelmaking between China and other regions will persist and possibly amplify in the future. One reason for this is that recently a new Chinese state agency, the China Mineral Resources Group (CMRG), was established to further centralise all of China's iron ore procurement in order to lower prices for local steel companies and secure supply with the raw material in the long term (OECD 2023).

The development of steel prices depends strongly on the price of iron ore. Another important factor is the price of coking coal, which is mainly used for the reduction of iron ore in blast furnaces. Other factors are the prices of input materials for the refinery process as well as steel scrap (Mercier et al. 2022). The international steel market is characterised by a strong level of competition, which limits the prices that can be achieved (BMWK n.d.). This is one of the reasons why profits in the steel industry are significantly lower than in the mining industry (Treadgold 2020; Mercier et al. 2022). As the costs of steel production in the EU are higher on average, mainly due to higher raw material and labour costs, the profit margins of European steel producers tend to be lower than in other world regions (Medarac et al. 2020). One unique selling point for European steelmakers that partly compensates these disadvantages is the production of a larger share of high-quality steel products than in other world regions. For this they require higher-quality raw materials (high iron ore grades, low impurities). The production of flat steel products like quality steel sheets for the automotive industry also follows this logic (Fastmarkets 2018). Steelmakers deal with the price mechanisms on the steel market in two ways. When profit margins are higher and steel production is more profitable, it pays to use high-purity ore to maximise production efficiency. When profit margins fall, they resort to lower-grade inputs (Fastmarkets 2018).

2.5 Power relationships

As the previous chapters show, China is a key player in the iron ore and steel market and the market activities in the People's Republic also have a significant influence on pricing in global markets, for example. The market structures in China differ significantly from those in the rest of the world market due to strong state intervention (e.g. subsidisation) and operate as a closed infrastructure, partly shielded from world trade. For this reason, the following chapter describes the typical power structures outside the Chinese iron ore-steel products sector.

The initial steps in the iron ore-steel supply chain in particular are characterised by large, financially strong companies dominating significant market components, as economies of scale make the infrastructure investments required in mining and steel production more bearable. Both mining and steel production are highly capital-intensive industries requiring high investments in large equipment and continuous operating and capital expenditure (Kim et al. 2022). This leads to some power imbalance, which can hinder the effective implementation of environmental, climate and resource protection measures due to highly competitive purchasing practices.

Following Gereffi et al.'s (2005) approach, the relationship between **mining companies** and steel producers can be described as a **market**, dominated by **strong suppliers**. Although mining companies usually offer a broad portfolio of product specifications and are also oriented towards market demand and the quality requirements of steel producers, production and value addition take place without much input from the buyer (OECD 2017; Hannah and Fan 2021). The **pricing power** lies with the seller rather than the buyer and the complexity of the information exchanged is rather low, so transactions can be comparatively easily governed. The strong position of large mining companies in particular is reflected in the fact that certain iron ore products (especially in the high-grade segment) originate mainly from certain regions and are only sold by specific companies. For example, DSOs are mined predominantly in regions such as Australia's Pilbara and Brazil's Carajas area, where they are sold by mining companies such as Rio Tinto, BHP and Vale (Hannah and Fan 2021; Eames 2021).

Further down the value chain, where **steel producers** sell their products to the **automotive industry**, a different business model is dominant according to Gereffi et al. (2005). While less information is available on typical contract models at this stage of the supply chain, it became clear from interviews with industry experts that automotive suppliers purchase their steel products from a wider range of suppliers; they buy steel coils for further processing in their own pressing plants directly from steel companies, from dealers, as well as finished components from component manufacturers. This suggests that a **captive market** is more likely, with buyers purchasing from different sources according to their product requirements in order to flexibly meet demand depending on production volumes. In the specific supply chain of steel coils for the construction of cars, many of the complementary activities such as design, process technology upgrading, etc. tend to lie with the automotive component manufacturers or OEMs.

The steel industry is more fragmented and less dominated by very big companies than iron ore mining (Kerkow et al. 2012), but it is still concentrated in comparison to other industries (Küblböck et al. 2022). This is partly due to the heterogeneity of steel products and their uses. In comparison with other commodity-based industries there is a relatively low degree of vertical integration in the steel industry. While multinational companies often manufacture a range of different steel products in their large integrated steelwork complexes, intermediary products are usually traded across different companies and countries (OECD 2017). But as this makes production dependent on the continuous supply of raw materials at affordable prices, parts of the industry began to invest in upstream integration like the acquisition of mining assets when raw material prices became particularly high, also hoping to capture higher margins (McKinsey & Company 2014) as the market is very competitive and margins in steelmaking are rather low (Mercier et al. 2022; BMWK n.d.). At least some companies have already changed their strategies since then, refraining from further pushing into **upstream integration**. Additionally, the industry has begun to invest in downstream activities. Large steel producing companies which own production plants in different locations across the globe may therefore operate all along the entire value chain, handling steps from iron ore mining all the way down to the production of steel products such as elevators in globally spread intra-firm trade (OECD 2017). This **can also lead to shifts in the typical distribution of power** within the supply chain, e.g. towards hierarchical structures based on integrated firms.

Purchasing practices

The main business models to source iron ore for the German/European automotive market can be summarised as in Table 2:

Table 2: Dominant business models and governance in the iron ore/steel value chain

Business model	Type of buyers	Governance	Type of relationship	Procurement procedure
Mix of key & occasional suppliers	Steel makers	market	mid-term sourcing contracts	Competitive; strategic factors (e.g. reliable supply, high quality)
Mix of key & occasional suppliers	Automotive industry (OEMs, component manufacturer)	captive	Mix of short-term and long-term contracts	Competitive; price dominant

Suppliers (mining companies) use targeted marketing strategies to achieve the highest possible margins for their products. Producers of the highest-purity ores usually try to sell their products directly to DRI steel mills, as they are willing to pay the price premium for the good quality, since the iron ore can be used directly in their plants without further processing. Here, mostly **bilateral direct contracts** are concluded between mining companies and steel mills, so there is little spot liquidity in the area that could create price transparency for these products (Hannah and Fan 2021). Similar approaches can be seen in the trade of high-quality BF-grade pellets: these are mainly demanded/purchased by steel mills in Europe, Japan, South Korea or Taiwan, due to the nature of their blast furnaces and the stricter local operating regimes with respect to environmental regulation. Here, too, **direct contracts** are mostly preferred, the terms of which are **negotiated quarterly**, as steel mills do not want to risk supply uncertainty by leaving some allocation to spot markets. The high proportion of direct contracts leads to low price transparency for high-value iron ore products. The **productivity** of steel mills is in some cases highly dependent on the products they source from mining companies (Hannah and Fan 2021); for example, Vale's IOCJ product, which serves as a reference for the 65% Fe Fines Index, is among the most sought-after brands in the market for optimising productivity via the sintering process (Argus Media 2019; Hannah and Fan 2021). As described in Section 2.4, since 2010 suppliers have also changed the business model of the iron and steel industry towards more short-term contracts that follow indices based on spot market prices. While suppliers are profiting from this change, steelmakers are struggling with volatile world market prices. Passing on higher prices to downstream steel-consuming industries is difficult because contracts on the less financialised steel market are not based on raw-material indices, but negotiated directly. Steelmakers thus carry a high risk, due to the volatile world market prices of iron ore (Bekaert et al. 2021).

In addition, steel producers are not only dependent on the purchase of iron ore, but also on the price development of other key raw materials for steel production, such as coking coal or alloy metals (Mercier et al. 2023). This current/traditional[7] "sandwich position" of steel companies in the supply chain is also reflected in the relatively low profitability of steel producers in recent years. According to the OECD, about 25% of steel producers worldwide operated with a profitability of less than 5% in 2021 (Mercier et al. 2022). At the same time, the largest iron ore miners achieved a gross profit margin (before accounting and other costs) of up to 700% the year before (2020) (Treadgold 2020). Nevertheless, steel producers also exercise a certain power over their suppliers, which is reflected in the **quality controls** they impose on mining companies – for example, according to interviews with experts, each delivery is checked by the steel company to see where the iron ore purchased comes from and whether it meets the quality requirements for Fe content, impurities, etc. This can be checked quite easily for iron ore by means of chemical testing by steel companies.

Information on the typical contractual relationship between steel producers and automotive manufacturers is not readily available. However, interviews with industry experts indicate that automotive customers purchase their steel products from a wider range of suppliers. They buy steel coils for further processing in their own press shops directly from steel companies and from distributors (percentage distribution not known). In addition, finished components are also purchased from component manufacturers for direct installation.

2.6 Addressing environmental impacts by voluntary measures

In recent years, voluntary initiatives and standards have been developed as additional instruments for companies in the iron ore-steel supply chain to implement due diligence and set more stringent environmental and social requirements. However, as several experts interviewed for this study pointed out, the market supply of certified iron ore/steel products or equipment is quite limited. Iron ore – among other metals – is covered by the stakeholder **Initiative for Responsible Mining Assurance (IRMA)**, established in 2006. IRMA has developed one of the most comprehensive and widely recognised standards for responsible mining, covering environmental issues (e.g. waste management, water, air quality, greenhouse gas emissions, biodiversity) as well as various social and corporate responsibility requirements (IRMA 2018). IRMA requires independent third-party certification for mines of all commodities. As of July 2023, IRMA audits were ongoing for three iron ore mines in Brazil and two iron ore mines in South Africa. To date, only three mines worldwide have undertaken an independent third party audit based on the IRMA standard, none of which are iron ore mines (IRMA n.d.). Companies undergoing the assurance process at site level have to pay for the independent service provider (IRMA 2021). As an industry expert interviewed for the study pointed out, the initial tentative

[7] While this supply chain profile focuses of the status quo, future trends in steelmaking described under Section 2.7 might change power relationships within the iron ore-steel supply chain significantly. "Green steel" production based on the EAF route requires different input materials such as high-grade iron ore and scrap steel. This puts mining companies and steelmakers in new power positions, especially in times where demand for "green steel" is high and supply is still low.

interest in sustainably produced iron ore has so far come exclusively from the automotive industry and partly from the white goods and high-end construction sector. However, as the low number of IRMA-certified mines shows, there is no significant market for certified iron ore as of yet.

The first **multi-stakeholder standard and certification initiative for steel** (by its own account) is the **Responsible Steel Initiative** (first incorporated as the Steel Stewardship Council in 2016). The initiative published their ResponsibleSteel Standard in 2019 (which was slightly updated in 2021), which covers environmental, social and governance issues on the basis of 12 principles. The standard has been criticised for being vague on some requirements and for lacking criteria for responsible sourcing of raw materials – as of yet, the standard only applies to operational steel mills and production facilities that process raw materials for steelmaking. A comprehensive revision of the standard is to be carried out in 2023 (ResponsibleSteel n.d.). As part of the comprehensive review, Responsible Steel intends to cooperate with existing certification programmes for mine sites, including IRMA, Towards Sustainable Mining (TSM) and the Responsible Jewellery Council (RJC). However, auditing of the responsible sourcing of raw materials is voluntary for members (Küblböck et al. 2022). In an interview conducted in the framework of the project, an industry expert emphasised that stakeholders along the iron ore-steel supply chain have so far mostly approached environmental issues in isolation, only in the context of their direct business activities, and that there has been a lack of cooperation and joint initiatives along the supply chain.

In addition, organisations such as the **World Steel Association** and the Global Oil and Gas Industry Association for Advancing Environmental and Social Performance (**IPIECA**) provide their international members with information on due diligence processes and environmental and social sustainability in the steel sector. However, neither of them offers any verification of standards or certification themselves (Küblböck et al. 2022).

Large players in iron ore mining and steel production usually operate individual sustainable supply chain management (SSCM) and due diligence systems (including supplier code of conducts [CoCs], supplier self-assessments etc.) to meet at least minimum legal requirements. For example, social and environmental **standards for steel production facilities and iron ore mines** on environmental management (ISO 14001) or social responsibility of organisations (e.g. ISO 26000) are applied (Rechlin et al. 2022).

The industry's current focus on sustainability issues is on the production of **"green steel"**, i.e. low-carbon steel[8], for which demand from customer industries such as automotive production is also increasing (Faye 2022). The steel industry is responsible for 7-10% of global greenhouse gas emissions and is the largest industry in terms of carbon footprint, so a comprehensive shift to low-emission steel production is a priority (Hannah and Fan 2021). Predictions foresee a three-step process towards green steelmaking: 1) optimisation of existing processes (in mining, transportation etc.) to reduce emissions, 2) transitions, e.g. equipping existing plants with carbon capture and storage technology, and 3) switching the entire technology to new production routes, i.e. replacing the BF-BOF production route with DR plants and EAFs, using steel scrap and hydrogen-based DRI as input material (Hannah and Fan 2021; Guevara Opinska et al. 2021; Schreck et al. 2023). Currently, most steel companies seem to be pursuing options 1 and 2 to mitigate environmental impacts, which is reflected in the fact that BF/BOF steelmaking capacities are increasing worldwide, especially in Asia (OECD 2023b). However, some European steel producers, such as the HYBRIT initiative in Sweden and all primary steel producers in

[8] While there is no uniform definition of "green steel" so far, Verret (2021) suggests a definition of "steel with less than 0.6 tonnes of CO_2 emissions per tonne of steel produced".

Germany, are already working on option 3, the switch to hydrogen-based steelmaking (Hannah and Fan 2021; Schreck et al. 2023). While hydrogen-based steelmaking is the most advanced option, various alternative technologies are being piloted (Koch Blank 2019). Some companies have developed their own **sustainability labels for selected "low-CO_2 produced" products** and offer them on the market. These include bluemint® steels from thyssenkrupp and XCarb™ green steel from Arcelor Mittal. However, both labels/certificates are based on the reduction of CO_2 emissions in conventional steel production in the blast furnace (e.g. through the use of hot briquetted iron instead of iron ores) and work with balance sheet approaches in which total GHG emission savings in production are converted into small quantities of "green" steel output (ArcelorMittal 2021; thyssenkrupp n.d.).

As of now, many low-carbon-alternative products still come at "a cost premium of 50% or more" (BCG 2023). As a result, debates are underway on political control instruments such as the CO_2 tax to compensate for the higher costs in market competition (see Section 2.8) (Koch Blank 2019). A 2023 report by the World Economic Forum and the Boston Consulting Group predicts that demand for green materials will grow faster than supply in the coming years due to decarbonisation targets set by many downstream companies, including in the automotive sector (World Economic Forum 2023). This makes the payment of "environmental premiums" for low-carbon material more likely (Faye 2022; Azevedo et al. 2022; World Economic Forum 2023). According to calculations made by McKinsey, demand for low-emission steel will "surge from around 84 million tons in 2021 to nearly 200 million tons in 2030, mainly driven by automotive and construction demand in Europe and China"[9] (Azevedo et al. 2022). According to reports, the first steelmakers have started to demand green steel premiums in negotiations for long-term contracts with car makers, among others (Richardson 2021; Bolotova et al. 2023). As the production of green steel requires, among other things, high-quality iron ore[10], in the future there could also be price premiums for "green iron ore" that meets the higher quality requirements for the production of "green steel" (Faye 2022). However, higher prices are already being charged for high-grade iron ore products, which enable low-emission steel production, but these are the result of a combination of their higher quality, costs for processing and demand (see also Section 2.4) (Hannah and Fan 2021).

2.7 Current/future trends and developments

Due to the tightening of environmental legislation worldwide to reduce GHG and air pollutant emissions from the steel and automotive industries (for details see Section 2.8), both sectors have turned to the development of low carbon products. This translates into a global rise in demand for higher-quality iron ore, which allows for low(er) emission steelmaking. Especially demand from China for these high-grade iron ore products has increased significantly since the Chinese government introduced a shift from "quantity" to "quality" steelmaking in 2016. This also increases global market competition for higher-quality iron ore products affecting buyers e.g. from Europe who were considered traditional buyers of these type of ores because of the properties of their BF-BOF steel mills (Hannah and Fan 2021). Similarly, an increase in demand for scrap steel is predicted, which is a possible alternative low emission input material for the EAF production method (but so far has only a small market share) and an increasing demand for recycled steel is predicted, especially from car producers (WMW 2023). Stakeholders along the entire supply chain are slowly starting to work together in the area of emission reduction, as evidenced by collaborations in recent years between car makers and steel makers in the

[9] In this quote the authors use the unit "ton" and "metric ton" (which corresponds to the unit "tonne" that is used in this publication) inconsistently. We assume that metric tons/tonnes are meant throughout the source.

[10] Alternative input material: steel scrap.

production/sourcing of green steel, such as those entered into by the Volvo Group and SSAB in 2021, General Motors with Nucor in 2021, the Volkswagen Group and Salzgitter AG in 2022, the BMW Group, H2 Green Steel and Salzgitter AG in 2022, and Mercedes Benz AG with H2 Green Steel in 2023 (Green Steel World 2022). However, as the annual figures reflect, these are still fairly new efforts and, as the low number of certified mines for iron ore shows, sustainability efforts that cover topics beyond GHG and air emissions reduction and cover the entire supply chain are still limited (for details see Section 2.6).

As for other supply chains, the COVID-19 pandemic and the Russian war in Ukraine have had severe impacts on the supply chains of the iron ore and steel industry with high energy prices as well as supply chain disruptions, leading to soaring commodity prices[11]. The destruction of steel production facilities in Ukraine, in particular, led to slumps and production stoppages in steel production in Europe. European steel producers were therefore confronted with rising iron ore prices and falling steel market prices, which put pressure on their margins. Additionally, rising interest rates and weaker spending were impacting demand adversely, causing prices to decline further (Mercier et al. 2022). The crises have thus put the spotlight not only on the vulnerability of the iron ore-steel supply chain but also shown the volatility of iron ore and steel prices. These developments coupled with bans on exports from Russia also led to some restructuring of steel supply chains with Russia now exporting more than half of its steel to Asian markets (in comparison to 10-20% before the war in Ukraine) (CUMIC Steel Limited 2022; Mercier et al. 2022).

The lingering effects of the war in Ukraine, the global economic slowdown and persistent inflation mean that only limited growth in steel demand is expected in 2024. The OECD also points out that regional differences in steel prices are increasing: In December 2022, steel prices for flat and reinforcing steel products in Europe were 39% and 65% higher than in China. These differences can be partly attributed to the fact that global coking coal prices have risen sharply in the wake of import bans on Russian products, while some countries continue to have access to cheap Russian coking coal – a trend that is expected to intensify (Mercier et al. 2023). Weaker demand from the automotive sector in the EU is also a contributing factor. The production of passenger cars in the EU decreased by 23.5% from 2019 to 2020. In 2021, it fell again by 6.7% and in 2022 it recorded a slight increase of 8.3% for the first time since the COVID-19 induced disruptions (ACEA 2023). Despite continued economic weakness and inflation, car sales registrations in Europe also increased by 26% in March 2023, indicating a recovery in demand (Eckl-Dorna 2023). Accordingly, a slight recovery in steel demand from the European automotive industry is also predicted. While consumption of steel products by the automotive industry increased by 3.3% annually between 2021 and 2022, it slowed down to 1.2% in 2023. Forecasts predict that demand for steel will continue to fall in 2024 (by 1.8% year on year) (Grigorenko 2023).

Table 3 summarises the market, consumer and technology trends that may gain importance in the near future.

[11] Prices for 62% FE iron ore reached a near 10-year high of $176.45 at the end of December 2020, making iron ore one of the best-performing commodities of the year (Hannah and Fan 2021).

Table 3: Market, consumer and technology trends

Market trends	▶ Fluctuation of iron ore prices with a current increase reflecting the economic recovery after the Covid-19 pandemic ▶ Overall decreasing steel prices (regional and product-specific differences exist) ▶ Increasing financialization of the iron ore market (especially in China) ▶ Decreasing global steel production due to global economic slowdown, high energy prices, accelerating inflation and impacts from the war in Ukraine ▶ Potential long-term trend: geographical shifts of steel mills based on availability of hydrogen and increasing demand for steel scrap ▶ Progressive financialization of the iron ore market
Consumer trends	▶ Global economic slowdown, accelerating inflation etc. lead to decrease in vehicle production, thus also lowering steel demand ▶ Rising demand for 'green' steel to meet tightening environmental policy regulations
Technology trends	▶ Steel industry is piloting various low-emission steelmaking technologies, with a current focus on hydrogen-based EAF steelmaking ▶ Rising use of high(er)-grade iron ore products for lower emission steelmaking (especially in China since reform to 'quality phase' of steelmaking in 2016) ▶ Adoption of digital tools to increase information sharing and transparency along the value chain

Sources: Own illustration, adapted from Jégourel 2020; Hannah und Fan 2021; OECD 2022a and interviews with industry experts

2.8 Institutional incentive mechanisms and barriers

Environmental legislation in producing countries

As illustrated in Table 1, both the mining of iron ore and the production of steel are associated with significant negative environmental impacts. The establishment of new mining sites in the major iron ore mining countries is therefore subject to a statutory permit procedure, which generally includes the performance of an EIA (Döhne et al. 2015; Wittmer and Murguía 2015; Sydow et al. 2021). The EIA is a formal administrative procedure that systematically evaluates the positive and negative impacts of specific mining projects on environmental goods such as soil, water, air, climate, landscape, fauna, flora and habitats. The EIA also serves to implement measures to minimise the negative impacts of a mining project. EIAs are required and monitored by environmental authorities and have become a recognised environmental policy instrument in the mining sector in most countries worldwide. Nevertheless, there are still some shortcomings that can prevent EIAs from being effective management systems for environmental protection. In industrialised countries, this is mostly manifested in a lack of public participation, monitoring and review (Wittmer and Murguía 2015). In developing and emerging countries, on the other hand, economic development and related investments are sometimes prioritised over environmental protection and this, combined with corruption and a lack of resources and trained EIA auditors, could result in poor quality EIAs (Wittmer and Murguía 2015; Williams and Dupuy 2017; Cárcamo et al. 2018; Transparency International Australia 2021; Sydow et al. 2021; Neto and Mallett 2023). Generally, economic interests can compromise the effectiveness of an EIA: in most countries, proponents are allowed to directly contract an organisation for the implementation of the EIA, so that a direct financial dependency exists (Sydow et al. 2021). In addition, the indigenous people's right to consultation and free, prior, and informed consent is often violated in the development of new mining projects (BMZ n.d.). Overall, there are strong regional differences in the legal requirements for EIAs in terms of scope, control, independence of EIA auditors and public disclosure/participation requirements, often leading to unreliable results (Wittmer and Murguía 2015). The dramatic rupture of an iron ore tailings dam at a mine in Brumadinho, Brazil, owned by the world's largest iron ore exporters, Vale SA, in 2019 demonstrated the serious consequences that can result from inadequate or insufficiently implemented and audited regulatory requirements. Shortly before the dam failure, the safety of the plant had been officially confirmed by the German certifier TÜV SÜD (ECCHR 2019). In immediate response to the rupture, the International Council on Mining and Metals, the United Nations Environment Programme and the Principles for Responsible Investment convened the Global Tailings Review, which aimed to develop international standards to help prevent similar disasters in the future. The process, which was led by a multidisciplinary panel of scientific experts and received input from an advisory group that included scientists as well as representatives of industry, international institutions and civil society, led to the launch of the Global Industry Standards on Tailings Management in 2020 (Global Tailings Review 2020; Global Tailings Review n.d.).

Environmental legislation in consuming countries

From an environmental perspective, the iron ore/steel sector has so far been most influenced by increasing regulatory requirements regarding emissions of CO_2 and air pollutants, which are already concretely reflected in shifting market dynamics. Hannah and Fan (2021), among others, name environmental policy as one of the most important "stick factors" influencing the price development of 65%-62% Fe iron ore fines. One of the easiest approaches to reduce GHG emissions and air pollutants in blast furnace steelmaking is to use higher grade ores – as there are fewer impurities in 65% Fe ores, they have better sinter quality, reducing the amount of slag and thus the amount of metallurgical coal consumption, resulting in lower emissions. Steel mills are already prepared to pay premiums for higher iron ore grades in order to avoid pollution penalties or forced shutdowns due to higher emission levels. This is particularly evident in China, a major steel-producing country, where spot demand for higher-grade products rose sharply in 2018 after anti-pollution measures were tightened by the government. This has also led to an increase in the floor level price for higher-grade iron ore products in other regions. Since 2016, China has also been pursuing the longer-term goal of converting its steel mills to EAF production in order to achieve its climate protection goals (Hannah and Fan 2021). In general, the transition to low-carbon steel production is still in its infancy worldwide and will require a lot of time as well as high investments to pay for the costs involved. In order to make low emission steel market-ready and to create a level playing field between e.g. hydrogen-based steelmaking and the traditional BF-BOF route, the planned reform of the *European Emissions Trading Scheme* (EU ETS) and the planned introduction of the *Carbon Border Adjustment Mechanism* (CBAM) can be helpful. The introduction of a carbon border tax on imported products, including steel, can help European steel producers to remain competitive in the international market despite raising costs for the low-carbon transformation. This can be an important stimulus for the European industry to make the necessary investments in green technologies (Hannah and Fan 2021).

Furthermore, legislation on corporate responsibility also plays a role in the supply chain of steel products for the automotive industry. Among other things, new and upcoming regulations at the European level may increase the pressure on actors in the supply chain to improve transparency, traceability and implementation of environmental and social standards beyond CO_2 reduction. Legislation such as the CSDD, the CSRD as well as the already enacted *German Supply Chain Due Diligence Act* are also expected by the experts interviewed to contribute to improved cooperation between suppliers and buyers in the iron ore/steel sector.

One expert interviewed for this project also highlighted that the pressure from investors regarding sustainability requirements for the steel industry will be much stronger in the future than requirements from buyers, for example from the automotive industry. In the European market, new regulations such as the *Sustainable Finance Disclosure Regulation* of 2021 aim to make financial market participants such as asset managers, insurance companies, pension funds, etc. take their consideration of negative environmental or social impacts into account in their investment decisions by requiring them to regularly disclose their "principal adverse impacts" in statements. The *EU Taxonomy Regulation* of 2020 also aims to steer financial flows towards more sustainable products by providing clarity on which economic activities can be considered "environmentally sustainable" (Holly et al. 2023).

Trade agreements and policies

Overall, the global crises of recent years and COVID-19 and war-related disruptions to supply chains have brought the issue of supply security in the mineral sector to the fore. Many countries are therefore trying to secure access to key raw materials such as iron ore through trade regulations like free trade agreements and export restrictions. Free trade agreements, which also include iron ore, are also being negotiated and/or are in progress between Europe and major iron ore producing countries.

The possible association agreement between the EU and MERCOSUR (Argentina, Brazil, Paraguay and Uruguay), for which negotiations have been ongoing for 20 years, is subject of particularly intense discussion. The proposed trade agreement, which would create the world's largest free trade zone, would eliminate tariffs on 91% of all goods traded between the two regions (BMWK n.d.b). After an initial agreement had been reached in 2019, negotiations stalled again over environmental issues. In 2021, the EU submitted an addendum to the agreement that sets out sustainability and climate change commitments and introduces penalties for countries that do not meet the targets of the 2015 Paris Agreement on climate change. These additional requirements led to criticism on the MERCOSUR side and a renewed freeze of the negotiations (tagesschau 2023). Environmentalists had repeatedly criticised that, without a comprehensive sustainability chapter, the agreement would contribute to a progressive destruction of the environment in the MERCOSUR countries, including through a further expansion of mining without strengthened environmental requirements (Mirkes n.d.).

Negotiations on a possible free trade agreement between the EU and Australia have also been ongoing since 2018 (BMWK n.d.a). Industry voices see the agreement as a possible step towards securing Europe's supply of key metallic raw materials (DIHK 2023). According to the EU, the negotiations aim to introduce "ambitious provisions on trade and sustainable development, showing a shared commitment to labour rights and environmental protection (including climate change) in trade" (European Commission 2023a). Details on the content of a possible trade chapter are not known.

Germany's most important iron ore suppliers have also entered into trade agreements with the EU: the Comprehensive Economic and Trade Agreement (European Commission 2017) with Canada and the Economic Partnership Agreement between the EU and the Southern African Development Community (Botswana, Lesotho, Mozambique, Namibia, South Africa and Eswatini) (European Commission n.d.a).

Against the backdrop of the COVID-19 pandemic, re-shoring strategies were also discussed, in the context of which the production of key products such as iron ore mining and steel products should be brought back to the EU (EU 2021). The trend is reflected, among other things, in the fact that there are now more exploration projects for new mines in the EU than ever before (Harder 2018).

Steel and steel products are also repeatedly the subject of trade policy disputes. In 2017 and 2018, for example, the Trump administration in the U.S. imposed tariffs on imports of steel and other products from China, Canada and the EU in order to protect domestic production and national interests. However, concerns about the implementation of environmental standards did not play a role (EU 2021).

Traceability along the iron ore-steel supply chain

Compared to many other mineral commodities, traceability in the iron ore-steel supply chain is relatively straightforward, especially at the lower levels of the supply chain. Steel companies can usually use laboratory tests to trace the geological regions from which iron ore products originate. Industry representatives confirmed in interviews that geological tracing is already common practice in the quality control of delivered goods (for each sea shipment), when controls reveal a deviation from the required quality requirements in terms of Fe content and impurities. Batch production, where different products from different sources are mixed, affects traceability. The iron ore sector is using various technologies, such as “data storage and retrieval systems, barcode systems, or non-contact tagging systems such as radio frequency identification” to improve traceability and transparency towards customers (Bergquist 2012). The mining sector as a whole is also working on the implementation of blockchain technologies, for example, to increase traceability and transparency in the supply chain and facilitate the implementation of ESG requirements (Ellis 2021). For example, in March 2020, the mining group Vale announced that it had completed its first sale of iron ore using blockchain to the Chinese Nanjing Iron & Steel Group International Trade Co, Ltd. (Vale 2020). Despite the traceability initiatives that have been launched, interviews with experts suggest that there is still some reluctance to disclose the exact composition and origin of iron ore products to customers, because iron ore miners guarantee a certain quality of the product when selling it, but not a specific origin, in order to have cost-sensitive freedom in the composition and the planning of logistics – many iron ore products are blends and do not come from a single mine. There is therefore a good basis for traceability in the implementation of environmental standards, even if these controls are not yet common in the market.

Subsequent steps of mixing and merging with other materials in steel production make geological traceability more difficult, so technological solutions play an even more important role. At the interface between steel companies and the automotive industry, platforms such as the European Automotive Network “Catena-X” are working to improve transparency and the exchange of data on material flows along the supply chain. Catena-X points to current problems: at present, many suppliers are reluctant to share their data because they fear data loss and lock-in effects (Catena-X 2023). This also hinders the sharing of environmental data. For example, as confirmed in interviews with industry representatives, automotive companies at the end of the supply chain face the challenge that their global suppliers do not use a consistent methodology in calculating the carbon footprint of their products. This limits the ability to share consistent targets for reducing emissions in the production process across the supply chain and makes it difficult to measure progress (Steinlein et al. 2022). Initiatives such as Responsible Steel are therefore working to develop uniform solutions and standards at industry level (ResponsibleSteel n.d.). However, some experts emphasised in interviews that, due to conflicts of interest, cooperation in these industry initiatives is slow.

Transparency in price building

The fact that much of the iron ore is traded on the basis of price indices based on spot market prices (index-linked contracts) is unique in the mining industry (Jégourel 2020). While being a good mechanism to deal with the price risks that come with volatility, the system of trading on spot markets is still fairly new and is characterised by a number of problems that result from the brokers' need/will to maximise liquidity instead of focusing on the highest quality of data that can be used for price assessment in indices. These include a lack of transparency, timeliness of information, anonymity of transactions as well as the fact that sometimes orders are placed on the spot market even though the small number of potential buyers of a company's raw material should render this mechanism inefficient. These problems lead to diminished trust in indices, and continued disagreement over pricing (Hall 2020). There is a risk that increasing competitive price discovery mechanisms and decreasing trust between sellers and buyers will also complicate negotiations on price premiums for the implementation of sustainability standards.

Outlook

The world's available resources of crude iron ore are estimated at over 800 billion tonnes with an iron content of about 230 billion tonnes (U.S. Geological Survey 2023a). The World Steel Association 2022, among others, forecasts that these resources will continue to be exploited and that global demand for steel will increase by 20% by 2050. While steel demand from the European automotive sector is forecast to decline over the next few years (Grigorenko 2023), global developments such as urbanisation and industrialisation in fast-growing economies like China and India are driving overall demand. In order to meet the rising demand for steel products, it is expected that new iron mines will be developed and steel mills (also based on the BF-BOF route) will be built. In parallel, however, new technological routes for the recycling and recovery of steel scrap and new low-emission processing technologies, e.g. based on hydrogen, must be further developed and brought to market maturity. Otherwise, the ambitious climate protection targets set for the industry in many countries of the world cannot be achieved (Kerkow et al. 2012).

As the previous sections show, the industry has been slow to address the issue of sustainability, with a strong focus currently on GHG emissions reduction. However, new technological opportunities also aim to improve the monitoring of the implementation of environmental and social standards along the entire supply chain through improved data exchange. At the same time, global crises and supply disruptions, for example in the EU, have led to an increased focus by governments on security of supply, which could lead to a weakening of environmental standards in favour of an economic compromise, for example in negotiations on free trade agreements.

3 Sustainable supply chain management approaches and instruments

This chapter is an excerpt of the report "Cost allocation and incentive mechanisms for environmental, climate protection and resource conservation along global supply chains - Business approaches and instruments of sustainable supply chain management" (Grüning et al. 2024). The chapter shows which approaches and instruments for SSCM are used in the iron ore/steel supply chain and to what extent. The information is based on desktop research, interviews with industry experts and consultation with an Expert Advisory Board comprising individuals from business, civil society and academia. The chapter concludes with a matrix in which the observed and described SSCM approaches and instruments are categorised.

3.1 Main environmental impacts in the iron ore/steel supply chain

Various environmental impacts are generated along the supply chain from the mining of iron ore to the manufacturing of steel products for the automotive industry, which can have negative effects depending on the regional context and applied technology. Table 4 provides an overview of such possible impacts and negative effects at selected supply chain stages.

At the level of mining and beneficiation there are high risks for a wide range of negative environmental impacts. Iron ore mining, like other mining activities, consumes large quantities of water, e.g. for extraction, washing, dust control and slurry transport. The wet processes used to beneficiate the ore, such as flotation, can also consume significant amounts of water. Depending on the location of the mines and water management systems, this can pose a threat to groundwater levels, local water supplies and biodiversity (Drive Sustainability n.d.; Kerkow et al. 2012; Weiss et al. 2022). Ecosystems and biodiversity are also strongly impacted by the use of land and fragmentation of habitats for mines (mostly open-pit), mining infrastructure and the transportation of the ore to ports (Groneweg 2020). According to Drive Sustainability (n.d.), 49% of all global iron ore mines (especially in Brazil, India and Russia) are located in forests, making iron one of the top three (by volume) minerals that are mined in forests. Large areas of native forest are repeatedly cleared for the development of new mines; for example, 9 % of the deforestation in the Brazilian Amazon between 2005 and 2015 has been attributed to mining activities (Sonter et al. 2017). Air pollution caused by dust emissions that result from blasting, drilling, or excavating as well as transportation is a major environmental problem and has strong negative impacts on the local ecosystems as well as livelihoods (e.g. agriculture) and health of the local population (Drive Sustainability n.d.; Groneweg 2020). Additionally, the beneficiation of the ore causes massive amounts of waste in the form of solid or wastewater tailings and can lead to the contamination of water (and soil) through the release of waste water (containing heavy metals and industrial refuse like chemical reactants that are used for beneficiation) that may result from the possible leakage from tailing ponds or breach of tailing dams (Drive Sustainability n.d.; Groneweg 2020; Weiss et al. 2022).

Next to water consumption and air pollution, which are relevant in the production of iron, steel and finished steel products (Drive Sustainability n.d.), one of the most important environmental hotspots in the steel industry is energy use. Due to the use of non-renewable energy sources (e.g. coking coal that is used as a reducing agent) in the energy-intensive production processes of steel, the sector accounts for very high GHG emissions (Drive Sustainability n.d.; IEA 2020; Bookhagen et al. 2022; Harpprecht et al. 2022). This energy use does not only make the steel industry the emitter of between 7-10% of total global CO2 emissions, it also accounts for 95% for GHG emissions in the whole iron ore-steel supply chain (Deloitte n.d.; Drive Sustainability n.d.; Voigt et al. 2023). The decarbonisation of steel is therefore one of the single largest levers for the reduction of GHG emissions in the supply chain. In addition, iron and steelmaking are highly material-intensive processes; according to the European Environment Agency (2019) "[m]ore than half of the mass input becomes outputs in the form of off-gases and solid wastes or by-products". Steel production also uses large quantities of water for cooling, descaling of intermediate products, dust emission abatement etc., which needs to be collected and reused in order to avoid negative environmental impacts on the local/regional water availability (WSA 2020).

Table 4: Main environmental impacts along the iron ore-steel supply chain

	Raw material extraction and processing		Iron and crude steel production		Steel sheet manufacturing	
	Mining	**Beneficiation**	**(pig/sponge) iron production**	**Crude steel production**	**Refined steel and alloy production**	**Casting and rolling**
Water	water used for extraction process, washing, dust suppression, slurry transport	water used for flotation beneficiation and slurry transport; risk of contamination with waste water (containing heavy metals and industrial refuse) through leakage from tailing ponds/breach of tailing dams	High water usage for quenching of coking coal	water used e.g. in cooling operations, descaling, dust scrubbing; discharge of cooling water can raise temperature in receiving water body (impact on aquatic ecosystem)		
Land use / Soil	use of land for (mostly open-pit) mines, infrastructure & transportation of the ore to ports; risk of contamination with waste water (containing heavy metals and industrial refuse) through leakage from tailing ponds/breach of tailing dams					
Energy	Diesel generators often used to generate power at mining sites		highly energy-intensive processes lead to high GHG emissions (depending on energy source and technology)			
Chemicals		usage of chemical reactants				

	Raw material extraction and processing		Iron and crude steel production		Steel sheet manufacturing
Air	dust emissions from blasting, drilling, excavating & transportation of ores; emissions from diesel generators		sinter plant operation produces emissions of nitrogen oxides (NOx), sulphur oxides (SOx) & on Group from combustion activities; dust emissions from coking coal input (for BF route), sinter plants and stockyards	Process emissions include particulates, heavy metals, NOx, CO and SOx	
Waste		Significant amounts of solid waste and/or wastewater tailings, risk of tailing dam failure	Large amounts of solid waste (sludge), wastewater & off-gases		

Source: adelphi, based on information from based on information from Drive Sustainability n.d.; Kerkow et al. 2012; European Environment Agency 2019; WSA 2020; Groneweg 2020; Weiss et al. 2022; ENCORE n.d., and expert interviews.

In recent years, unsustainable practices in the mining industry have been subject to increasing attention (Böhling et al. 2019). This also holds true for the mining of iron ore. Schmidt et al. (2019) highlight that “there is still a huge gap between aspirations for sustainable transformation of the sector and existing mining practices, especially in countries with transitional economies”. Accordingly, many of the above-mentioned negative environmental impacts associated with the mining and processing of iron ore remain unaddressed, depending strongly on the extent of local environmental regulations and legislation governing mining operations (Andersen and Noailly 2022) (lack of government-enforced compulsory approaches/instruments: regulation from developing or industrialising countries; cf. also chapter 3.5.6 of Strasser et al. 2024). In the steel sector, the implementation of environmental sustainability measures has a longer history. But while there is a growing focus on reducing greenhouse gas emissions, primarily in steel plants themselves, but increasingly also in the supply chain, other environmental issues have received less attention as of yet (Conejo et al. 2020; WSA 2020; Fastmarkets 2022).

3.2 Sustainable supply chain management approaches and instruments used in the iron ore/steel supply chain

As part of the efforts to green the industry a growing number of the instruments and tools for sustainable supply chain management are being introduced along the iron ore-steel supply chain. Many of those instruments aiming to incentivising stakeholders to implement environmental protection however have only been developed in recent years and are only applied by selected frontrunners, so that the overall impacts in the actual environmental impacts remain ambiguous. With regard to the instruments and approaches described in chapter 2 of Grüning et al. (2024) mainly buyer-individual and buyer-collective approaches as well as supply chain collective approaches that are applied on a voluntary basis have been observed. As suppliers in the iron ore-steel supply chain are generally more powerful than in other supply chains such as the agricultural and crop-based supply chains that are also analysed in this study, buyers have less leverage in directing suppliers. Nevertheless, due to greater customer exposure and stronger regulations, it is still mainly buyers from the automotive industry at the downstream end of the supply chain, that drive the process towards environmental protection and the sustainable production of steel. An increasing number of regulations in industrialised countries to achieve decarbonisation have led these stakeholders and their initiatives to focus primarily on reducing GHG emissions along the entire iron ore-steel supply chain (Government-enforced compulsory approaches/instruments: Regulation from industrialised country governments; cf. also chapter 3.5.6 of Strasser et al. 2024).

Buyer-individual approaches

Most common in the steel and automotive industry are buyer-individual voluntary approaches and instruments. Large companies across the industry often apply self-set commitments, sustainability targets, indices or sustainability reports. For example, ArcelorMittal, one of the largest steel producers, has developed a roadmap to carbon neutrality (ArcelorMittal 2021; Deutsche Bank 2021) and Nippon steel, another of the world’s leading steel producers, included a commitment to carbon neutrality by 2050 in the company’s sustainability report (Nippon Steel 2023). The “Green Steel Tracker” by LeadIT (2023) provides an overview of which steel companies have already committed publicly to a carbon neutral target year. Some buying companies translate these self-set environmental targets also into requirements for their suppliers, e.g. by developing develop supplier code of conducts (CoCs) that include environmental clauses (Rechlin et al. 2022). In the automotive industry, Toyota is aiming for zero carbon emissions from its products and plants by 2050 and BMW lists its suppliers' carbon footprint as one criterion for the awarding of contracts (Paragamian et al. 2021).

In the steel industry, Thyssenkrupp's Supplier CoC includes the expectation for suppliers to apply an appropriate environmental management system (e.g. in accordance with ISO14001). The company states that it regularly audits its suppliers to determine the fulfillment of the expectations and that it "reserves the right to terminate individual or all contractual relationships" in case the supplier fails to meet the expectations or to strive for improvement (thyssenkrupp n.d.), thus applying a punishment-based approach. As specific mixtures of iron ore grades are necessary as input material for the production of high-quality steel products, regular product quality controls are carried out along the iron ore steel supply chain and interviews with industry experts confirmed that technical exchange between the mining and steel sector happens regularly. However, according to interviews with experts, these regular audits and exchanges do not generally include inspections of compliance with environmental standards.

Buyer-collective approaches

In order to emphasise their commitment to the environment, companies also frequently refer to their membership and engagement in voluntary sustainability initiatives. Nippon Steel, for instance, refers to its involvement in the environment committee of the World Steel Association (WSA) (Nippon Steel 2023). Such organisations exemplify buyer-collective approaches that are particularly present at the level of steel production, often aimed at harmonising voluntary standards across the industry. One example: the sustainability indicators, including those related to environmental performance22, that were developed by the WSA. In 2023, the steel producers whose sustainability performance was assessed either on the basis of voluntary or publicly available data accounted for 53% of global crude steel production (WSA 2023b). The WSA also has a reward-based recognition programme that includes the awarding of "Sustainability Champions". The World Steel Association and its activities are being paid for with annual membership dues that are calculated on the basis of steel production volumes (WSA 2023a). At the automotive industry level, there are also voluntary buyer-collective approaches aimed at improving environmental performance along the supply chain. For example, the Automotive Industry Action Group (AIAG) and the Drive Sustainability initiative have jointly developed "Guiding Principles to enhance Sustainability in the Supply Chain", which were last updated in 2022 and, together with a practical guidance, are intended to support car manufacturers in the uniform implementation of sustainable purchasing practices (AIAG and Drive Sustainability 2022). Another joint approach initiated in 2020 by frontrunner companies in the automotive industry, the Catena-X Automotive Network, aims to increase the exchange of data along the automotive supply chain. The data can not only be used for quality management but also to improve traceability and support decarbonisation efforts, e.g. by making possible the measurement of carbon footprints for products. The network offers certification for its standards, which is carried out by third-party auditors that have undergone training and are paid for by the customers from the automotive industry and its suppliers (Catena-X n.d.a; Catena-X 2023). According to an interview with WorldSteel, the development of joint standards in more collaborative initiatives such as Catena-X is an important prerequisite for improved sharing of environmental data (such as CO2 emission values) along global supply chains. Today, many companies along the various stages of the iron ore/steel supply chain use individual IT systems for their data management that hinder the effective sharing, compilation and processing of information from and with suppliers or buyers. According to Catena-X, the application of uniform rules and standards would result in added value for all stakeholders along the supply chain by reducing cost and data loss. Antitrust concerns are a sensitive topic in the development of uniform standards and the sharing of e.g. CO2 emissions-related data and need to be addressed while providing as much data transparency as possible (Catena-X n.d.b).

Supplier-individual approaches

As the iron ore - steel supply chain is characterised by large, financially strong companies even at supplier level, mining companies increasingly implement supplier-individual voluntary approaches and instruments that appear to be guided less by direct pressure of their buyers, but can rather be traced back to increasing attention with regard to the lack of sustainability of their practices and business models, and global regulation of the sector (cf. chapter 3.5.6 of Strasser et al. 2024). For example, major mining companies such as BHP, Rio Tinto and Vale publish self-set commitments, sustainability targets, indices and sustainability reports (BHP n.d.; Rio Tinto n.d.; Vale n.d.). Beyond such pledges, the activities of mining companies are still rather limited.

Supplier-collective approachesWhile supplier-collective voluntary initiatives are often not raw-material specific, some do play a role for the mining of iron ore. Among these is the “Towards Sustainable Mining” (TSM) standard, that has been established by the Mining Association of Canada in 2004 (The Mining Association of Canada n.d.) that addresses issues from water and tailings management to biodiversity conservation and climate change. TSM participants are obligated to publish performance protocols that inform about their management of certain indicators, including “environmental stewardship” at facility level. The initiative offers trainings for participants as well as for verifiers. Its standard is based on yearly self-assessments and reporting with the results being verified through external verification by a “trained and accredited verifier” where the client carries the cost of verification audits (The Mining Association of Canada 2021). Innovative projects and initiatives can be awarded with the TSM “Environmental Excellence Award” (The Mining Association of Canada n.d.), providing for a reward-based approach to the implementation of environmental best practices. The International Council for Mining and Minerals’ (ICMM) Mining Principles, including the “Global Industry Standards on Tailings Management” (Global Tailings Review 2020; Global Tailings Review n.d.), are another example of supplier-collective efforts to address sustainability in the iron ore industry and are being referred to throughout the industry (ICMM n.d.). The ICMM is an industry initiative whose company members’ performance is subject to self-assessments, third-party validation that the member has to pay for, and disclosure (ICMM 2023).

Supply chain collective approaches

With regard to the buyer- and supplier-initiated approaches and instruments listed until now, it can be said that power relations between different actors in the supply chain, the voluntary character of existing initiatives as well as the variety of standards that do not follow a consistent methodology mitigate the impact of these initial advances, an issue that is acknowledged by industry experts as well as industry bodies such as the International Council on Mining and Minerals (ICMM) (Palekhov and Palekhova 2019; ICMM n.d.). It has been argued that sustainability initiatives along the iron ore-steel supply chain often lack more collective approaches. According to Palekhov and Palekhova (2019), “original equipment manufacturers in the automotive industry are failing to account for environmental risks and difficulties, especially in early stages of the value chain, because contact with and control of companies beyond first-tier suppliers is limited or considered irrelevant for business success". However, in recent years, the growing salience of environmental issues and an increase in regulations, particularly with regard to GHG emissions has led to an increase in supply chain-collective approaches and instruments, a development that may point to changing practices in the future.

ResponsibleSteel is an independent standard and certification initiative and belongs to the more collective approaches, as business organisations from the whole supply chain, organisations from civil society, government and standard setting are among its members (ResponsibleSteel n.d.). The initiative first published their ResponsibleSteel Standard in 2019 for the voluntary certification of steel producers, which covers environmental (i.e. GHG emissions, biodiversity, waste management, water use), social and governance issues on the basis of 12 principles. Until recently, the standard only applied to operational steel mills and production facilities that process raw materials for steelmaking (ResponsibleSteel n.d.). The revised ResponsibleSteel International Standard V2.0, which was launched in September 2022 as a preliminary version, now also includes criteria on GHG emissions and the responsible sourcing of input materials through the recognition of existing certification schemes for mining companies. The new version stipulates that in order to obtain a "Certified Steel" certification, steel companies must have at least "good visibility of their supply chain links" (ResponsibleSteel 2022), and be able to verify whether their suppliers are certified under one of the three recognised standards Bettercoal, TSM and the Initiative for Responsible Mining Assurance (IRMA). According to RSI, the inclusion of responsible sourcing criteria is intended to create a market demand for responsibly sourced input materials. However, these additional requirements are not (yet) mandatory in order to achieve a "Certified Steel" certificate, but can be obtained voluntarily by ResponsibleSteel members. According to RSI, a mandatory introduction of these requirements is currently not possible, as "participation by suppliers in recognised input material programmes is too low to achieve them" (ResponsibleSteel 2022). ResponsibleSteel explains that first, market demand for responsibly sourced material has to grow and that instead of an obligation, the organisation foresees that "expectations from downstream customers, investors, regulators, civil society and other stakeholders will provide incentives" to purchase certified/verifiably sustainably produced input material in the future, thus taking a rather reward-based approach (ResponsibleSteel 2021). The revised and expanded standard is currently being put through a one-year test phase with public consultations before the official and complete revision of the standard begins in 2024 (ResponsibleSteel 2022). The audits that are necessary for certification with the standard “are carried out by independent third-party certification bodies approved by ResponsibleSteel and contracted by the site applying for certification” and are paid for by the steelmakers to the certifier (ResponsibleSteel 2022).

Within the context of ResponsibleSteel’s ambitions to recognise mining-level standards, it should also be highlighted that such third-party offered voluntary profit-focused approaches and instruments are still in their infancy in the iron ore sector. One example for such an approach is IRMA, a voluntary certification initiative established in 2006, whose members come from the mining sector, downstream industries, civil society and trade unions. IRMA has developed one of the most comprehensive and widely recognised standards for responsible (large-scale) mining, covering environmental issues (e.g. waste management, water, air quality, greenhouse gas emissions, biodiversity) as well as various social and corporate responsibility requirements (IRMA 2018; Groneweg 2020). As of July 2023, IRMA audits were ongoing for three iron ore mines in Brazil and two iron ore mines in South Africa, none of which had been finalised at the time of publication of this report (IRMA n.d.). As of November 2023, interviews with industry experts suggest that several iron ore mines have undergone the necessary assessments and will be officially listed as IRMA certified from 2024 onwards. Companies undergoing the assurance process at site level have to pay for the independent service provider implementing the necessary audits (IRMA 2021). IRMA charges a certification fee (a combination of administration and licensing fee) which is charged to all mines that undergo an independent third-party assessment and wish to declare IRMA-related information on their performance (IRMA 2021). Another way to demonstrate compliance with certain social and environmental standards in steel production facilities and iron ore mines is to certify facilities in accordance with the requirements of environmental management standards such as ISO 14001 or ISO 2600, which are already being applied by various companies along the supply chain (Rechlin et al. 2022).

The ResponsibleSteel standard and similar approaches also aim to improve traceability and information sharing along the entire supply chain. The guidance for responsible sourcing of the ResponsibleSteel standard mentions chains of custody as part of their certification process. In this context it means that "input material from different suppliers can be blended and mixed throughout the supply chain, but that the share of input material from mine sites and processing sites that are part of a recognised programme is recorded at each supply chain stage and that related information is transferred from one stage to the next. Suppliers may sell this share as 'CoC Input Material'." The guidance states that certain levels of certification with TSM, IRMA and Bettercoal include a chain of custody element (ResponsibleSteel 2023). Blockchain technology is discussed as another solution to the problem of traceability, but the discussion of its advantages often does not include mentions of benefits for sustainability improvement. Nevertheless, some companies in the iron ore-steel supply chain are experimenting with it. For example, BHP mentions its benefits for tracking emissions and environmental sustainability but does not yet use it for iron and steel. Vale has completed first iron ore sale using blockchain technology (sold to Chinese steelmaker Najing iron & steel) but sees it as a technological innovation that is applied for reasons of efficiency and security (Vale 2020). The increasing interest in the technology is also reflected in a research project on traceability in the steel industry that is financed by the Canadian state (ISED n.d.).

Current developments

For the future sustainable transformation of the iron ore-steel supply chain, third-party initiated voluntary profit-focused approaches and instrument such as the provision of green finance could also be important: Sustainability and environmental protection in the mining and steel industry require large scale investments. A study by the Mission Possible Partnership therefore states that while "one might think that giant, multinational firms can readily implement innovations for decarbonisation […], the capital intensive and oligopolistic nature of the iron and steel sector hinders the low-carbon transformation of the industry, although it is true that the companies can invest in big research and development projects" (Mission Possible Partnership 2021). Therefore, initiatives and actions that assure mining and metal companies that more sustainable products such as green steel will find a market and that the additional costs will be covered by buyers (price premiums) are therefore essential (Mission Possible Partnership 2021; Kim et al. 2022). Government regulations often provide initial incentives as well as security for investments but changes in sourcing strategies need to be negotiated directly between buyers and suppliers. Such agreements have started to become more and more common over the course of the last few years.

The HYBRIT tractive Hydrogen Breakthrough Ironmaking Technology) initiative, a cooperation by the companies SSAB (steel producer) LKAB (mining company) and Vattenfall (electricity provider) so far is the only example of a supply chain-collective approach that aims at minimising CO2 emissions in the whole supply chain from iron ore pellets to steel, also making use of third-party provided financial support. Through the use of green energy and hydrogen it aims to create the first fossil-free steel by 2026. The initiative is incorporated into a research project and financially supported by Swedish State and EU (Hybrit n.d.). In terms of costs, this project is only possible through public financing and even so, there is uncertainty as to how the steel will fare on the market.

For the commercialisation of green steel, there are different possibilities, depending on whether or not it is perceived as a differentiated product. Price premiums or closer relationships with downstream supply chain partners in the form of offtake agreements might be an instrument to make sustainable steel competitive (Olsson and Nykvist 2020). There are several examples of this change of procurement models establishing the longer-term certainty that is necessary to enable investments in sustainability and environmental protection measures, with some sources stating that "green-material sourcing has already begun to disrupt traditional buyer–supplier relationships" (Fredershausen et al. n.d.) in the iron ore-steel supply chain. There are examples of bilateral supply chain-collective approaches developed jointly by steelmakers and mining companies that apply such offtake agreements, but also memorandums of understanding (MoUs) and joint ventures (this also signifies strategic changes in buyer-individual voluntary approaches/instruments: supplier contracts). Some steel producers have adopted MoUs with mining companies, mainly to secure their future access to high-grade iron ore necessary for the production of green steel. Nippon Steel and Anglo American have agreed "to jointly deliberate and discuss solutions for accelerating the transition towards carbon neutral steelmaking" (Nippon Steel 2023). Rio Tinto and Baowu state that they want to collaborate for the research and development of technology, e.g. for the production of low-carbon iron. In collaboration with Salzgitter AG, Rio Tinto has decided to invest 10 million over the next ten years to "improve environmental performance along the value chain" and "explore the potential for greenhouse gas emission certification across the steel value chain" (Rio Tinto n.d.). Such collaborative settings are also applied by new players in the steel industry who focus only on the production of low carbon/green steel. For example, H2 green steel (H2GS) which builds a "green-steel plant and a green-hydrogen plant that will produce the fuel needed for steelmaking" (Fredershausen et al. n.d.), has signed MoUs with AngloAmerican and Rio Tinto (Stegra 2023).

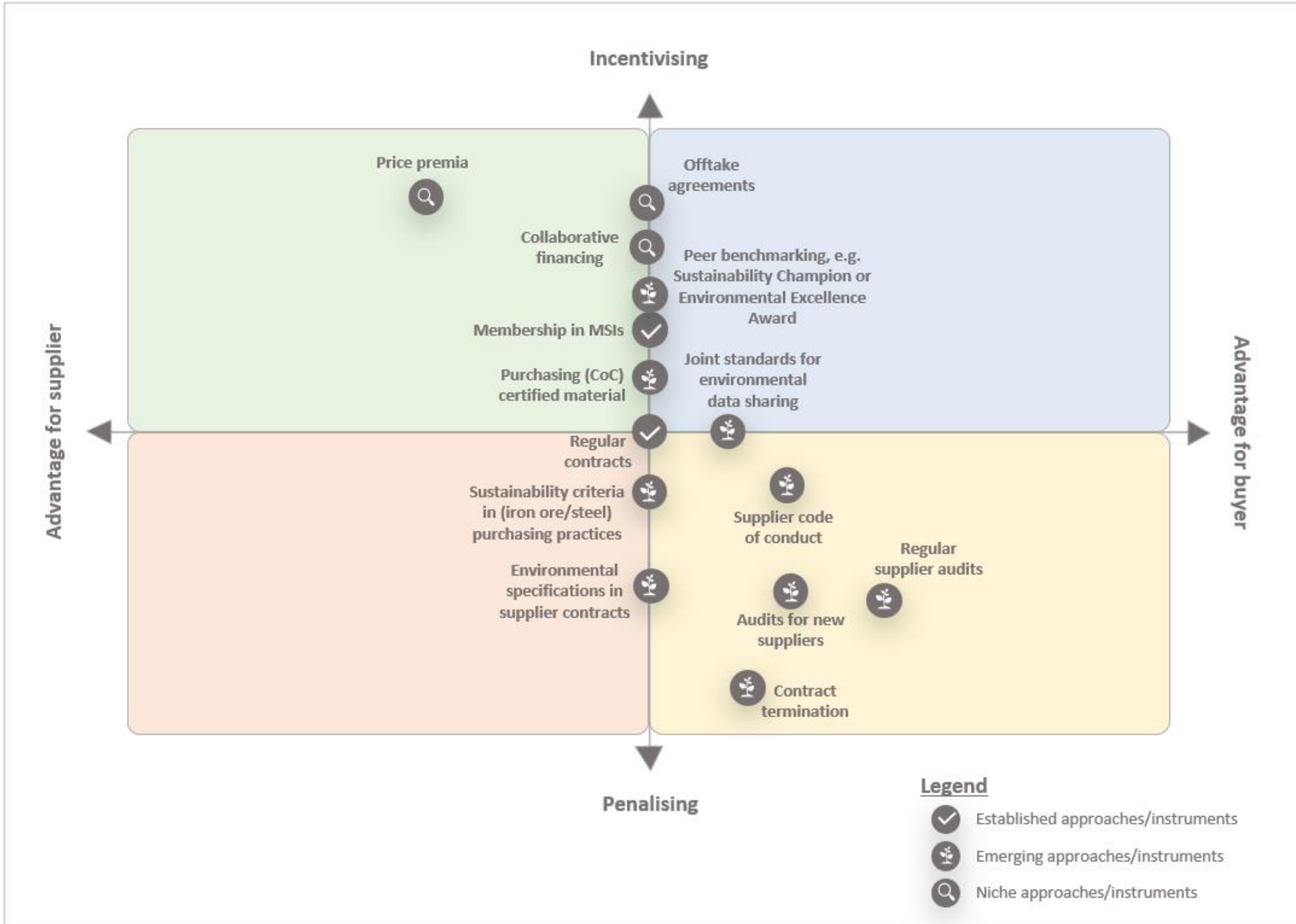
Similar developments can be observed in partnerships between the automotive industry and the steel industry, where "some companies are financing innovation and production-capacity increases for the low-emissions materials they require" (Fredershausen et al. 2022). In light of tightening regulations, car manufacturers are eager to secure their supply of low carbon steel. Volvo is partnering with SSAB, while BMW and BHP have invested in Boston Metal, and Scania, Daimler and Kingspan's are cooperating with H2GS (Mission Possible Partnership 2021) and Volkswagen has and signed an MoU with Salzgitter "to source near-zero-emission steel starting in late 2025" (World Economic Forum 2023). A study by the World Economic Forum states that such "bilateral offtake agreements with steel producers are impacting the market, offering convenient access to buyers who secure their supply in advance" (ibid.). A recent study argues that indirect signals of future demands, such as the definition of the terms of investments many years into the future are essential to release investments into decarbonise supply chains (Mission Possible Partnership 2021). These examples show that the decarbonisation commitments and pledges that have been made by stakeholders along the supply chain, do translate into real actions and can be the basis on which partnerships are agreed.

Offtake agreements are closely linked to the debate regarding price premiums paid for input materials necessary for the production of green steel (Morgan Stanley 2023). A study states "that the automotive industry is a likely candidate for green steel demand, where a market could be supported by price premiums paid by willing consumers, such as those of high-end luxury and heavy-duty vehicles" (Muslemani et al. 2021). According to other reports, the first steelmakers have already started to demand such price premiums for green steel in negotiations for long-term contracts with car makers, among others (Richardson 2021; Bolotova et al. 2023). According to Voigt et al. (2023) as of 2023, "green steel in Europe already includes significant premiums of 25-40%" per ton of hot rolled coil (HRC). As the production of green steel requires, among other things, high-quality iron ore, in the future there could also be price premiums for "green iron ore" that meets the higher quality requirements for the production of "green steel" (Faye 2022). However, higher prices are already being charged for high-grade iron ore products, which enable low-emission steel production, but these are the result of a combination of their higher quality, costs for processing and demand, not necessarily the implementation of stricter environmental standards/the mitigation of environmental impacts during the mining process (Hannah and Fan 2021). While the ability of customers to absorb the resulting premiums is “untested beyond prototype projects” (World Economic Forum 2023) such as the ones mentioned above, increases in the cost of steel translates into much lower green premiums for end consumers (estimates are around 0,5% per passenger car (Zinchenko 2023; World Economic Forum 2023)) and could therefore possibly be passed on to the consumer “without disrupting the economic model of companies” (Mission Possible Partnership 2021).

Matrix of SSCM approaches and instruments

Placing the described business approaches and instruments observed in the iron ore-steel sheet industry in a matrix, according to the definition of (perceived) distributional fairness (advantage for supplier/advantage for buyer) and approach to influence the desirability of the requested changes for the business partner (incentivising/penalising) presented in this Chapter, the following pattern emerges:

Figure 6: Matrix of instruments and approaches in the iron ore-steel sheet supply chain



Source: own illustration (adelphi)

As shown in Figure 6, the approaches that rely primarily on penalties tend to result in a perceived advantage for the buyer, while more collaborative approaches that operate via incentives, joint commitments of different stakeholders and rewards lead to an equitable situation in which both buyers and suppliers gain a perceived benefit. We use the term “perceived” because calculating the total costs would be very complex, especially as the data is often not available. However, when looking at the figure, it also becomes clear once again that not all of the approaches and instruments placed in the matrix are used across the whole sector, but, as described in the text, many of them are only emerging and some are even just niche approaches and instruments that are only used by a few stakeholders. In particular, approaches in which, for example, steel companies and automotive manufacturers jointly invest in the development of more environmentally friendly technologies continue to be the exception across the industry (in fact, these are mostly small pilot projects) and there has so far been very little cooperation between iron ore mining companies and steel producers to improve environmental and climate protection in the supply chain, as can be seen from the previous text. The matrix should therefore serve primarily as an indication of which measures are particularly promising and should be investigated further with regard to their potential scaling.

4 Roadmap for the iron ore/steel supply chain

This chapter is an excerpt of the report “Cost allocation and incentive mechanisms for environmental, climate protection and resource conservation along global supply chains - Roadmaps for the implementation of sustainable supply chain management approaches and instruments” (Grüning et al. 2025). It presents an exemplary roadmap for the implementation of key instruments to improve the cost-benefit sharing and sharing of environmental information in the iron ore-steel supply chain. The roadmap can assist companies in the sector and other stakeholders in advancing the environmental performance of suppliers and sub-suppliers primarily through incentives and cooperation. The roadmap includes a description of the environmental upgrading target, tailored sustainable supply chain management instruments, key actors for implementation, interactions between the instruments, and necessary framework conditions.

4.1 Environmental target and background

The iron and steel industry currently account for 7 to 10 % of total global CO_2 emissions (Deloitte n.d.; Drive Sustainability n.d.; IEA 2020; OECD 2023; Voigt et al. 2023), making it one of the most emission-intensive subsectors. As a result, GHG emissions are a key topic in the iron ore–steel supply chain (OECD 2023; Schreck et al. 2023). Although the CO_2 emission intensity of steel has remained relatively stable in recent years, the total global emissions from the sector have increased over the past decade, primarily due to rising steel demand (Kueppers 2023). Overall, the use of non-renewable energy sources for the energy-intensive steel production processes in particular leads to very high GHG emissions (Drive Sustainability n.d.; IEA 2020; Bookhagen et al. 2022; Harpprecht et al. 2022). In traditional blast furnace production, the majority of emissions come from the use of coke as a reducing agent to reduce the iron from iron ore (Kueppers 2023). Earlier stages of the supply chain are also associated with significant amounts of GHG emissions. For example, the mining industry accounts for a total of 2 to 3 % of global CO_2 emissions (Bellois 2022). The main source of GHG emissions in mining is the use of non-renewable energy sources such as diesel to power heavy trucks and machinery (e.g. trolleys) and poor energy management during extraction, grinding and transportation (Dietz et al. 2021), which leads to low energy efficiency (Drive Sustainability n.d.; IRMA 2023). Other relevant emission sources in the iron ore-steel supply chain are the use of electricity and natural gas for the extraction of coke and the combustion of heavy fuel oil during the transport (usually freight/overseas transport) of raw materials (Na et al. 2024). Key downstream sectors are also associated with significant GHG emissions – for example, CO_2 emissions from the production of cars in the EU in 2022 totalled 7.38 million tonnes, mainly due to the use of non-renewable energy sources or low energy efficiency of production processes (ACEA 2023).

Reducing GHG emissions along the entire supply chain from iron ore to steel requires far-reaching technological change, particularly at the steel production stage. Central approaches focus on improving energy efficiency and process optimisation, fuel switching and the conversion to new production routes such as a combination of (renewable) hydrogen-based direct reduction and electric steelmaking (DR-EAF production route). Converting steel production plants to the DR-EAF route and securing access to renewable hydrogen require very high investments, especially in the early stages of transition (JRC 2022). Improving material efficiency and the circular economy are also effective means to reduce GHG emissions (OECD 2023). Due to the importance of the environmental issues for the industry and on the basis of discussions with practitioners and industry experts in workshops and interviews, we selected an environmental upgrading target that was considered as relevant and ambitious to develop a roadmap for the iron ore-steel supply chain. The following target was defined on this basis:

Environmental upgrading target – iron-ore steel

Within 15 years, GHG emissions at all stages of the iron ore-steel supply chain are reduced significantly.

A roadmap with approaches and instruments to achieve this target was developed together with a **focal company**. An assessment interview and a roadmap development workshop were conducted with the focal company. Representatives of the company also took part in two previous expert workshops in which general challenges and a 'smart mix' for the implementation of environmental upgrading targets were discussed. While the roadmap was developed in close collaboration with a specific company, it is intended to provide guidance to any company along the entire iron ore steel supply chain. For this purpose, additional insights from research, interviews and workshops were considered for the finalisation of the document.

The focal company that supported the roadmap development process is a multinational mining company that has several iron ore operations. Over 90 % of the organisation's annual iron ore sales come from its own production, while the remaining 5 % is purchased from smaller iron ore producers. The company primarily sells high-quality iron ore products, which are required for the production of high-quality steel and are also an important raw material for (renewable) hydrogen-based direct reduced iron (DRI) production processes. The company sells most of its iron ore products directly to steel mills with which it has long-standing business relationships and multi-year contracts. A small proportion of the iron ore is sold on the spot market for price discovery reasons. The focal company is not involved in any further downstream stages of the value chain.

The focal company, selling directly to EU steel companies, is indirectly impacted by various EU decarbonisation regulations and initiatives. The EU aims for **climate neutrality by** 2050 (EC n.d.), which requires a significant industrial and economic transition, and has issued related decarbonisation strategies for the EU steel sector. The **REPowerEU** project expects around 30% of primary steel production in the EU to be decarbonised by 2030 using renewable hydrogen (JRC 2022). This will also increase demand for steel scrap and high-grade iron ore suitable for the DR-EAF route (Nicolas 2024). This demand is further fuelled by the mandatory participation of steel companies in the **EU Emissions Trading System (ETS)** (EC n.d.), which imposes increasing penalties on carbon emissions emitted by steel producers (Forster 2023). The **EU's Carbon Border Adjustment Mechanism (CBAM)**, in transition since 2023 and fully effective by 2026, is also relevant. CBAM is a tax on imports from outside the EU on the estimated amount of CO_2 emitted in their production that is equal to the price that EU-products already pay for such emissions under the EU ETS scheme. While mining companies are initially only indirectly affected, CBAM covers iron and steel and could thus also boost the demand for high-grade iron ore for low-emission steel production (EC 2024d). In addition, the EU steel mills that the focal company is selling to must comply with the **CSDDD** from July 2026, requiring them to develop a detailed climate mitigation transition plan with intermediary targets for Scope 1, 2, and 3 (Bertazzi 2024). This might lead to an increased effort by EU-based clients of the focal company to reduce their Scope 3 emissions, thus effecting upstream and downstream business partners. In addition, all clients of the focal company listed on an EU-regulated market are covered by the **CSRD** and the related ESRS. GHG reporting under CSRD and ESRS E1 Climate Change involves disclosing direct and indirect emissions across an organisation's value chain (covering Scope 1, 2 and 3) (European Parliament and Council of the European Union 2023). This can lead to an increased demand for the provision of detailed GHG emissions data towards the focal company. The focal company, being listed on the London Stock Exchange, has also been reporting under the **Taskforce on Climate-related Financial Disclosure (TCFD) framework** since 2022, as per UK legislation (Government of the UK 2021).

The focal company has set GHG emissions reduction targets for Scope 1, 2 and 3 and **has implemented some SSCM approaches and instruments** to support the reduction of GHG emissions in its supply and value chains relevant to iron ore-steel. The basis for this is the continuous accounting and public reporting of Scope 1, 2 and 3 emissions according to a science-based and internationally recognised methodology (aligned with the GHG Protocol). The focal company cooperates with strategic customers to obtain more granular emission data from them and to work together in specific research and development (R&D) projects on how to customise their products to enable the lowest-possible emission steel production at the customer (e.g. piloting the DR-EAF production route and supplying particularly high-quality iron ore products). The focal company also discusses with customers how product delivery can be organised as efficiently as possible with shortened transport routes between processing site and steel mill and/or improved accessibility of renewable energy near new sites. The focal company has also introduced a blockchain-based traceability solution that allows customers to view key provenance and sustainability indicators (incl. carbon intensity) of a product for each delivery via a digital label. In addition, the focal company is a member of various voluntary industry initiatives such as the International Council on Mining and Metals (ICMM) and ResponsibleSteel, where it supports collaborative efforts to improving the granularity of Scope 3 emission reporting and standardising GHG emission reporting in the industry. In addition, the focal company has had several of its mining sites externally assessed by the Initiative for Responsible Mining Assurance (IRMA), which specifies measures to reduce the company's impact on climate change through increased energy efficiency, reduced energy consumption and reduced direct/process-related GHG emissions (IRMA 2023). Additional SSCM approaches and instruments are in place, but do not cover GHG emissions specifically.

The focal company faces several **challenges and barriers** in achieving its GHG emission reduction targets. From its perspective as a mining company, the biggest challenges in reducing Scope 1 and 2 emissions relate to the (still) limited availability of hydrogen as an alternative fuel for trucks and the slow development of hydrogen systems, which are also very costly and likely to remain so in the future. Additionally, transitioning to electric vehicle fleets is costly and time-consuming. A lack of sufficient renewable energy sources near production facilities further complicates the reduction of Scope 2 emissions (depending strongly on geographical framework conditions of individual sites).

For Scope 3 emissions, the focal company encounters difficulties in their GHG emission accounting due to a complex network of upstream and downstream partners, along with delayed or incomplete GHG data from these partners. This results in reliance on spend-based calculations for important upstream categories rather than more accurate activity-based methods, complicating planning processes. Although a growing number of companies in the supply chain have set net zero targets, the industry remains in the early stages of addressing environmental issues, including CO_2 emissions (Kueppers 2023). Small-scale iron ore suppliers usually still lack medium or long-term GHG reduction targets, because they are usually only active for a few years due to a limited efficiency and profitability of smaller mining operations. In addition, the implementation of GHG management requirements in many key producer countries is limited and important sustainability standard schemes in the sector, like IRMA or Towards Sustainable Mining (TSM), are not yet sufficiently widely adopted.

With regard to steel companies, which account for most of the focal company's downstream Scope 3 emissions, the fact that many of these customers have set less ambitious climate targets than the focal company poses a challenge, because this affects the focal company's ability to achieve its own Scope 3 targets. In general, research, interviews and workshops with experts have shown that both the mining and steel sectors are still in the relatively early stages of decarbonisation and corresponding supply chain collaboration, despite their crucial role in the broader industrial transformation. Dealing with Scope 3 emissions and considering collaborative approaches to achieve reduction targets is still uncharted territory for many companies. And as described above, for the decarbonisation of the steel sector in particular, very high investments are required in the early stages of the transformation (JRC 2022). According to the focal company and various steel companies interviewed, funding possibilities for this are insufficient.[12] In addition, investments in R&D activities are generally neglected by companies in periods of economic slowdown. In concrete terms, this also means that R&D projects that have already been launched to pilot the production of green steel – in which the focal company is involved in the form of Memorandums of Understanding (MoUs), for example – have been delayed, and the emission reduction potential of the new products and processes cannot be tested. This corresponds to the general observation that announcements of low- and near-zero GHG emission projects in the steel sector are currently often lagging behind actual implementation and the necessary scale (Kueppers 2023).

Furthermore, there is still no standardised definition of 'green' steel, which hinders industry-wide cooperation and financing. Moreover, demand for third-party verified products from customers in the steel and automotive sectors is low, with little willingness to pay premiums for verified low(er)-carbon products. The same applies to steel products manufactured, for example, in a plant certified by the ResponsibleSteel initiative or otherwise labelled as 'green' or 'low-carbon' steel. Here too, various experts in interviews and workshops recognised no willingness on the part of most end consumers or car manufacturers to pay a price premium to compensate for the additional costs of low-carbon production and/or corresponding external verification. One exception is reportedly the production of 'green' steel using renewable hydrogen as a reduction agent: for example, the Swedish start-up company Stegras (formerly: H2 Green Steel) has concluded numerous offtake agreements for its planned future 'green' steel production, which reportedly provide for a price premium of at least 20% compared to traditional steel (Stegra 2022; Bhat and Salazar 2023; Keating 2024). However, as these are commitments for the payment of future prices, as production is planned to start only in 2025 (Chan and Vargas 2024), corresponding premiums seem to have not (yet) reached other stakeholders in the supply chain and so far only appear to be focussed on the new breakthrough technology of renewable hydrogen-based steelmaking.

The financing of decarbonisation in the steel industry and associated supply chains is generally discussed in terms of necessary new and improved industrial policies as incentive mechanisms and the provision of loans by commercial banks and governments as the main source of funding (i.e. carbon contracts for difference) (Kim et al. 2022; Kim and Purvis 2023; Hüttel and Lehner 2024; BMWK 2024a). These were also repeatedly highlighted in the interviews and workshops conducted for the research project as the key levers for driving decarbonisation forward overall. At the same time, however, improved cooperation between business partners along the supply chain can also provide important financial and non-financial incentives for decarbonisation and make the implementation of reduction targets more efficient. The following roadmap focuses on this level of cooperation between business actors.

[12] It should be emphasised that the question of the actual costs of the industry decarbonisation as well as the necessity and amount of external funding is being intensively discussed and examined. At European and German level, for example, new financing options and targeted policy support are being developed and made available on an on-going basis; see amongst others (Hüttel and Lehner 2024; JRC 2022; Kim et al. 2022; BMWK 2024b).

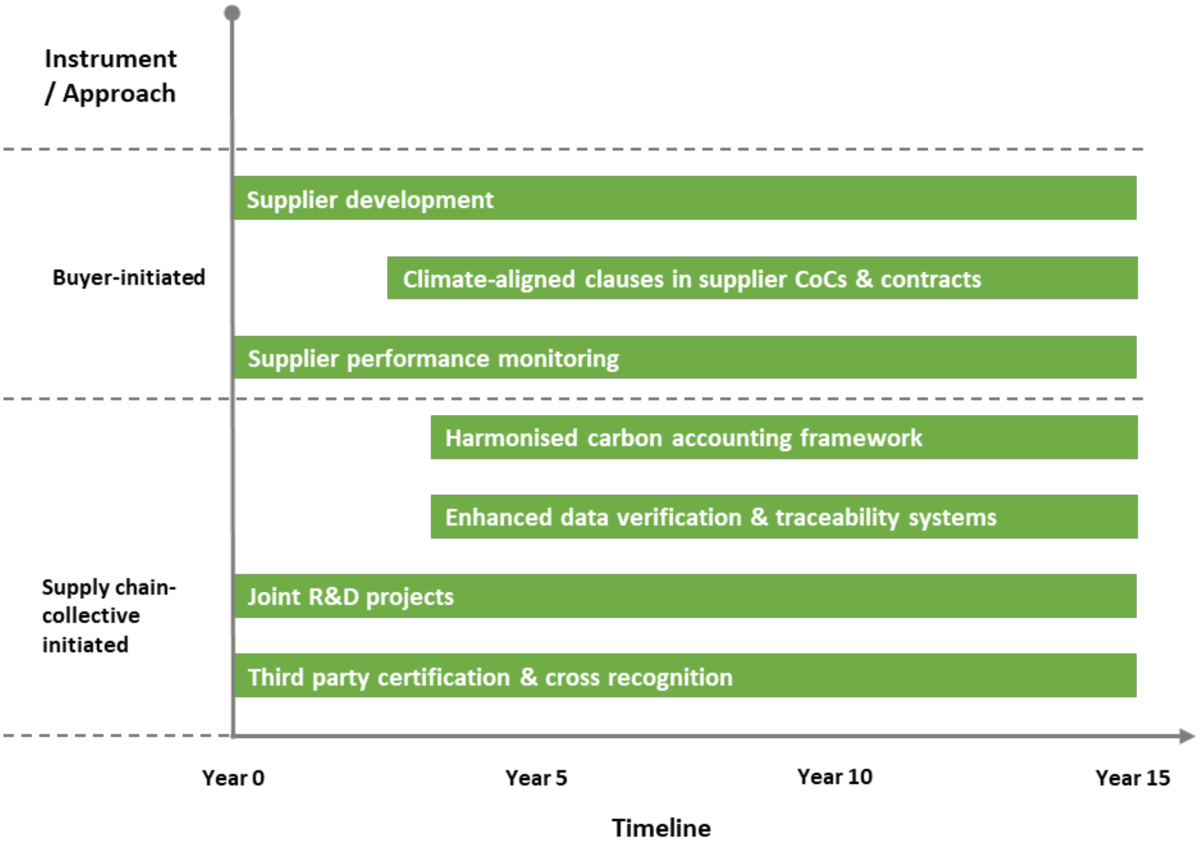
4.2 Description of the roadmap

This roadmap is largely based on the results of a workshop with representatives from various departments of the focal company described above, in which the roadmap was jointly developed, and individual approaches and instruments were discussed in detail. The roadmap does not entail all possible SSCM instruments and approaches that companies could apply in the iron ore-steel supply chain, but only those identified as the most impactful ones when it comes to reducing GHG emissions. The roadmap also comprises the results of research and findings from interviews and workshops with various industry experts from business, civil society, science and standardisation organisations, etc., which were used to supplement the roadmap and make partial adjustments. This is intended to ensure that broader findings from the course of the project that go beyond the experiences of the individual focal company are incorporated into the general guidance meant for companies at different stages of the iron ore-steel supply chain and external actors.

Figure 7 shows that a combination of instruments initiated by individual companies (usually the buyer) and instruments initiated at the collective level of the supply chain is proposed. The approaches and instruments cover a timeframe of 15+ years to achieve the environmental target consistent with the goal of limiting global warming to no more than 1.5°C – as called for in the Paris Agreement – by reducing GHG emissions by 45% by 2030 and reaching net zero by 2050 (UN n.d.). Some approaches, such as instrument 1 'supplier development' and instrument 6 'coordination of interests to enable design for sustainability in joint R&D projects' are implemented from the outset, as it has been established that such approaches are already being implemented by various actors in the supply chain and it can therefore be assumed that they can also be applied by other businesses and other organisations in the sector in the near future. Other approaches and instruments, such as instrument 4 'harmonised carbon accounting framework', can only be implemented once some of the other instruments are applied by more businesses or on a larger scale. For example, the introduction of a harmonised carbon accounting framework depends for example on supplier development activities, as many suppliers do not currently account for and report their GHG emissions at all. The timing of the approaches and instruments in the roadmap is therefore partly based on the necessary changes required to achieve a significant reduction of GHG emissions along the iron ore-steel supply chain. However, it also reflects current limitations, such as many SSCM approaches and tools not yet being utilised on a large scale or in an appropriate manner, as identified in the research conducted as part of the project.

Each approach and instrument and the specific activities recommended for the respective actors, are explained in detail in the sections 4.2.1 to 4.2.7. A more detailed description of the interconnections and dependencies between different approaches and instruments in the roadmap is presented in section 4.3.

Figure 7: Roadmap for improved environmental performance in the iron ore-steel supply chain



Source: own illustration (adelphi research gGmbH)

4.2.1 Instrument 1: Supplier development

Large companies along the iron ore-steel supply chain often use external support to calculate their GHG emissions or have already developed sufficient internal resources (i.e. in the form of dedicated sustainability departments) and established systems for their emissions accounting. However, smaller companies along the supply chain often lack sufficient resources and require support both in calculating their GHG emissions and in the definition of reduction targets.

This is where the instrument ‘supplier development’ comes in, which can be designed either as a **buyer-individual approach** (see Grüning et al. 2024, chapter A.1.9) or as a **buyer-collective approach** (see Grüning et al. 2024, chapter A.2.4). When a company screens its existing suppliers and discovers that those with high emissions are lacking GHG-emission reduction targets, it can provide targeted support.

Information documents, dialogue formats, training courses, or workshops can be offered to selected or strategic business partners, presenting suitable GHG emission accounting methodologies and providing support for their practical implementation. For non-strategic suppliers, such offers can also be provided at a collective level together with other purchasing companies – in the context of the iron ore-steel supply chain, for example, the ICMM would be a suitable forum that brings together central mining companies, including for iron ore. In both cases, a harmonised carbon accounting framework (instrument 4) is important, i.e. the sharing of information on standards that are as widely established as possible (and possibly harmonised in the future) instead of individual accounting requirements. Purchasing companies can also refer their less-critical suppliers to a large number of existing and freely available options for

GHG emission accounting standards, such as the GHG Protocol, or relevant standards of the International Organisation for Standardisation (ISO) (ISO 14064-1 and ISO 14068) and approaches for formulating science-based reduction targets, such as the Science-based Target Initiative (SBTi) and related guidance material from CSOs, industry associations, chambers of foreign trade, consulting firms, etc. Preference should be given to options that comply with those established and recognised standards as far as possible to prevent suppliers from receiving different, potentially contradictory information from their various purchasing companies. In the iron ore-steel supply chain, this instrument is particularly relevant for the (rather small number of) small-scale iron ore miners, for whom training material from larger mining companies that have been working on GHG emission accounting and reduction for some time can be helpful. For businesses such as the focal company, most of which only purchase a small proportion of iron ore from small-scale miners, this is a measure with a low leverage effect, as emissions from small-scale miners are likely to be marginal in relation to the total emissions in the supply chain – but the measures can be a quick win for individual companies, as the corresponding offer could be made available rather fast. In addition, targeted supplier development activities by larger mining companies can help to ensure that smaller mining companies do not lose market access despite the increasing environmental requirements that result in higher expenditure and costs. This is also relevant in light of the fact that mining contributes to added local value, for example by creating jobs and promoting employment, and can thus be a driver of social development (provided that minimum human rights and social standards are also implemented in small and micro enterprises) (EC n.a.; Kickler and Franken 2017). Furthermore, the emissions from small-scale mining as a whole should not be underestimated. For the gold sector, for example, the climate impact of gold production in artisanal and small-scale mining (ASM) is in the same order of magnitude as the CO_2 emissions of large-scale mining, depending on the location (Fritz et al. 2024). Every company can thus contribute to reducing the overall emissions in ASM through measures in its own supply chain. In addition, targeted supplier development activities by larger mining companies can help to ensure that smaller mining companies do not lose market access despite the increasing environmental requirements that result in higher expenditure and costs.

Table 5: Key actors and actions for implementing supplier development

Key Actors	Actions for Implementation
Individual companies (especially large iron ore mining companies)	- Provide suppliers (especially small-scale miners) with guidance (i.e. in the form of guidance documents, dialogue formats, training courses, or workshops) on a science-based GHG emission accounting methodology with reference to harmonised standards (instrument 4).
Sector initiatives (e.g. ICMM or region-specific initiatives such as the Minerals Council of South Africa, the Minerals Council of Australia)	- Members jointly develop targeted information material, training and workshops etc. on GHG emission accounting for small scale miners, which can be accessed by the target group for free.
Other providers of information/training material (e.g. NGOs, international organisations)	- Actors provide free guidance material, workshops or training material for companies from different sectors, referring to existing established standards (where available).

Financial and human resources are required to implement the instrument at the individual buyer level, so buyers should focus on key suppliers for individual provision. The effort for individual companies in supporting their less-critical suppliers can be reduced by developing guidance and information for suppliers in a collective setting, such as sector-wide initiatives. In these settings, lower financial resources of each member companies may be required to finance the joint development and free provision of information material and formats. Other providers of free workshops, training materials etc. – such as NGOs and international organisations – may develop training material, workshops etc. aimed at small-scale miners or other specific groups of suppliers independently or join MSIs and collaborate directly with companies in the development or review of said material and formats.

4.2.2 Instrument 2: Climate-aligned clauses in supplier Code of Conducts and contracts

Large companies in the iron ore-steel supply chain usually already have their own CoC, which is internally orientated, as well as a supplier CoC, in which basic expectations are formulated for the implementation of certain environmental standards at least by key or strategic direct suppliers. Regarding GHG emissions, these supplier CoCs usually do not contain any quantifiable reduction targets, which in many cases would not be practicable due to a lack of detailed knowledge about the business partner's reduction strategy. They rather require GHG emission disclosure or encourage the introduction of systems for improved management of GHG emissions at the business partner.

The integration of so called 'climate-aligned clauses' in supplier CoCs and contracts offers the possibility of achieving greater commitment to reducing GHG emissions on both sides – for both the buying and the selling company. To this end, the Chancery Lane Project provides guidance and concrete examples of such clauses. In particular, obligations that are included in commercial contracts should not be unilateral obligations of a contracting party; contracts should also stipulate how the achievement of higher ambition targets, for example, will be rewarded by the other contracting party. For example, a special supplier status (e.g. preferred supplier) can be linked to regular proof of maintenance of the agreed GHG emission reduction targets; improved contract terms or faster payment processes can be agreed for the achievement of certain targets. The Chancery Lane Project also provides an overview of possible starting points in this regard (The Chancery Lane Project 2024). The definition of an ambition level or target achievement should not only be aimed at ensuring that the supplier accepts the buyer's CoC, as the targets described in the CoC may not fit the supplier's individual strategy. Rather, such target agreements and clauses should be defined individually for each business relationship in close consultation with the strategic supplier. For legal definitions of climate-related performance obligations within a business relationship, it is also not necessary to refer to pre-defined quantitative reduction targets; the Chancery Lane Project website also includes some example clauses that business partners can use to make the mutual commitment to climate targets binding. One example is "Zain's Clause", which can be incorporated into commercial contracts, and which sets out mutual obligations "to allow all parties to either perform their own obligation in a way that reduces their carbon footprint and/or require other parties to do so" (The Chancery Lane Project 2021). The wording of the clause obliges both parties to work on reducing their carbon footprints, but gives them sufficient freedom in the design of specific activities. Depending on the differences in the level of ambition and the existing negotiating positions, the appropriate clause must be selected individually for each business relationship/contract negotiation.

Table 6: Key actors and actions for implementing climate-aligned clauses in supplier code of conducts and contracts

Key Actors	Actions for Implementation
Individual company (buyer and supplier)	- Share relevant information regarding climate ambition and strategy with business partner in negotiations. An important prerequisite for this is the establishment of a strong internal climate governance and support from the top-down management level for the introduction of the instrument in legal documents and commercial clauses. As a result, climate-aligned clauses should be introduced in supplier CoC and contracts. A process for monitoring needs to be set up and exchanges/updates with the supplier need to be scheduled in regular intervals.
NGOs and other relevant organisations	- Support the effective implementation and mainstreaming of climate-aligned clauses by providing guidance to frontrunner companies (i.e. via provision of MCC, workshops, legal advice).

The implementation of the instrument requires human and financial resources on both sides – supplier and buyer – because such agreements and the monitoring of their compliance may take longer than traditional contractual relationships and parties involved possibly need additional legal advice. More importantly, however, the clauses described above can only be introduced if the company with the more ambitious climate targets has sufficient negotiating power to introduce corresponding requirements in contract negotiations. Compliance with the agreed targets must also be monitored (see instrument 5) accordingly and any agreed incentives (e.g. faster payment process) must be implemented so that the clauses are not simply a declaration of intent. In order to compensate for any imbalances of power and the (short-term) disadvantages of increased additional effort that can come along with the introduction of climate-aligned clauses, strong climate-related regulations and requirements for environmental due diligence are necessary, which oblige purchasing companies not to simply pass on climate commitments to their suppliers, but to actively find joint solutions to reduce GHG emissions. Under these circumstances, climate-aligned clauses could become much more attractive as an effective and flexible means of achieving climate targets in the supply chain. Alternatively, strong internal support in both companies for the agreement of corresponding legal obligations is needed. This is also reflected in the fact that the climate-aligned clauses established by the Chancery Lane Project, for example, have so far been implemented primarily by a small number of 'frontrunner' companies with strong, science-based decarbonisation targets, which already seek to reduce their Scope 3 emissions even in the absence of specific mandatory commitments (The Chancery Lane Project n.d.; Keating 2021).

4.2.3 Instrument 3: Supplier performance monitoring

Large companies in the iron ore-steel supply chain have typically established systems to review the sustainability performance of their suppliers, which can be organised differently depending on environmental topics and individual business relationships with suppliers. According to the focal company, monitoring regarding GHG emissions specifically is only taking place to a limited extent to date. For example, in its role as a supplier to steel companies, the focal company is increasingly being asked to complete self-assessment questionnaires (SAQs) (first-party audit), in which information on GHG emission reduction targets, existing management structures and strategies for reducing emissions must be described. From the focal company's experience, GHG-emission related monitoring usually does not go beyond the level of SAQs. Second-party audits by clients are generally not carried out. However, a growing number of clients are recommending that their suppliers have audits carried out by third parties to prove certain levels of environmental performance at their sites (see also instrument 7). This however is usually not a mandatory criterion for cooperation. The same applies to the cooperation between the focal company and its (few) small-scale iron ore suppliers.

The **buyer-individual voluntary instrument** 'supplier performance monitoring' aims to strengthen efforts in this area. For example, in order to implement the measures described in instrument 2, i.e. to link benefits such as the contract term or accelerated payment processes to the individual GHG emission reduction performance of a supplier, continuous monitoring of supplier performance is necessary.

For strategic suppliers, companies should consider carrying out second-party audits or demand that third-party audits are carried out. Instead of obliging suppliers to carry out new third-party audits, it is also possible to check whether suppliers have already had a reliable third-party audit as part of a certification programme (see instrument 7), for example, in which the desired sustainability performance can already be demonstrated. Proof of an existing assessment by a third party can be accepted/recognised in order to avoid additional costs and duplication of effort for the supplier when carrying out multiple audits.

Table 7: Key actors and actions for implementing supplier performance monitoring

Key Actors	Actions for Implementation
Buyer	- Establish a continuous monitoring system and, where necessary, specify audit requirements towards all relevant suppliers. - Retrieve information from public supplier sustainability reports, environmental performance platforms or, if not available, consider using sector-harmonised SAQs or carry out second-party audits at supplier sites. - Examine the possibility of recognising the evidence of third-party audits, which have already been carried out by suppliers instead of implementing new additional checks and audits. - After new audits have been implemented or existing third-party results have been screened: evaluate the suppliers performance based on the monitoring results and develop corrective action plans with suppliers if necessary. - In addition, engage in sector initiatives or MSIs to support the development of reporting and third-party assessment standards and processes that can match the company's individual sustainability requirements.
Supplier	- Familiarise oneself with the buyer's requirements and information needs. Provide reliable information to customers and business partners. - Consider publishing a targeted sustainability report or get involved in an environmental performance platform, which can fulfil the information needs of customers and business partners and may replace the multitude of SAQs. If audits are required, prepare for them and train employees accordingly. - Implement necessary corrective actions, if performance is evaluated as inadequate. If third-party audits have already been carried out: publish the (key) results in order to attract customers with high(er) sustainability demands and discuss

Key Actors	Actions for Implementation
	the question of whether the results of the third-party audit can replace some of the planned buyer-individual monitoring activities.

Regular audits are associated with significant costs, particularly for the supplier, as well as the utilisation of personnel and time resources, as comprehensive data etc. must be made available (see also Grüning et al. 2024, chapter 3.2.7).

If, instead of conducting a new audit, proof of an existing third-party audit or certification is accepted from a supplier in order to save effort and costs, additional resources are required from the buyer. In this case, the buyer must build up sufficient capacity and knowledge of existing third-party certification schemes offered and the underlying audits, so that it can check whether its own sustainability requirements are adequately covered by them. This should be reviewed at regular intervals in the event that the underlying standards of a third-party offered scheme or audit change or the supplier's own sustainability targets are updated. In order to build up the relevant expertise and ensure that own requirements are met by certification schemes, companies can join sector initiatives in which various industry representatives, possibly from different stages of the supply chain, work on corresponding standards and processes for the comprehensive auditing of suppliers' sustainability performance (especially with regards to the management and reduction of GHG emissions). Please refer to instrument 7 (Third-party certification and cross-programme recognition) for examples of relevant MSIs.

4.2.4 Instrument 4: Harmonised carbon accounting framework

The basis for the reduction of GHG emissions along the entire iron ore-steel supply chain, effective target setting, prioritisation and targeted management of all other approaches and instruments in the roadmap is a reliable data basis, i.e. accurate GHG emission accounting. In addition, on the basis of reliable and comparable GHG emission reports, targeted investments for demonstrably greener production processes can be made available by financial market players and governments. The design and awarding of favourable contractual conditions to particularly sustainable suppliers, for example, also requires reliable information on the emissions intensity of individual products and production steps. In recent years, numerous different organisations have developed methods and guidelines for calculating (lifecycle) emissions of products and services and setting up GHG inventories for companies, some of which are sector-agnostic such as the Greenhouse Gas Protocol, ISO14064-1 (organisation level) and ISO 14067 (product level); others focus specifically on the steel sector such as ISO 14404, the ResponsibleSteel Standard and the Worldsteel CO_2 Data Collection User Guide (Biberman et al. 2022). There are fewer sector-specific standards and guidance documents available for the mining sector, but the Scope 3 Emissions Accounting and Reporting Guidance published by ICMM in 2023 should be mentioned here, for example (ICMM 2024). When accounting for Scope 3 emissions from procured raw materials and products, activity-based calculations are generally preferable to the more superficial spend-based calculations, because they provide a more accurate database. In any case, the variety of viable accounting methods, sometimes even within one standard, means that actors along the supply chain base their emissions calculations on a different footing, hindering comparability of reported information. This also makes it difficult for companies to correctly calculate their Scope 3 emissions, which must form the basis for meaningful target setting in the supply chain, prioritisation of suppliers and SSCM measures to jointly achieve a reduction of GHG emissions. If, for example, a purchasing company wants to introduce a system in which a selected number of suppliers who can demonstrate the lowest CO_2 emissions in a specific production process in direct comparison to their competitors receive a 'preferred supplier' status or comparable benefits, the purchasing company must first be able to create a benchmark of all suppliers and their respective contributions to its own Scope 3 emissions. Only then can progress towards a reduction in GHG emissions and differences between suppliers be reliably measured and rewarded. Activity-based calculations in particular, for which granular, product-level GHG inventory data must be collected from suppliers, are often not yet possible due to incompatible methods or a lack of willingness on the part of suppliers to release this detailed data, meaning that Scope 3 emissions can often only be calculated on a spend-based basis or estimated from secondary data sources.

This is where the **supply chain-collective instrument** 'harmonised carbon accounting framework' comes in. This aims to ensure that as many companies as possible along the iron ore-steel supply chain use the same methodology for their carbon accounting. To this end, individual companies should check which general or sector-specific standards already exist and follow these as far as possible for their own carbon accounting. It is advisable to follow the GHG Protocol Corporate and Scope 3 Standards (developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development) (Greenhouse Gas Protocol n.d.) as the most widely used standard for corporate GHG emissions reporting, to which the majority of the sector-specific standards already developed are also orientated. In addition, since the GHG Protocol also leaves methodological flexibilities, companies should enter into dialogue with strategic and, where applicable, long-standing business partners and discuss which methodology they use, work out differences and, if possible, reduce them in order to harmonise carbon accounting as far as possible. However, in order to achieve the broadest possible standardisation, engagement at industry and multi-stakeholder level – i.e. between individual companies within the mining sector, within the steel sector, within the automotive industry, across industries between companies from all relevant stages of the supply chain and in cooperation with other relevant organisations from civil society, academia, standard organisations etc. – promises greater leverage. By developing a harmonised standard and approach that can then be used by a majority of purchasing companies in an industry to request emissions values from their suppliers, the effort required by suppliers can be significantly reduced. If all of their clients would request emission-related data to be delivered in the same format and based on the same calculation methodology and standards, suppliers would not have to carry out the process anew for each new buyer. This could thus reduce the problem of supplier unwillingness to share data and instead emphasise the advantages of data transparency for suppliers; those who could present their emissions data in a standardised format that numerous purchasing companies can easily work with, could gain a market advantage because such a standardised process would also simplify the subsequent buyer-supplier communication and cooperation. A similar approach is proposed specifically for the automotive value chain by the Expert Group on the Transformation of the Automotive Industry (ETA) set up by the German Federal Ministry for Economic Affairs and Climate Protection (BMWK). The proposal published in 2024 for the development of a harmonised carbon accounting methodology also emphasises that it is essential to ensure that the methods used in the automotive industry are compatible with relevant supplier industries, including steel (ETA 2024).

Table 8: Key actors and actions for implementing a harmonised carbon accounting framework

Key Actors	Actions for Implementation
Individual companies (at each level of the supply chain:	- Exchange with key business partners to harmonise the GHG accounting methodology currently in use.

Key Actors	Actions for Implementation
mining, steel making, automotive)	- Engage with business peers and other actors in (multi-stakeholder) initiatives to develop/improve sector-specific GHG accounting standards/guidance that can be applied in the future.
MSIs (*usually initiated by companies and/or CSOs)*	- Coordinate efforts of stakeholders from all stages of the supply chain to harmonise and/or refine existing GHG emission accounting standards. - Develop sector-specific guidance on GHG emission accounting based on existing recognised standards that can be used by companies at different stages of the supply chain for free.

In order to implement the activities listed above, the different actors need various resources. The engagement of individual companies with many different actors to harmonise GHG emission accounting standards requires considerable time and ties up personal resources. Engagement in MSIs can reduce this effort for each individual company, but the process of harmonisation in a multi-stakeholder setting can be very lengthy, so both measures should ideally be carried out in parallel. An important framework condition for the implementation of the instrument is also the commitment of civil society, academia, standard organisations etc. in MSIs and comparable organisations, which contribute external expert knowledge on carbon accounting and ensure that the level of ambition of a harmonised standard is feasible for companies of different sizes and framework conditions but is nevertheless ambitious and goal oriented. For the ultimate implementation of a harmonised standard, it is also important that governments and/or financial market players (banks or stock exchanges, etc.) provide clear guidance on the methodologies to be used for mandatory reporting obligations in order to create a level playing field for all business actors.

4.2.5 Instrument 5: Enhanced data verification and traceability systems

The high significance of accurate (preferably activity-based) calculation of GHG emissions along the entire supply chain described in instrument 4 as a basis for setting targets, implementing appropriate reduction measures and designing the most effective incentivisation systems possible is leading to rapidly increasing requirements for the provision of data by all business actors along the supply chain. Many companies do not have sufficient resources or systems to collect and process such large volumes of data. For the calculation of Scope 3 emissions, they are dependent on secondary data from databases, or the often qualitatively inadequate data provided by their suppliers and have no way of verifying their data. At the same time, many suppliers are confronted with different, sometimes contradictory requests from their customers, to whom they are supposed to supply GHG emission data in various formats.

This is where the instrument 'enhanced data verification and traceability systems' comes in, which can be implemented by **individual companies using third-party offered approaches** (see e.g. Grüning et al. 2024, chapter A.6.2, and chapter A.6.3) or in **supply chain-collective settings** (see Grüning et al. 2024, chapter A.5.2).

Individual companies can develop their own digital platforms (or have them developed) to provide their customers with individualised, comprehensive information, e.g. on the emissions intensity of their products, with every delivery. Blockchain technology can be used to support the provision of reliable and verified data.[13] As relevant, reliable data sharing platforms have

[13] It should be mentioned here that blockchain technology is not essential and is not a panacea for establishing corresponding data exchange platforms or systems. The decisive characteristics that such a system must demonstrate in order to create a real advantage for both sides (data providers and data retrievers), namely public verifiability, transparency, privacy and integrity, can also be

hardly been implemented along the iron ore-steel supply chain to date, this can be a competitive advantage. However, the disadvantage of such an individual approach is that, as described in instrument 4, there is currently no uniform GHG accounting standard, and the comparability of this data can therefore be questionable.

In order to prevent individual companies from developing individual systems for passing on emission data that are not technically compatible with each other, the development of a standardised system or platform on which all actors in a supply chain feed in their data centrally and thus make it directly accessible to their business partners is suitable. Such a platform can also be used to coordinate third-party verification and thus the reliability of the data fed in. One possible approach for the cross-supply chain exchange of data is being piloted by the Catena-X initiative, for example (Catena-X 2023). Such a system may also render the use of company-specific (e.g. blockchain-based) solutions obsolete, as such solutions only make sense in situations "when multiple mutually mistrusting entities want to interact and change the state of a system, and are not willing to agree on an online trusted third party" (Wüst and Gervais 2018).

Table 9: Key actors and actions for implementing enhanced data verification and traceability systems

Key Actors	Actions for Implementation
Individual companies (at each level of the supply chain: mining, steel making, automotive)	- Provide high-quality data and participate in the further development of harmonised and up-to-date platform requirements. - Establish interfaces with existing internal data management systems were possible to lower the effort of data provision and updates.
MSI (or similar cross-company cooperation forum, i.e. Catena-X)	- Coordinate open and trusted exchange of different actors along the supply chain regarding existing challenges and systems in use for data management and exchange. - Offer trusted forum for business stakeholders to establish minim data requirements and rules to ensure data privacy and avoid breaches against antitrust rules. If needed: determine a trusted third party to be put in place for the verification of data provided by individual actors to the centralised system.
Third-party technology provider	- Provide the necessary digital infrastructure; ensure data security and potentially provide third-party verification of the data that is fed in.

The (further) development of such an instrument requires various resources from numerous actors. Companies must invest human resources and time, and possibly membership fees, in order to fill and finance the development of a collective platform with the support of third parties. Funding can/must also be provided by governments or financial actors, especially in the initial phase.

For a collective solution to really lead to savings in efforts and resources for individual companies, such a solution must be rolled out quickly and to as many members of the supply

established, for example, via a regular centralised database or the involvement of a trusted third party for data verification (Wüst and Gervais 2018; Egberts 2017). For such systems to be reliable, it is still crucial that the people who enter relevant information into the digital platforms are reliable and honest, a challenge that cannot be solved solely by a blockchain-based solution (Wüst and Gervais 2018). The use of blockchain solutions may also require verification by third parties to establish the necessary trust in the quality of the data provided, for example, which can significantly impair the promised simplicity and efficiency of a blockchain solution (Egberts 2017).

chain as possible so that companies do not duplicate efforts to share all data in a joint initiative while continuing to receive individual requests from customers for data in a different format. The provider and the members of a collective solution must ensure that this guarantees data security and does not violate antitrust law. It must also be ensured that comprehensive transparency, for example with regard to the GHG emission intensity of various products, does not lead to poorer performing market participants simply being dropped as suppliers, but instead are enabled to improve their performance; e.g. through supplier development measures as described in instrument 1 and in Grüning et al. 2024, chapter A.1.9 or chapter A.2.4). To achieve this, it is also necessary to design access to a possible collective solution to be as low-threshold as possible so that suppliers who do not (yet) work digitally or only to a limited extent can also participate in the system. In addition, it should be ensured that all participating companies follow a uniform standard/methodology when calculating their GHG emission data in accordance with instrument 4, so that the data is comparable. Only when sufficient members of the supply chain can provide their GHG emission data in the necessary granularity and quality will a collective data sharing platform provide benefits for all participants. If additional control is needed in order for members to trust the quality of the data provided via the centralised platform, a third party could be determined, which is responsible for verifying the data provided by individual members.

4.2.6 Instrument 6: Coordination of interests to enable design for sustainability in joint R&D projects

Research into and (further) development of ‘clean’ or ‘low-emission’ technologies, particularly in the area of decarbonisation of steel production as a GHG emission hotspot in the supply chain, is complex and requires a significant amount of funding. A growing number of companies along the entire supply chain have therefore already joined forces in various R&D projects in which, for example, renewable hydrogen-based DR-EAF steel production is to be tested. Examples of such MoUs and existing collaborations between mining companies, steel manufacturers and hydrogen producers are listed in chapter 5.5. of Grüning et al. (2024).

This **supply chain-collective approach** enables business actors along the supply chain to exchange knowledge with other companies and sometimes additional external actors, for example from the scientific community, as part of pilot projects (in the sense of coordination of interests and context, see Grüning et al. 2024, chapter A.5.1) in order to jointly develop the most innovative and efficient processes possible for the decarbonisation of the supply chain. In addition, these collaborative settings serve to share costs, particularly during the often complex and risky pilot phase of newly developed technologies. Existing projects usually profit from substantial financial support in the form of state financing, which is granted to various decarbonisation projects in the steel sector. The Swedish start-up company Stegra (formerly: H2 Green Steel) for example, which plans to produce large amounts of ‘green’ iron and steel via the DR-EAF production route (Stegra n.d.) and which has signed offtake agreements with a large number of customers in various industries (including steel service centres, producers of pipes and tubes, passenger vehicles and heavy commercial vehicles, whitegoods and construction products) (Bhat and Salazar 2023; Keating 2024), received significant amounts of state aid for the construction of their new plant: the company was awarded a EUR 250 million grant from the EU Innovation Fund (Stegra 2024). In addition, in June 2024, the European Commission approved support from the Swedish government for Stegra totalling EUR 265 million (EC 2024b). In July 2023, the European Commission also approved EUR 2 billion in funding from the German Federal Ministry for Economic Affairs and Climate Protection (BMWK) to promote the decarbonisation of steel production at thyssenkrupp steel Europe (BMWK 2023). The steel manufacturer SAAB, which has signed an MoU with the car manufacturer Volvo for the purchase of low carbon steel, is also receiving millions in financial support from the Swedish state (EC 2024a). The MoU between car manufacturer VW and steel producer Salzgitter AG on the purchase of low-carbon steel is also accompanied by state funding for Salzgitter AG's decarbonisation programme (Salzgitter AG 2022). This externally provided state funding represents an important financial incentive to participate in and ambitiously implement corresponding R&D projects. In addition, participating companies can actively shape green lead markets and also gain a head start in the development of innovative products that will later offer them an important market advantage. Such projects also usually contain offtake agreements, for example when commitments are obtained from car manufacturers that green steel produced as part of a pilot project will be purchased in certain quantities in the future. Offtake agreements or guarantees are just as important as the provision of governmental aid, as they offer companies switching to more sustainable technologies the certainty that necessary investments can be refinanced by the expected future demand for the new 'greener' products. In addition, offtake agreements enhance the creditworthiness of suppliers or specific R&D projects and can thus facilitate an improved access to credit or loans provided by financiers like banks and investors, which are often essential for the effective implementation of costly piloting projects (WEF 2024).

Table 10: Key actors and actions for implementing coordination of interests to enable design for sustainability in joint R&D projects

Key Actors	Actions for Implementation
Individual producer companies (at each relevant level of the supply chain, e.g. mining, steel making)	- Provide knowledge and funds within the specific setting of the collaborative R&D project.
Clients (e.g. automotive companies)	- Support the implementation of R&D projects through future offtake guarantees to allow for the development and piloting of promising 'green' products or technologies.
Financial institutions	- Provide credit or loans to promising R&D projects, which are aimed at the (further) development of 'clean' or 'low-emission' technologies. - Build internal expertise and refer to existing guidelines and criteria to assess whether a proposed project can effectively contribute to the reduction of GHG emissions in a specific sector, process or product.
Governments	- Provide additional funding for the kick-off phase of the R&D project in order to secure risks and allow companies to obtain credits/loans from finance institutions.

For implementation, all actors involved in a MoU/collaborative R&D project contribute human and (in some cases) financial resources that are required in addition to on-going internal R&D measures. In the longer term, however, the instrument should lead to savings in the individual resources required for R&D for all actors.

Despite reported delays in the implementation of some of the on-going collaborative R&D projects, the instrument was described by the focal company as an important approach for driving forward decarbonisation in the supply chain in the future and testing new innovative approaches. It is crucial that results from the various individual pilot projects are rolled out in a timely manner in order to actually contribute to a comprehensive decarbonisation of the supply chain.

4.2.7 Instrument 7: Third party certification and cross-programme recognition

A number of initiatives have been developed at the level of both iron ore extraction (including IRMA, TSM) and steel production (including ResponsibleSteel), which use third party audits to examine, verify and certify the sustainability performance (including GHG emission management) of individual sites on the basis of a standard developed in a multi-stakeholder setting. In the iron ore-steel supply chain, these initiatives are still in their infancy, with some of them still having a low uptake (see also Grüning et al. 2024, chapter 5.5). Nevertheless, they provide the basis for continuous improvements in site-specific sustainability management and offer the opportunity to incentivise supply chain collaboration.

Against the background of the goal of reducing GHG emissions along the iron ore-steel supply chain, the workshops and interviews particularly discussed the (potential) role of the ResponsibleSteel initiative and standards as a **supply chain-collective** 'third party certification and cross-programme recognition' **instrument**. ResponsibleSteel certifies sites that produce, or process steel based on a standard developed in a multi-stakeholder setting. Companies that undergo a third-party audit in accordance with the standard can achieve different progress levels in two categories: 'Decarbonisation' and 'Materials Sourcing'. The 'Decarbonisation' levels indicate, for example, whether a company has set an appropriate site level decarbonisation target, and measures its GHG emissions in accordance with a defined standard (see also instrument 4). In order to meet the requirements of the 'Materials Sourcing' category, steel companies have to demonstrate in the audit, among other things, that they "increasingly source from suppliers that participate in a recognised input material programme" (ResponsibleSteel 2024). ResponsibleSteel has so far recognised IRMA and TSM as input material programmes with relevance for the raw material iron ore considered here. Only if steel companies can prove that they encourage and support their direct and indirect suppliers to have a third-party audit carried out under one of the recognised programmes can they market their products as 'ResponsibleSteel certified'. In order to achieve higher levels within the Responsible Steel certification system, which correspond to a better result, steel companies must prove that they not only encourage their suppliers to participate in third party certification programmes, but that a relevant proportion of their suppliers actually have their sites audited by third parties and that these suppliers achieve certain minimum performance levels as part of the recognised programmes. This initially staggered approach is explicitly aimed at generating a higher market demand among steel companies for appropriately certified input materials and thus also promoting the implementation of sustainability standards at the level of iron ore mining, for example (ResponsibleSteel 2024).

Table 11: Key actors and actions for implementing third party certification and cross-programme recognition

Key Actors	Actions for Implementation
Buyer (*in this case*: steel company)	- Participate in the ResponsibleSteel initiative by having own sites certified and revise the internal decarbonisation strategy in accordance with the requirements of the ResponsibleSteel standard. Additionally, enter into an exchange with suppliers and promote participation in one of the recognised input material programmes. Assess whether and in what form suppliers need support for the

Key Actors	Actions for Implementation
	implementation of the third-party assessment through input material programmes. - Participate in the further development of collaborative standards in relevant multi-stakeholder processes.
Supplier (*in this case*: iron ore mining company)	- Participate in relevant input material programmes by adapting the own production conditions to meet the programme's site-specific standards. - Participate in the further development of collaborative standards in relevant multi-stakeholder processes.
MSIs, other sponsors of assurance/certification systems or certification bodies (*in this case: ResponsibleSteel, IRMA, TSM)*	- Ensure an independent third-party audit according to the standards, award certifications and organise the exchange of stakeholders at different levels of the supply chain to further develop the standard. - Involve external stakeholders from civil society, science, etc. to ensure the continuous development and a high level of ambition of the standard.

Participation in a third-party audit and certification programme such as ResponsibleSteel and the aforementioned recognised input material programmes is initially associated with a high level of resource expenditure for both buying and selling companies. The companies must adapt their production processes to meet the requirements of the respective standard, train employees and collect and provide comprehensive data for the audits. Purchasing companies should also enter into an intensive exchange with at least their strategic suppliers and examine the possibilities of participating in recognised input material programmes together with them (also in the sense of instrument 1: supplier development). In the longer term, however, suppliers may be able to save resources by using third party audits and certification, for example if, as described in instrument 3, purchasing companies accept these certifications as proof of compliance with the highest possible environmental standards and refrain from carrying out additional individual audits as part of their supplier monitoring.

4.3 Discussion of the roadmap for the iron ore-steel supply chain

The key instruments presented in the roadmap are intended to overcome some of the challenges described in section 4.1 of this chapter, which the focal company and other actors along the iron ore-steel supply chain face in reducing GHG emissions in particular and improving environmental performance at all stages of the supply chain in general. The roadmap only includes those instruments which, according to experts and the focal company, promise a particularly high leverage effect and does not represent a comprehensive guide to the implementation of an appropriate SSCM approach for GHG emission reduction.

The instruments in the roadmap are divided into two categories, depending on whether an instrument is initiated by an individual company (usually the buyer) or at a collective supply chain level (see also Grüning et al. 2024 for further derivations of the categories). With regard to instruments that companies can implement individually, three instruments were identified that promise a particularly high leverage effect for the improved achievement of the environmental upgrade target. This includes the supplier development instrument (instrument 1), which should form the basis for the formulation of sustainability performance expectations in supplier CoCs or contracts (instrument 2). The implementation of continuous supplier performance monitoring (instrument 3) is necessary in order to identify supplier development needs and check the implementation of sustainability requirements. In addition to measures that individual companies can take, the roadmap focuses primarily on instruments that (must) be implemented collectively by various actors in the supply chain in order to achieve the goal of decarbonisation along the supply chain more effectively, and to keep the effort and costs for all actors as low as possible. This is also due to the fact that in the iron ore-steel supply chain, unlike the cotton-garment supply chain, for example, the power imbalance between buyers and suppliers does not run exclusively from top to bottom. Rather, the value chain is characterised by financially strong players at all stages of the supply chain, who generally possess sufficient expertise to reduce their own GHG emissions, but who are only just beginning to take their upstream and downstream value chain into consideration when dealing with their environmental impacts. Power distribution between the actors can also change over time, depending on current market developments. According to the experts interviewed, it can be observed that negotiating power tends to shift towards the downstream sector in times of low commodity (especially: iron ore) prices, while the upstream sector has an improved negotiating position when iron ore prices rise. Depending on the current market environment, this results in different windows of opportunity to implement new environmental requirements vis-à-vis business partners.

Partly due to new legislation such as the CSRD or the CSDDD, which will oblige companies to also check their Scope 3 emissions data and report it in an increasingly granular form, efforts are initially focusing on improving the exchange of emissions data along the supply chain. The focus of supply chain cooperation is therefore initially on improved communication and harmonisation of the respective industry efforts. This is reflected in the fact that a harmonised carbon accounting framework (instrument 4) and enhanced data verification and traceability efforts (instrument 5) were considered to have a high potential leverage effect. During the workshops, it was also discussed that this improved harmonisation was necessary in order to increasingly negotiate price premiums for demonstrably 'greener' products in the future, as these instruments could improve comparability between the emissions intensity and GHG savings potential of different products.

According to various experts, discussions about a possible premium for effectively reduced GHG emissions and other comparable sustainability services (e.g. for participation in a third-party audit and certification scheme, instrument 7) are still in their infancy in the iron ore-steel supply chain. Interviewees at all levels of the supply chain (mining, steel production and automotive manufacturers) report that there is currently no significant willingness on the part of purchasing companies to pay price premiums for certified iron ore or 'green' steel from DRI production. The only exception at present appears to be commitments for the future payment of premiums for the purchase of 'green' steel, which is produced on the basis of renewable hydrogen in the DR-EAF route (Stegra 2022; Bhat and Salazar 2023; Keating 2024). However, these are currently forecasts for the future, as the corresponding 'green' steel has not yet been produced at scale (Chan and Vargas 2024). Similar investments in joint R&D projects (instrument 6), which were actually identified as a central instrument for the cross-supply chain exchange of knowledge and further development of innovative green technologies, are also repeatedly deprioritised by participating companies in times of economic downturn and are heavily dependent on governmental subsidies (tagesschau 2024).

These insights also indicate that incentives from the supply chain actors themselves are likely to only have a minor leverage effect for effective decarbonisation and environmental protection. Rather, it became clear in the workshops and interviews that the fourth-party/government enabled and enforced approaches described in chapters 2.8 and 2.9 of Grüning et al. (2024) and earlier in section 0 of this report, are urgently needed to further promote cooperation to achieve environmental protection goals along the entire iron ore-steel supply chain.

List of references

This report is a compilation of content from the following research reports. The literature cited in this report is accessible in the list of references of the respective reports.

Grüning, C.; Jüde, J.; Martin, K.; Strasser, J.; Tran, C.; Grabs, J. (2025): Cost allocation and incentive mechanisms for environmental, climate protection and resource conservation along global supply chains. Roadmaps for the implementation of sustainable supply chain management approaches and instruments. TEXTE. Umweltbundesamt. https://doi.org/10.60810/openumwelt-7704.

Grüning, C.; Jüde, J.; Martin, K.; Strasser, J.; Tran, C.; Hofstetter, J. (2024): Cost allocation and incentive mechanisms for environmental, climate protection and resource conservation along global supply chains. Business approaches and instruments of sustainable supply chain management. TEXTE. Vol. 161/2024. Publisher: Umweltbundesamt. In: https://www.umweltbundesamt.de/publikationen/cost-allocation-incentive-mechanisms-for-0, Retrieved: 15.04.2025.

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