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REPORT

The potential of EU-Chinese cooperation in the decarbonisation of the steel and automotive industries

Anastasia Steinlein, Carolin Grüning, Daniel Weiß, Lina Li, Paula Janssen and Philipp Wagner

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Executive summary

Recent crises such as the COVID-19 pandemic or the conflict in Ukraine have led to the collapse of global trade flows and delayed the delivery of key goods. This has shown policy makers worldwide how vulnerable global supply chains can be and has in many cases led to the idea of relocating production back in order to reduce dependence on international partners. This also applies to trade relations between China and the EU.

As this study shows using the example of the steel and automotive industries, the European and Chinese economies are currently strongly interlinked through complex supply chains. These links are likely to remain in place in the long term, despite efforts to diversify supply chains. This is because demand is growing in both sectors in China and the EU, and building alternative supply chains is a lengthy process.

This makes Sino-European supply chains central to achieving global climate goals. The production of steel and automobiles generates large amounts of GHG emissions. A significant amount of these emissions occurs in the global supply chains – for example in the extraction of raw materials, or the production of components or transport. As of yet, however, political and economic strategies for industrial decarbonisation developed in both countries/regions do not sufficiently address supply chain emissions. Rather, it can be observed that solutions are formulated at the national level with an emphasis on reducing the complexity of supply chains and increasing localisation. This is mainly due to economic considerations.

Policy makers seem reluctant to decarbonise products with high exposure to international trade, as this could affect their competitiveness and lead to "carbon leakage". First steps towards addressing this field have been taken by the EU and China and include the idea of introducing import tariffs or carbon border adjustment mechanisms. However, discussions about these proposals have revolved around growing conflicts instead of enhancing the climate cooperation between the EU and China. In the context of a highly interconnected global economy, however, climate targets can only be achieved through cooperation, especially in the area of supply chain decarbonisation.

Against this backdrop, this report aims to strengthen cooperation through a better mutual understanding of the decarbonisation strategies of the Chinese and European steel and automotive sectors. One of the key findings of the study is that China and the EU share many common strategies and challenges in the decarbonisation process for steel and automotive sector supply chains. This provides many opportunities for cooperation and scaling of solutions to a bilateral/international level.

Regarding the steel sector, both China and the EU have set ambitious sectoral targets and are focusing their efforts on developing the maturity and scale of new production methods, especially hydrogen-based steelmaking as a decarbonisation strategy. Major challenges include the need for substantial investment in the development of pilot and demonstration projects of current decarbonisation technologies.

In the automotive sector, both the EU and China have embarked on a transition towards electric mobility, placing even greater focus on supply chain GHG emissions in decarbonisation strategies. Policy makers and industry stakeholders face challenges in appropriately calculating vehicle life cycle emissions due to the complexity and length of automotive supply chains, and are therefore developing approaches to uniform standards. Other challenges include the insufficient availability of "green" materials (e.g., green steel), which have not yet been able to fully meet the demand of the automotive sector, and the lack of availability of green energy. In addition, both China and the EU have identified improving the circular economy as a key approach to reducing environmental impacts in the automotive supply chain, particularly for electric vehicle batteries.

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List of Abbreviations

ADC	Automotive Data of China Co., Ltd
BF-BOF	Blast Furnace-Basic Oxygen Furnace
CAFC	Parallel Management Regulation for Corporate Average Fuel Consumption
CATARC	China Automotive Technology and Research Center
CBAM	Carbon Border Adjustment Mechanism
CCUS	Carbon Capture, Utilisation and Storage
CDP	Carbon Disclosure Project
CO2	carbon dioxide
DRI	Direct Reduced Iron
DRI-EAF	Direct Reduced Iron-Electric Arc Furnace
EAF	Electric Arc Furnace
ETS	Emissions Trading System
EU	European Union
EUR	euro (€)
EV	Electric Vehicle
GDP	Gross domestic product
GHG	Greenhouse Gas
HBIS	Hebei Iron and Steel
H-DRI	Direct Reduction of Iron using Hydrogen
ICE	Internal Combustion Engine
JV	Joint Venture
kWh	Kilowatt hour
LCA	Life Cycle Analysis
MSP	Minerals Security Partnership
NEV	New Energy Vehicle
NMC	Lithium-Nickel-Manganese-Cobalt-Oxide (LiNiMnCoO2)
OEM	Original Equipment Manufacturer
PHEV	Plug-In-Hybrid Electric Vehicle
R&D	Research and Development
SOE	State-Owned-Enterprise
t	ton
USD	United States Dollar

Introduction

The EU-China relationship is of major importance for the climate-neutral future of economies. To stay within the 1.5°C limit, as required by the Paris Agreement, the EU and China have a vital role to play due to their high greenhouse gas (GHG) emissions per capita, their funding of projects worldwide, as well as their prime position when it comes to global trade. Together they account for around one-third of global economic output – and of global GHG emissions.

Both China and the EU are in the process of strengthening their climate targets and have adopted ambitious climate objectives. In Europe, the “Fit for 55” package entered into force in July 2021, setting new binding EU-wide climate targets, including a 55% reduction in GHG emissions compared to 1990 levels target for 2030 and a net zero emissions target for 2050. China is on a similar path, as it has confirmed key targets to peak emissions by 2030 and achieve carbon neutrality by 2060 as part of its climate policy package, the “1+N” policy framework. The “1” refers to the 2030 emissions peaking and 2060 carbon neutrality, whereas the “N” stands for a concrete action plan for carbon dioxide peaking even before 2030.

To achieve these climate targets, political and economic measures have been taken in both countries/regions to decarbonise key sectors of the economy. However, these largely do not cover a key area with great potential to reduce global GHG emissions: supply chains. For the average consumer company, the supply chain accounts for about 80% of total GHG emissions (Bové and Swartz 2016, p. 3). Efficient mitigation of GHG emissions in globally interlinked supply chains can only be achieved through global cooperation. Current decarbonisation measures on the part of the EU and China, however, aim at isolation or ignore the supply chain perspective. Reasons for this include: the complexity of supply chains; different standards for measuring CO_2 emissions along the supply chain; incomplete information about procured goods; and approximate values regarding carbon footprints. The main reason, however, appears to be economic – policy makers seem reluctant to decarbonise products with high exposure to international trade, as this could affect their competitiveness and lead to “carbon leakage”.

This has changed in recent months. Recent policies aim to increase pressure to decarbonise supply chains and companies are facing growing pressure to reduce emissions across their entire value-chain. While some policies targeting supply chain decarbonisation are not contentious, as the adoption of taxonomies in the EU and in China, others may result in great dissonance between the EU and in China. This is particularly true for the European idea of introducing a carbon border adjustment mechanism (CBAM) alongside the EU emissions trading system (ETS), to prevent carbon leakage, protect industry competitiveness, and safeguard the EU’s new climate targets as well as the idea of a “climate club” proposed by the German G7 presidency. The dissonance on steel has arisen since European stakeholders suspect China of producing dumping prices for Chinese steel, whereupon European policy makers have imposed increased tariffs on Chinese steel products. This has significantly dampened joint efforts to decarbonise the steel industry and its supply chains.

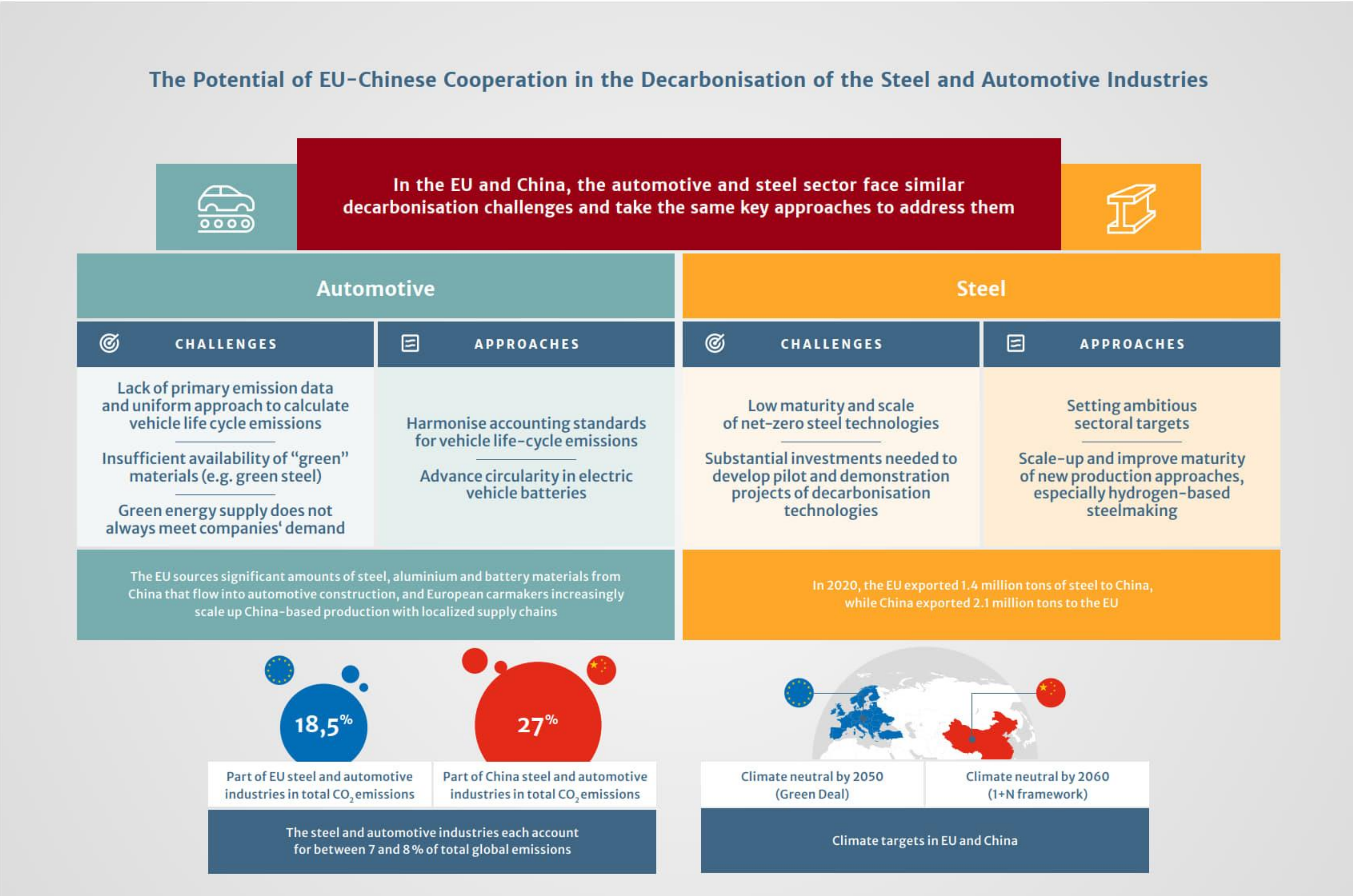
To overcome potential conflict between the EU and China, it is imperative to promote dialogue between the stakeholders. To efficiently reduce GHG emissions in global supply chains, cooperation between key stakeholders in the EU and China is essential. Solutions that have so far been developed at national level need to be scaled up to the bilateral and global context. Against this backdrop, the present study proposes to examine how mutual understanding and cooperation between EU and China can be enhanced in two areas where trade flows between the two powers are particularly important, namely the steel and automotive sectors. Cooperation between China and Europe in these sectors is critical, as the supply chains are closely interlinked and decarbonisation can technically only be tackled jointly.

Steel is one of the so-called “hard-to-abate sectors”: it generates low profits relative to generated emissions. While important and innovative approaches to decarbonise the sector are developed in both China and the EU, it is nevertheless at the centre of recent trade debates. Indeed, a significant volume of steel is traded between the EU and China, making this a particularly sensitive sector. Improved understanding of the respective decarbonisation strategies is therefore urgently needed to develop a common understanding of the situation and a productive approach to overcome potential conflict. This is especially relevant due to several entanglements between the European and the Chinese steel industry: steel exchanges between both regions are significant with a trade volume of 3.5 million tons in 2020, even if strong competition has evolved regarding domestic and international sales markets.

The automotive sector is closely linked to the steel sector, as the latter accounts for a significant share of materials and emissions from car manufacturing. In addition to steel, the GHG hot spots in the automotive supply chain are aluminium and battery materials. In this sector, the supply chain between the EU and China is particularly interlinked, and the interconnection may increase over time as European car manufacturers plan to import more battery materials from China to ramp up its electric vehicle fleet. Several European automobile companies have already started to decarbonise their supply chain, including production processes in China. This is a good starting point for increased trade and cooperation. At the same time, both China and the EU are striving to become less dependent on imports and to protect themselves from supply chain disruptions. Increasing competition and alienation in some areas of the supply chain may complicate future cooperation on decarbonisation.

The findings of this research are based on an extensive literature review and on 15 interviews with representatives from government, business and civil society from both the EU and China. The study aims to promote EU engagement with China and its key stakeholders to push for higher climate ambition via supporting joint efforts to reduce emissions in the chosen sectors. The responsible and sustainable greening of supply chains requires joint EU-China efforts based on mutual understanding and willingness to cooperate given that China is an essential part of European supply chains – and vice versa.[1]

[1] The results of this study will serve as input for workshops with European and Chinese experts from business, politics, science and civil society. Based on the overview of the study and the identified areas for action, recommendations for an enhanced EU-China cooperation on decarbonisation of supply chains in the steel and automotive sectors will be developed.



Source: This infographic depicts the study results, for further references see study.

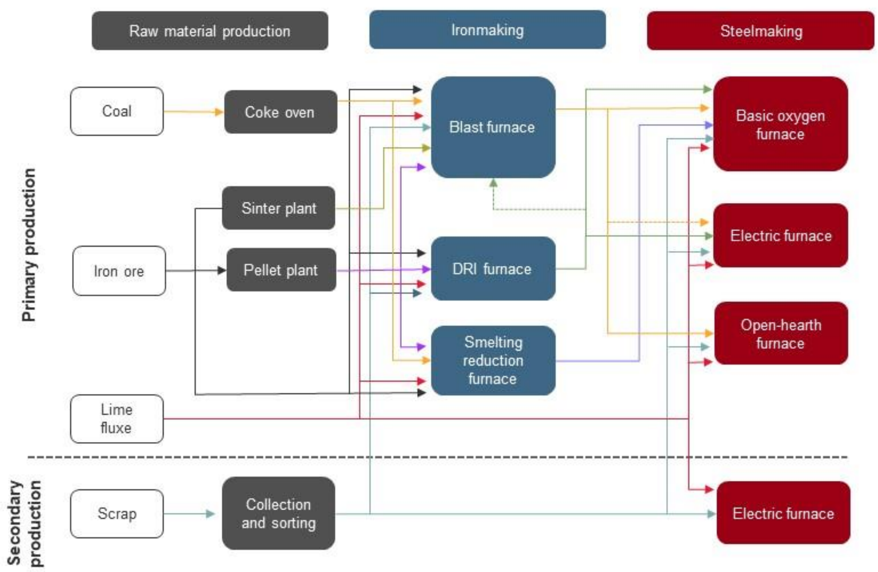
The steel sector

1. Background: the steel industry in the EU and China

Steel is a key material in manufacturing supply chains such as the automotive or the construction sector. It is responsible for a significant share of emissions along the supply chain, as its production processes are energy-intensive compared to other industries (Roland Berger 2020).GHG emissions occur on different levels along the steel sector's value chain: on a scope 1 level during the production process, on a scope 2 level for energy supply and on a scope 3 level for mining activities and for transport and shipping.

Two main methods are used in the steel sector's **production process: the primary and the secondary production route.**

Figure 1: Primary and secondary production route



Source: Adapted from IEA 2020, p. 27

The **primary production route** makes up 95% of the world's steel production. Coal and iron ores are required as raw materials in the pre-processing, coming from mining activities around the globe (Li et al. 2022). Coal is used as a reducing agent for the separation of iron and oxygen. The iron ore is processed to produce iron sinter or pellets, whereas the coal is transformed to coke in a coke plant. Afterwards, the iron sinter or pellets are melted in a blast furnace with coke to produce pig iron (Roland Berger 2020).

Within the primary route, two main methods can be distinguished. The **Blast Furnace-Basic Oxygen Furnace** (BF-BOF) method uses pig iron that is being processed to create steel. Oxygen is blown onto the liquid iron for the fabrication of steel, and finally the liquid steel is poured into various moulds, depending on the intended use (Eurofer 2022). This method is often used for the manufacturing of long products (made from steel blooms), such as bars or wires, but also flat steel strips (made from steel slabs), by using tempering and coating techniques.

The **Direct Reduced Iron-Electric Arc Furnace** (DRI-EAF) method is also one way of the primary route. It uses high-quality Direct Reduced Iron (DRI) pellets, whereas hydrogen and carbon monoxide are used as main reduction agents. Nevertheless, this method is more energy-intense and mainly makes use of natural gas to generate the reducing syngas (IEA 2020).The **secondary production route** makes up around 25% of the global steel production. Different production methods are used: scrap metal is heated in an electric arc furnace (EAF) with graphite electrodes to create steel (Roland Berger 2020). All kinds of high quality steels can be produced with this method, for example basic products or special steels that require flexibility and smaller capacities (Eurofer 2022).

Different levels apply to the steel market for the **distribution and storage of steel**: the distribution can pass directly to the steel-using sectors, or through intermediate operators such as stockists or traders who add additional steps to the steel products and will be responsible for the stocking and inventory levels of the distribution (Eurofer 2021). However, in the **use of steel,** a distinction must be made between apparent steel consumption and real steel consumption: real steel consumption refers to the final steel use, whereas the apparent steel demand can be much higher due to the stocking of steel products (Eurofer 2021).

End-of-life of steel can take different forms: even after the average product lifespan of steel products of 35 years (Cooper et al. 2014), steel scrap can still be used for production in EAF, as it consumes only 50% of the energy demand of primary steel production (Kong et al. 2021).

On a **global scale**, steel production plays a central economic role. This is primarily because it provides crucial raw materials for other industrial sectors: in 2020, 49% of steel raw materials were used for the construction sector, 16% for mechanical engineering and 9% for the automotive sector (steelonthenet 2020). Steel production has steadily been globalising: today, around 25% of its annual production volume is traded between nations each year (IEA 2020). Since the steel demand is forecast to grow to 2.5 billion tons per year by 2050 from current production levels of 1.8 billion tons (Energy Transitions Commission and Material Economics), new low-carbon and carbon mitigation technologies such as hydrogen or carbon capture and storage have been introduced in order to cut carbon emissions in the production process. However, these new technologies are still in a pilot phase and are not yet used on a large scale. In addition, the use of steel scrap is increasingly considered as a technology that can both reduce production costs and carbon emissions. This is why the prices for steel scrap have doubled since the beginning of the COVID-19 pandemic, a tendency which has increased even more since Russia’s invasion in Ukraine (Hoffer 2022).

1.1 The Chinese steel industry

China is the **world’s largest steel producer**. In 2020, China produced 1064.8 million tons of crude steel, whereas in 2019 the country had produced 995.4 million tons (World Steel Association 2021a). Despite the COVID-19 pandemic, China’s steel production increased in 2020 and 2021 (IEA 2021a). In 2020, this represented a share of 56.7% of the world’s total crude steel production (World Steel Association 2021a). On a comparative level, the country had a total production volume of 88.3 million tons in March 2022 (World Steel Association 2022).

China’s apparent steel use has been increasing rapidly, reaching 995 million tons of finished steel products in 2020 (World Steel Association 2021a). This represented a share of 56.2% of the world’s total apparent steel use that year (World Steel Association 2021a). The BF-BOF route accounts for 90% of China’s steel production, with around 80% of the steel production made from iron ore (IEA 2021a). The use of scrap is mainly part of the primary production via the BF-BOF route (IEA 2021a). Electric arc furnace-based secondary steelmaking accounts for only 10% (Chen et al. 2021).

On an international level, China has **comparably high imports of the steel raw material needed for iron ore production**, with 1069.1 million tons of iron ore imported in 2019 (World

Steel Association 2021a). In 2018, China imported 67% of all globally traded iron ores since the country's stocking capacities for own mining activities are not sufficient (DERA 2020). In the same year, 60% of iron ores and concentrates have been imported from Australia, 24% from Brazil (DERA 2020). 39.9 million tons of steel products have been imported in 2020 (World Steel Association 2021a), mainly from Japan (5 million tons in 2020) and the rest of Asia (23.8 million tons in 2020) (World Steel Association 2021a).

China's export rate of raw materials is relatively low, with 14.7 million tons of iron ore exported in 2020 (World Steel Association 2021a). 51.4 million tons of steel products were exported in 2020 (World Steel Association 2021a), however China uses most of its steel productions domestically, with 95% of production in 2018 being used by next-tier manufacturers (IEA 2020). Exports of steel products mainly went to Asia without Japan (27.5 million tons in 2020) and Africa (8.3 million tons) (World Steel Association 2021a).

The **major steel industry clusters within China** are concentrated in the central and east regions, with Hebei, Jiangsu, and Shanxi provinces making up 40% (Chen et al. 2021). The three biggest steel companies in terms of production quantity are China Baowu Steel Group Corp, Hebei Iron and Steel (HBIS), and Jiangsu Shagang Group (Chen et al. 2021). In the 1980s and 1990s, China's steel industry focused on the construction of production capacities before entering a phase of high-speed development (Lin et al. 2021). However, the relatively low age of existing production capacity leads to regular replacements of production facilities, often after a single operation cycle (IEA 2021a). Emissions-intensive assets in China have an average lifetime of 25 years only, compared to 40 years on international average, because facilities are usually replaced after a single operating cycle instead of undergoing a substantial refurbishment (IEA 2021a). This is likely to hamper the decarbonisation of the Chinese steel sector.

The Chinese steel sector is **embedded into domestic supply chains** for the overall industry. Steel is especially relevant for the construction sector (58.3% consumption in 2020), machinery (16.4%) and the automotive sector (5.4%) (Chen et al. 2021). Since the Chinese construction sector has already exceeded its economic peak, the steel sector's supply chains have progressively been turning to the automotive sector which is likely to become the major downstream consumer of steel (Li et al. 2022). Moreover, steel production has been central for the development of the Chinese economy, contributing to industrialisation, urbanisation and the construction of public infrastructures (Lin et al. 2021).

China's economic exchange for steel is **based on important overland and maritime transport routes** in the framework of the Belt and Road Initiative that are likely to be expanded due to growing economic exchanges with Central Asia and Europe (Maçães 2016). Steel industries have been relocated to Western China and to countries that participate in the Belt and Road Initiative (OECD 2018). Furthermore, the sector's political importance within the global market is central as well. Out of the ten largest steel producers worldwide, seven companies are Chinese (World Steel Association 2021a). In this sense, China controls great parts of the global supply chains in terms of steel exports.

1.2 The EU steel industry

In 2020, **the European Union**[2] **produced 139.3 million metric tonnes of crude steel**, accounting for 7.6% of the global share, making it the second largest producer after China (Eurofer 2021). The figure dropped by 11.5% compared to 2019, where production accounted for 159 million tons (Eurofer 2020a). This decline reflects a continued shift in demand from steel-using sectors that materialised in 2019 and increased during 2020 due to the COVID-19 pandemic. Germany is the leading producer with 35.66 million metric tonnes in 2020,

[2] The data includes the United Kingdom.

representing a quarter of European production, followed by Italy, which represents 14% of European steel production, and France and Spain, which each represent 8% (Eurofer 2021).

The EU uses two main processes of crude steel production: 57% of the production is done by the BF-BOF route and 42% of the production is done via the DRI-EAF route. When looking at the quality of the steel produced, 79.0% of the steel produced is “carbon steel non alloy”, meaning that no elements have been added when the steel is smelted, 16.5% of the steel is “carbon steel other alloy”, meaning that different elements have been added in the process, and 4.5% is stainless steel, meaning that it is corrosion-resistant (Eurofer 2021).

In 2020, **the real consumption of steel in the European Union amounted to 142 million metric tonnes of steel,** below the level of 2019 (158 million tons) and 2018 (162 million tons) (Eurofer 2021). Real consumption was 158 million tons in 2019 and 142 million tons in 2020. 38% of the total finished steel demand came from the construction sector, 16% from the automotive sector, 15% from the technical engineering sector and 14% from the metalware sector (Eurofer 2021).

Two main **raw materials** are needed to make steel: iron ore and coking coal. In 2020, the value of imports of iron ores to the European Union totalled $ 8.19 billion. The top importing partners were Canada (29%), Brazil (20%), Ukraine (16.7%), Russia (12.4%) and South Africa. The value of exports of iron ores totalled 1.96 billion, top export destinations were China (22%), Saudi Arabia (18.2%) and Turkey (11.4%) (TrendEconomy 2021). The European Union listed coking coal as a critical raw material, an important resource that has a high supply risk. The EU’s import reliance amounts to 62%. Main import countries are Australia (24%) and the United States (21%) (European Commission 2020a).

In 2020, the **EU imported 21.2 million metric tonnes of finished steel products** (Eurofer 2021), below the level of imports in 2019, which was 25.3 million tons (Eurofer 2020a). For flat products imports (including wire, rod, rail, and bars as well as types of steel structural sections and girders) the main importers were Turkey (19.6%), South Korea (16.5%), Russia (14.1%) and India (11.3%), followed by Ukraine (8%), Taiwan (China) (5.7%) and China (5.7%). In terms of long product imports (consisting of sheets and plates), main importers were Russia (19%), Turkey (16%) and Belarus (14.4%). China is number eight on the list, with 5.8% of imports (Eurofer 2020a).

The EU Steel Safeguard sets **quotas for specific steel products**, in the form of tariff-rate quotas based on the average volume of traditional imports over a certain period. If the quota is exceeded, a 25% tariff applies to the excess imported products. For example, the EU has imposed anti-dumping tariffs on Chinese steel fasteners (Reuters 2022) or Chinese steel wind towers (Reuters 2021), stating that these products were being sold at artificially low prices. Nevertheless, developing countries with an import share lower than 3% are not concerned by the measures. The quota size is regularly adapted and has increased by 5% three times (Eurofer 2019b).

In 2020, the **EU exported 17.7 million metric tonnes of finished steel products** (Eurofer 2021), below the export level of 2019 where the export amounted to 20.5 million tons of finished steel products (Eurofer 2020a). For flat products exports, the main export destination is Turkey with 24% of exports, followed by US (10.8%) and China (7%). For long product export destination, the main partners are Switzerland (13.2%), followed by Canada (9.3%) and Turkey (9.2%). China is the 8th most important export country representing 3.9% of exports (Eurofer 2020a).

Steel is a **major sector for the EU’s economy**. There are more than 500 steel production sites in 23 EU Member States that directly employ 330,000 people (European Commission 2021b). Steel provides approximately EUR 83 billion in direct value added to the EU economy. In addition, the steel industry is a major material for downstream industries such as automotive, machinery and construction, contributing more than EUR 1.4 trillion in value added to EU economy. Altogether, the steel industry and the main consuming industries account for about 9% of the total value added in Europe (Mc Kinsey & Company 2021).

1.3 EU-China steel trade relations

A **significant amount of steel** is being traded between the EU and China. In 2020, the EU exported 1.4 million tons of steel to China, which makes up 1.2% of the EU's total steel exports (118.5 million tons). China exported 2.1 million tons to the EU, representing 4.1% of China's total steel exports (51.4 million tons) in 2020 (World Steel Association 2021a). Nevertheless, in the context of the COVID-19 pandemic, steel exchanges between China and the EU have also led to additional bottlenecks, given that the steel production in both regions has faced several lockdowns and disruptions in logistic supply chains (Zhang 2022).

In general, China is currently ranked number six in terms of EU export destinations for steel products, with the traded volume slightly increasing between 2010 and 2020 (Eurofer 2021). In 2020, 7% of the EU's flat products exports and 3.9% of all long products exports went to China (Eurofer 2021).

China's steel exports volume to the EU generally increased between 2010 and 2020, but declined between 2015 and 2021 (Eurofer 2021). In 2019, 10.1% of the EU's flat products imports and 7.5% of all long products imports came from China (Eurofer 2020a), in 2020 it was less due to the COVID-19 pandemic (Eurofer 2021). Indeed, iron and steel products from China make up a major part of the EU's imports.

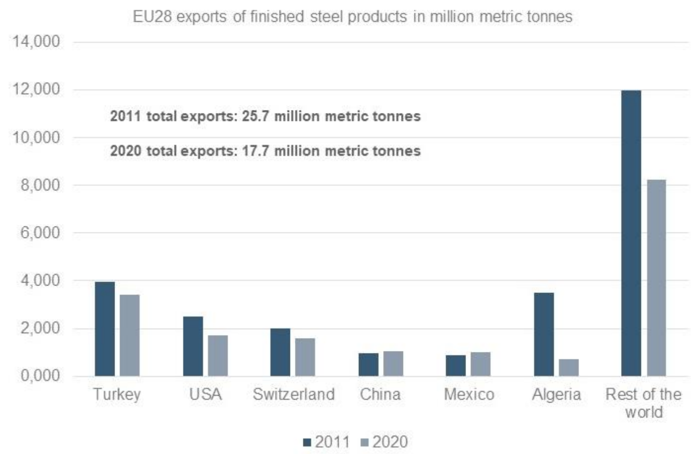
Overall, **China's steel exports to the EU** are more significant than the EU's to China (DERA 2020). In this sense, possible existing competition in steel procurement is less likely regarding the import of steel products: China's import volume (37.9 million tons) is lower than the EU's (128.4 million tons) (World Steel Association 2021a). In addition, EU countries trade 95.8 million metric tonnes among themselves. However, imports for both countries/regions are high from other Asian countries (except China and Japan) and the Commonwealth of Independent States (CIS) (Eurofer 2021).

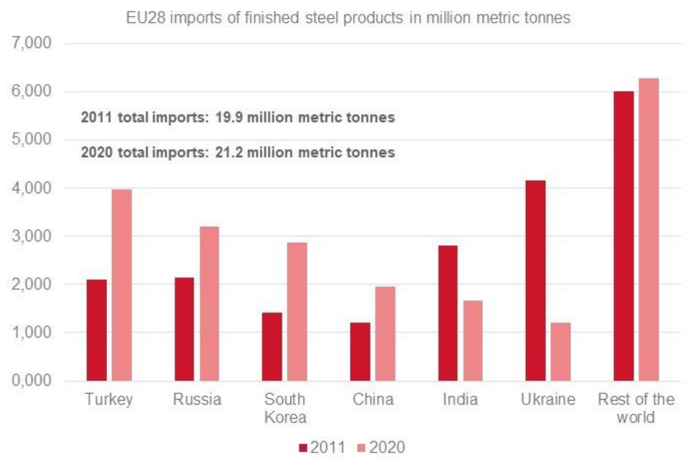
Competition emerges from a high demand for iron ore, since both the EU and China depend on imports of iron ores and cannot cover their needs with domestic mining activities (DERA 2020). For instance, China imported 67% of all globally traded iron ores in 2018 (DERA 2020).

Some competition also arises **from steel exports to other states and regions**. In some countries (e.g. India, Saudi Arabia, Mali, Madagascar, Bolivia) both European and Chinese metal exporters are active in steel trade (DERA 2020). At the same time, as a reaction to China's subsidies for steelmakers in third countries like Indonesia or India, the EU has set up compensatory duties against steel products that have benefited from this kind of financial support from China (European Commission 2022c). Nevertheless, China uses most of its steel production domestically, with 95% of production in 2018 being used by next-tier manufacturers (IEA 2020). For raw materials, competition in exports is unlikely regarding the export of iron ore raw materials since domestic needs are high. In 2018, China exported ores only on a minor scale (0.5% of total metal ore exports), with China being one of the main extractors of iron ore (IEA 2020). However, some competition on steel is possible regarding other export countries and sales markets.

Another field of competition emerges around **scrap steel**: indeed, there is fierce competition for scrap resources between BF-BOF-based and EAF-based steelmakers which varies periodically and regionally (Chen et al. 2021). China's demand for scrap is likely to grow in the coming years as scrap steel is less energy-intensive (IEA 2021a).

Figure 2: Principal trade partners for iron in the EU





Source: Eurofer 2021, p. 48, 42.

2. GHG emissions along the steel supply chain

2.1 Global emissions

The steel industry is the source of between 7% and 9% of global emissions, with 2.6 billion tons of CO_2 emitted in 2020 (World Steel Association 2021b). According to an International Energy Agency forecast, global steel demand could increase by as much as a third by 2050 and annual CO_2 emissions from the steel industry could reach 2.7 billion tons by that time, despite efforts to reduce the sector's carbon impact (IEA 2020). The steel industry is the largest industrial sector in terms of emissions, mainly due to its dependence on coal. On average, producing one ton of crude steel generates 1.4 tons of direct CO_2 emissions and 0.6 tons of indirect CO_2 emissions (IEA 2020).

GHG emissions vary significantly between the different production routes.

The **BF-BOF route**, which accounted for 71% of production in 2019, is the most emissions-intensive route. One ton of steel produced via this route emits around 1.2 tons of CO_2. In addition, it is estimated that an average of 1.0 tons of CO_2 is emitted indirectly from electricity and imported heat generation. The production of BF-BOF is based on coal injection for about 90% of the production, the remaining portion is based on the injection of other fuels such as gas or charcoal (IEA 2020).

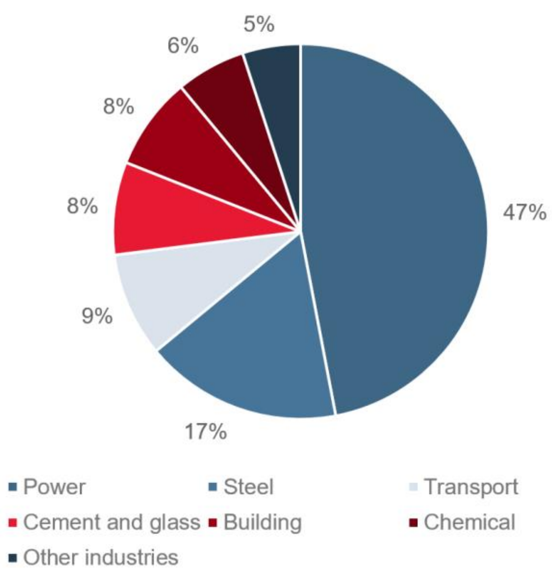
DRI-EAF, the second possible production pathway for steel, achieves lower emission intensities. This is primarily due to the fact that 70% of DRI-EAF production is based on natural gas instead of coal. One ton of crude steel produced by the natural gas-based DRI-EAF route results in 1.0 tons of CO_2 in direct emissions. At the current average CO_2 intensity of electricity generation worldwide – 538 grams of CO_2 per kilowatt hour – this pathway results in 0.4 tons of CO_2/t of indirect emissions from electricity generation (IEA 2020). The coal-fired DRI-EAF pathway produces almost three times the direct emissions and a similar amount of indirect emissions as the gas-fired DRI-EAF pathway due to electricity (IEA 2020).

The steel produced by the **scrap-based EAF** has a much lower emission intensity. This process generates only approximately 0.04 tons of CO_2/t of crude steel produced on a direct emissions basis. The scrap-based EAF route generates 0.3 tons of CO_2/t of additional indirect emissions (IEA 2020).

2.2 Emissions in China

The Chinese steel sector accounted for more than 1.5 billion tons of CO_2 emissions in 2017, representing 17% of the domestic total emissions. Steel is the second highest emitting industry after the power sector (RMI 2021).

Figure 2: China's carbon emissions by sectors



Source: Adapted from RMI 2021, p. 8

Little data is available on GHG emissions from iron ore mining activities in China: our interviews with experts revealed that there is little available information on GHG emissions in the mining sector in general, but there is a risk that these emissions will increase as mining industries move to more remote locations.

Steel production in China mainly relies on the BF-BOF route, which is more than twice as carbon intensive as the EAF process. The BF-BOF process accounts for 90% of China's steel production, whereas the secondary steel industry based on EAF accounts for only 10%. In comparison, the world average share of BF-BOF is 73%, well below the Chinese level (RMI 2021).

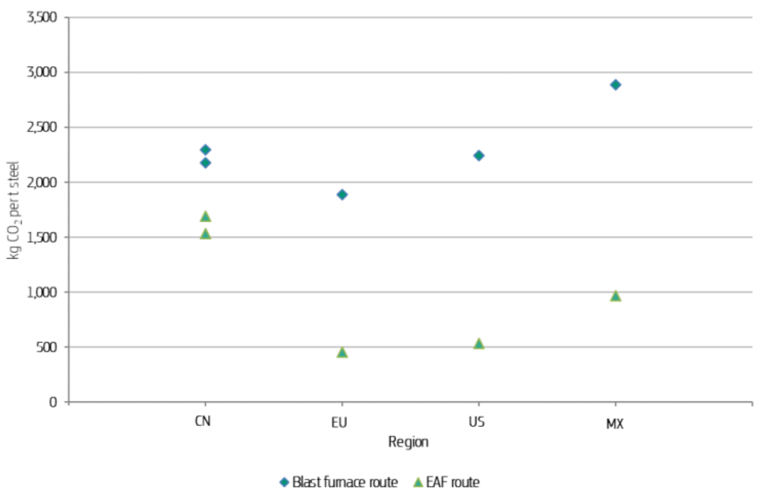
Electric furnaces account for only 10% of the country's crude steel production. The EAF route can only be used when enough scrap metal is available. However, in the early stages of a country's economic development, when its infrastructure, housing stock, automobile fleet and industry are growing rapidly, it is usually necessary to produce most of the steel from iron ore because there is little scrap metal available. Most of the scrap currently used in China is blended into primary production, which is almost entirely processed in the BF-BOF route (IEA 2022).

2.3 Emissions in Europe

The European steel industry is the source of 4% of total EU CO_2 emissions and 22% of industrial CO_2 emissions. About 60% of European steel is produced via the BF-BOF route and 40% via the EAF route (Roland Berger 2020).

CO_2 emissions per ton of steel produced by the BF-BOF route and the EAF route are lower in Europe than in China, the United States and Mexico, as illustrated in the graph below.

Figure 3: CO_2 emissions per ton of steel in China, the EU, the US and Mexico by route process



Source : European Commission 2021b, adapted from Fraunhofer 2017

This can be explained by different factors. The EU uses energy efficient blast furnaces and oxygen furnaces. They emit on average about 2.0 tons of CO_2 per ton of steel produced, taking into account direct emissions (scope 1), indirect emissions such as CO_2 embedded in electricity consumption (scope 2) and raw material supply (scope 3). The emission factor of grid electricity is a determining factor for CO_2 emissions from the secondary pathway (EAF), as a significant portion of the EU’s electricity is already decarbonised (European Commission 2021b).

In Europe, steel circularity is high. On average, the EU recovers 85% of end-of-life steel for recycling. According to the European Commission, this recycling works because of the economic value of steel scrap: the 131 million tons of scrap produced each year in the EU are worth EUR 30 billion. EU member states use 94 million tons of this scrap, which is half of the amount of iron used in the European steel industry (European Commission 2021b).

3. Approaches to the decarbonisation of the steel sector

In both China and the European Union, there is a growing demand to decarbonise the steel sector. According to Chinese and European experts interviewed for this study, the need to switch to low-carbon production routes has become a consensus among steel producers. Several reasons are cited for this development: the growing importance of national and regional carbon reduction targets in China and the EU; the requirements of importing countries to green the steel industry; and the carbon reduction targets of the companies themselves and the need for companies to promote their own brand. Downstream demand for green and low-carbon steel from the construction, automotive and machinery sectors is also cited as an important factor in the development of green steel.

The growing demand for sustainable steel is supported by ambitious approaches from political and industrial stakeholders in China and in the EU.

3.1 Policy approaches

Table 1: Central policy approaches in the EU and China

	China	EU
Key strategy	• 1+N: peak emissions by 2030, achieve carbon neutrality by 2060 (1+N政策体系：2030碳中和，2060碳中和) • Action Plan for Peak Carbon by 2030 (2030年前碳中和行动方案)	• European Green Deal ("Fit for 55" package): setting binding EU-wide climate targets for 2030 (55% reduction of GHG emissions) and 2050 (carbon neutrality)
Import restrictions	• None: zero import duty on steel raw materials	• Carbon Border Adjustment Mechanism
Emissions trading	• Steel sector not participating in the national ETS, but in the provincial pilots	• Steel sector under the EU ETS
Green finance	• Unified system of standards and statistics for green finance and instruments • Examples: 2015 Green Bond Approved Projects Catalogue (绿色债券支持项目目录（2015年版）); 2019 Green Industry Guidance Catalogue (绿色产业指导目录（2019年版）)	• EU taxonomy for sustainable investments
Cooperation with companies	• State-Owned-Enterprises under the authority of the central government	• Programs for Research and Development (see below)
Circular economy	• Sectoral and regional plans • Example: Industrial Resources Comprehensive Utilization and Industrial Synergy and upgrading Plan of Jing-Jin-Ji Area (京津冀及周边地区工业资源综合利用产业协同转型提升计划 (2020-2022年))	• EU Ecolabel • Ecodesign Directive of 2009 • National initiatives
Standards	• Unified standards by the China Securities Regulatory	• Energy Efficiency Directive

	Commission (中国证监会统一标准)	• Renewable Energy Directive • Industry associations • Standards set by industry initiatives such as the World Steel Association
Research and Development	• Cooperation between local governments, SOEs, universities, and public/private research institutes	• Horizon Europe with “European partnership on clean steel” • InvestEU Fund
International cooperation	• Belt and Road Initiative (一路一带倡议): infrastructure projects • Joint ventures between companies	• Global Arrangement on Sustainable Steel and Aluminium • EU Global Gateway

Source: adelphi table based on the policy documents mentioned in this chapter

3.1.1 Policy approaches in China

China’s key political targets to **peak emissions by 2030** and **achieve carbon neutrality by 2060** as part of the “1+N” policy framework (1+N’ 政策体系) have recently been confirmed: speaking at the United Nations General Assembly in September 2020, Chinese President Xi Jinping committed to accelerating China’s decarbonisation trajectory, to reach peak emissions by 2030 and carbon neutrality by 2060. At the **Climate Ambition Summit** in December 2020, Xi Jinping announced an increase in the emissions intensity target for 2030 (reducing CO_2 emissions per unit of GDP by more than 65% from the 2005 level, compared to the previously announced 60-65%). Furthermore, the government has vowed to raise the %age of non-fossil fuels in primary energy consumption to around 25% and to expand its total installed wind and solar power capacity to more than 1,200 gigawatts by 2030 (Ministry of Foreign Affairs of China 2020).

In October 2021, the Chinese government presented its updated **nationally determined contributions** (NDCs) and medium- and long-term low-GHG development strategy to the United Nations Framework Convention on Climate Change (UNFCCC). These presented targets are firmly embedded in China’s national policy framework. In March 2021, the 14th Five-Year Plan (十四五计划）covering the period 2021-2025 was released, in which China set a binding target of 18% reduction in emissions intensity relative to GDP and 13.5% reduction in energy intensity (Carbon Brief 2021).

These Nationally Determined Contributions were then translated into major policy measures that guide China’s transition process: on 26 October 2021, the State Council (China’s top administrative authority) released the “**Action Plan for Peak Carbon by 2030**” (2030年前碳中和行动方案), which outlines key tasks in ten areas and 43 points to achieve peak carbon by 2030 covering steel sector, electricity, industry, building, transportation, circular economy, carbon sinks, etc. The Plan includes a detailed political plan for the decarbonisation of the steel sector, which includes the promotion of the structural optimization of the steel industry and the replacement of clean energy, the promotion of non-blast furnace ironmaking technology, the improvement of the level of recycling of scrap steel resources and the implementation of the all-scrap electric furnace process. The plan also calls for deepening structural reform on the supply side of the steel industry, promoting advanced and applicable technologies, exploiting the potential of energy conservation and carbon reduction, promoting temperature-controlled co-production, exploring pilot experiments such as hydrogen metallurgy and the integration of carbon dioxide capture and utilization, and promoting the development of low-efficiency waste heat heating systems (State Council 2021).

These policy ambitions were confirmed on 15 November 2021, when China’s Ministry of Industry and Information Technology published the 14th five-year industrial green development plan (十四五”工业绿色发展规则). It aims to reduce carbon emissions per output growth of industries by 18% by 2025, compared to 2020 level for steel, non-ferrous metal and other industry sectors (Li et al. 2022).

The **availability of renewable energy** plays a major role in the decarbonisation of the steel industry in China. In 2021, several new policies were introduced that will influence the Chinese energy market. In response to the **energy supply bottlenecks** in 2021, the central government took administrative and fiscal measures, including a reform of coal power pricing to boost coal supply. Apart from the central government’s emission reduction targets, there were several reasons for the crisis: the mismatch between supply and demand for coal; and the increased energy demand of industry due to the COVID-19 pandemic (Der Spiegel 2021). One government measure supported the coal mining and power sectors with a lending programme of CNY 200 billion (USD 31.3 billion) for clean and efficient coal and to promote energy security (Tsang 2022). In addition to this programme, a low-cost loan programme to support low-carbon projects was introduced, including the installation of renewable energy, smart grid and carbon capture technologies security (Tsang 2022).

Moreover, coal power utilities now must sell their power through the wholesale market without a price guarantee. They can also pass-through part of the costs to commercial and industrial users. This new pricing mechanisms could **make coal less competitive against solar and wind power in the long term**. Another aspect that could increase the demand for renewable energies, is the relaxation of the rules on the energy control targets, so that certain renewable energy addition will not be counted in provinces total energy consumption targets. Beijing also stated categorically that renewable energy should be excluded in the system of absolute energy consumption targets (Tsang 2022).

China aims to accelerate the exchange of renewable energy among the Chinese provinces and municipalities. Renewable energy capacity has already expanded in recent years. The China Electricity Council forecasted that China’s total installed renewable capacity will reach 1.3 TW at the end of 2022, or 50% of the national total (Lin 2022). Currently, renewable electricity can be traded via direct deals (Green Electricity Certificates) or in a pilot market. Beijing is planning to establish **nationwide standards through a countrywide power market system** that incorporates provincial, cross-regional, and national trading schemes by 2030. This would accelerate the low-carbon energy exchanges among Chinese provinces and municipalities. Moreover, it can reduce risks for market participants, according to the National Development and Reform Commission, the central planning body (Lin 2022).

In March 2022, the Ministry of Industry and Information Technology, the National Development and Reform Commission and the Ministry of Ecology and Environment issued the “**Guidance on Promoting the High-Quality Development of the Steel Industry**” (关于促进钢铁工业高质量发展的指导意), putting forward clear carbon reduction targets for China’s steel industry. By 2025, the guidance requires that more than 80% of steel production capacity be completed with ultra-low emission transformation, integrated energy consumption per ton of steel be reduced by more than 2%, and water consumption intensity be reduced by more than 10% to ensure that carbon emissions peak by 2030 (National Development and Reform Commission 2022).

The **China Securities Regulatory Commission** has established unified standards for **climate and environmental disclosure by listed companies**; financial authorities have begun working on a unified system of standards and statistics for green finance and instruments, e.g. the 2015 Green Bond Approved Projects Catalogue or the 2019 Green Industry Guidance Catalogue. The green finance standards have set the basis for climate and environmental disclosure. Chinese companies have had to get accustomed to disclosing information and involving the public through the Information Disclosure Law, which came into effect in 2003, the Environmental Impact Assessment Law of the Environmental Protection Agency (EIAL 2002) and the Interim Measures on Public Participation in the EIA Process, which was added later (2006) (PowerShift 2021).

The above approaches to policy often have a direct impact on the Chinese steel sector. This is due to the structure of Chinese **State-Owned-Enterprises (SOEs)**. Given their political clout and industrial expertise, SOEs are closely involved in the policy-making process. So-called central SOEs (央企) are directly under the authority of the central government and have a high rank in the administrative order (行政级别). The CEOs of influential SOEs often have full ministerial rank, which means they have more authority than regional officials. Experts interviewed for this study argued that the close relationships between political and economic stakeholders in China can facilitate the decarbonisation of the steel sector and the development of low carbon technologies. In 2020, the top ten steelmakers in China accounted for 63% of Chinese steel production. Nevertheless, the future production will be concentrated in the largest enterprises and acquisitions of SOEs will be increase (Chen et al. 2021). Chinese SOEs adhere more to national policies and play a leading role for the whole steel industry. For instance, when president Xi Jinping announced China's carbon-neutrality target, SOEs such as Baowu, HBIS and Ansteel Group announced their own corresponding peak-carbon plans (Chen et al. 2021). The SOEs also cooperate closely with local governments, universities, and public and private research institutes at the subnational level in order to boost research and development on industry technologies, for instance in the field of green hydrogen (Brown and Grünberg 2022).

When it comes to long-term planning, China is also pursuing policies related to the **circular economy**. Indeed, the Chinese recycling system is continuously improving its efficiency and tends to strengthen the standard-setting at a national scale (Chen et al. 2021). Chinese state policies support trend. For instance, the "Industrial Resources Comprehensive Utilization and Industrial Synergy and upgrading Plan of Jing-Jin-Ji Area (2020-2022)" (京津冀及周边地区工业资源综合利用产业协同转型提升计划 (2020-2022年)) has been set up in order to create cross-sectoral recycling chains for raw materials and used steel scrap (Chen et al. 2021). This enhanced recycling process is closely linked to the increased lifespan of steel products and infrastructure as well as the increased recovery rate of steel scrap: the demand for primary steel is declining as secondary steel increases due to reduced CO_2 emissions (Chen et al. 2021). The concept of the circular economy and of the use of recycled steel is gaining in mainstream popularity and is backed through diverse policies and enhanced standards (Chen et al. 2021).

Although the steel sector is not included in the **Chinese national emissions trading system (ETS)**, steel companies already actively participate in the eight pilot provincial emissions trading systems and are expected to join the national carbon market in near future (Li et al. 2022). In this way, their emissions can be regulated on a national level. Interviewed experts highlighted that steel industries might be covered under the national ETS in the future and that the connection to the regional ETS might strengthen carbon pricing in China.

Increasing **international cooperation** is an additional part of China's framework for the low-carbon transition of the steel sector. While China's steel industry remains concentrated domestically, partner countries in the Belt and Road Initiative have been operating as buyers for large-scale infrastructure projects. This trend is expected to increase in the coming years, boosting steel demand and direct exports from China. Many steelmakers may also expand their operations internationally and engage in further steel cooperation projects, improving steel export routes and promoting more environmentally friendly steel production methods in China (Chen et al. 2021).

In summary, the Chinese policy-maker level plays a leading role in the adaptation of the demand side to the decarbonisation of the Chinese steel production. Setting the political framework through collective emission targets, promoting recycling processes and participation in international partnerships creates a certain level of predictability for the steel industry and can enhance cross-sectoral synergy effects along the supply chain.

3.1.2 Policy approaches in the EU

Unlike China, the European Union (EU) steel industry is privatised. However, it is influenced and driven by different policy frameworks and demand expectations. The decarbonisation of the European steel industry is accompanied by a variety of policy actions and carbon policies. This is particularly important for European stakeholders in order to meet the objectives of the Paris Agreement and the EU's own climate targets (VUB 2018).

In the European Union, the "**Fit for 55**" **package** was proposed by the European Commission in July 2021, setting new, binding EU-wide climate targets for 2030 (55% reduction in GHG emissions compared to 1990 levels) and 2050 (net zero emissions). To meet these ambitious targets, emission levels in Europe will need to drop significantly in the coming decades. The EU is currently working to strengthen and expand its climate, energy and transport legislation (European Council 2022).

The centrepieces of the "Fit for 55" package are the introduction of the **EU Emissions Trading System (EU ETS)** and the **Carbon Border Adjustment Mechanism (CBAM).** These two legislative files aim at the decarbonisation of the European industry, including the steel industry. They are currently under discussion among the EU co-legislators at both the European Parliament and the Council.

First of all, the European steel industry is covered by the **EU ETS**. It is regarded as an important instrument for reducing GHG emissions from the energy and manufacturing industries, including the iron and steel sector. It is built on the principle of "cap and trade," which sets a cap on the total amount of GHG emissions that installations covered by the EU ETS can emit and allows installations to buy or receive emission allowances that can be traded. Facilities must surrender enough allowances to cover their emissions. If, on the other hand, a facility reduces its emissions, it can use its surplus allowances to meet its future needs or swap them with another facility that does not have enough allowances. Under the "Fit for 55" package, GHG emissions from sectors covered by the EU ETS are to be reduced by 61% by 2030 compared to 2005 levels. This is to be achieved by a reduction of allowances in the overall emissions cap. The reduction of allowances in the steel industry will serve as an incentive to accelerate the transition to green steel. Since the beginning of the EU ETS in 2005, the steel sector has been involved in the European carbon market following a cap-and-trade principle – but the EU ETS has allowed for free allocations. As part of the "Fit for 55" package, these free allocations will gradually phase out. In this sense, the carbon market partially drives the decarbonisation process, with the quantity of allowances drastically decreasing in the coming years (Li et al. 2022). In this way, the European demand side constructs a predictable regulatory framework that minimizes adverse effects of the global competition (Eurofer 2019a). Indeed, as expert interviews for this study revealed, the steel sector is currently in a highly competitive environment: there has been overproduction of steel for a long time and plants tend to be closed at the moment, so investing in decarbonisation is very risky for investors.

The **Carbon Border Adjustment Mechanism** was initiated as part of the "Fit for 55" package to reduce the risk of carbon leakage as the EU increases its climate change ambitions. Carbon leakage refers to the situation where, due to strict climate policies, companies move their production abroad to countries with less stringent climate measures. The CBAM will initially apply to imports of goods that are considered to have a high risk of carbon leakage and high carbon emissions: iron and steel, aluminium, fertilisers, electricity and cement. The CBAM seeks to incentivize producers in non-EU countries to green their production and bring it in line with EU targets. Under the proposed system, EU importers will have to buy allowances equivalent to the carbon price that would have been paid if the goods had been produced under EU carbon pricing rules. The allowance price will be determined by the auction price of EU emissions trading allowances. The EU thereby aims to ensure that importers pay the same carbon price as domestic producers, thus preserving the competitiveness of their industry, including of the iron and steel sector. According to the European Commission, CBAM aims to address the problem of reducing GHG emissions in the Union, while at the same avoiding that these emissions reduction efforts are offset globally by emissions increase outside the Union. It could result in a global rise of green steel demand (European Commission 2021c). Under current policies, anti-dumping duties and tariffs are being imposed against the import of multiple Chinese steel products (EURACTIV and Reuters 2020): they focus in particular on state-sponsored subsidies for the Chinese steel industry as well as on anti-dumping measures. CBAM policies could complement or partly replace the tariffs that are currently applied against Chinese steel imports.

Other policies included in the “Fit for 55” package will also lead to increased demand for green steel and boost the **further development of common standards**. The proposal for a new directive on energy efficiency (**Energy Efficiency Directive**) will require EU countries to collectively ensure an additional reduction of energy consumption of 9% by 2030 compared to the 2020 reference scenario projections (European Commission 2022b).

The “Fit for 55” package also includes a proposal for a revised **Renewable Energy Directive**, with a new target for 2030 – 40% of renewable energy in final energy consumption as compared to the current target of 32% (European Commission 2022d).

The introduction of new technologies is additionally enhanced by the **support for research, innovation, and transformation for greener steel supply chains**. The investment in research and development can contribute to the establishment of industry roadmaps and possible industry standards that facilitate investment decisions (dena 2022). Since such investment programs can have direct effects on the transformation of the labour market and regional structural change (dena 2022), the EU has diversified its financial support options in this domain (Eurofer 2019a). The Horizon Europe programme has established a “European partnership on clean steel”, following the support of Horizon 2020 and of the Research Fund for Coal and Steel. About EUR 700 million are available for innovation activities for breakthrough technologies for carbon-neutral steel production (European Commission 2021b). The InvestEU Fund allows investments in energy-intensive industries (European Commission 2021b). Finally, the Innovation Fund of the EU ETS provides additional resources for the funding of research and innovation in the steel sector. For example, the fund is supporting a pilot project for a complete value chain for hydrogen-based iron- and steelmaking, from mine to fossil-free steel (SSAB 2022). In this way, European policy makers support the low-carbon transition through several low-interest investment tools that can be used by steel producers themselves, but also by other private and public actors such as research institutes.

Moreover, the lack of transparency regulations is to be mitigated by the **promotion of a demand for climate-friendly products**, such as transparent carbon footprints across the entire supply chain. European action in the field is also complemented through state initiatives, such as the Netherlands’ goal to establish a comprehensive circular economy by 2050 and reduce the consumption of metallic, mineral and fossil raw materials by 50% by 2030 (Reckordt 2022a). France, Finland and the Netherlands are also planning to expand building standards to embodied emissions. The European Commission could also make a corresponding suggestion (Chen et al. 2021). The setting of standards is also supported by industry associations that facilitate dialogue and support the creation of mechanisms, such as ResponsibleSteel or SteelZero (Li et al. 2022). The current proposal for the European directive on corporate sustainability due diligence also foresees the inclusion of climate obligations (European Coalition for Corporate Justice 2022).

Several labels like the **EU Ecolabel** or the **Ecodesign Directive** of 2009 provide a basis for further sustainability standards related to the entire life cycle of a product (dena 2022). They also go into the direction of a circular economy that might be enhanced through an expansion of the Ecodesign Directive, for example through a quantification of environmental impacts of a product or digital product passports (dena 2022). There has been criticism that the extension of a circular economy in Europe is hampered by a lack of harmonized rules and standards in the European internal market (dena 2022). The efforts to set standards might also be enhanced through an expansion of digitalization, for instance with standardised data exchanges covering the market communication between the supplier, the provider, and the consumer (dena 2022). This development is driven by several programs, for example the Carbon Transparency Partnership led by the World Business Council for Sustainable Development (WBSCD 2021).

On an **international level**, the EU has also been promoting the production of green steel via multiple mechanisms. For instance, the EU has made progress in negotiations with the USA regarding the trade of steel and aluminium. The *Global Arrangement on Sustainable Steel and Aluminium* focuses on common standards for the production methods and their decarbonisation, mainly related to green steel and aluminium. This agreement is also open to other countries than the US and the EU that aim to engage in common standards for the trade of low-carbon metals (European Commission 2021d).

To respond to the steel industry's demand for green energy, the EU has expanded its **international promotion of climate-neutral hydrogen** in the framework of energy partnerships and the EU Global Gateway strategy (see supply side). According to its hydrogen strategy, the EU intends to strengthen its partnership with neighbouring countries to the east and south. The European Clean Hydrogen Alliance of 2020 put forward cooperation programs with the Western Balkans, Ukraine, and the African Union (dena 2021). Imports are also possible from regions such as Australia and Chile (dena 2021). These transformation partnerships require joint infrastructure projects and common economic agreements in order to set shared international standards and increase the economic connectivity (dena 2022). The EU hopes that these production countries will benefit from more favourable production conditions and lower costs due to the higher availability of green energy.

The financial sector can also contribute to increasing the demand for green steel. Sustainable finance describes the process of taking environmental, social and governance (ESG) considerations into account when making investment decisions in the financial sector, leading to longer-term investments in sustainable economic activities and projects.

On 22 June 2020 the European Union adopted a legislative proposal on sustainable finance, including the regulation on the establishment of a framework to facilitate sustainable investment (**EU taxonomy**). The main objective is to define the concept of "sustainable investments" with a view to directing capital flows towards them. The taxonomy includes manufacturing of iron and steel, when GHG emissions (calculated according to the methodology used for EU-ETS benchmarks) associated with the production processes are lower than the values of the related EU-ETS benchmarks. Any new steel production, or combination of new and recycled steel production, is considered eligible if emissions are below the above thresholds. In addition, any steel production in an electric arc furnace where at least 90% of the iron in the final products comes from scrap is considered eligible. In this case, no other thresholds are applicable (European Commission 2021a).

In summary, the EU's demand side approaches cover carbon policies such as the EU ETS, financial support for research and development, common standards and international cooperation. These approaches go hand in hand with close communication with the steel sector. The objective of a complete decarbonisation of the European steel production involves several stakeholders within and beyond the EU that might find synergies for the enhancement of new technologies.

3.2 Industry approaches

The industrial sectors in China and the EU have undertaken several measures to strengthen the decarbonisation of the steel sector and related supply chains. Despite ambitious carbon reduction targets for the steel sector, clean technologies are still at an early stage (Kong et al. 2021). Most steel sector make use of the BF-BOF method which is known to be rather carbon-intensive, emitting about 2t CO_2 per metric ton of steel (Kong et al. 2021). However, steps such as EAF steel production using scrap steel or the hydrogen-based DRI method represent initial efforts to reduce GHG emissions.

3.2.1 Industry approaches in China

The **current state of the Chinese steel industry** requires a closer look at the average age of China's blast furnace fleet, which is about 13 years – i.e. less than one-third of the typical lifetime of these plants. Due to this relatively young age, China's costs for the high-carbon asset of the steel sector might be higher, since a fast transition in production methods may make the original production routes superfluous and uneconomical (Chen et al. 2021). China's blast furnace capacities are concentrated in the central and eastern areas of the country, particularly in Hebei, Jiangsu and Shanxi, which account for 40% of the national blast furnace capacities (Chen et al. 2021). EAF capacities are mainly located in southwest China, including the provinces of Sichuan, Yunnan and Guangdong (Chen et al. 2021).

The **announcement of China's dual-carbon goals in September 2020** has created ambitious impulse in the Chinese steel industry (Lin et al. 2021). The Chinese steel industry has responded positively and taken some key steps towards decarbonisation: central enterprises such as the Baowu Group, the HBIS Group, and the China Metallurgical Industry Planning and Research Institute aim to achieve their carbon neutrality by 2050, supported by specific action plans related to peak emissions their specific sector (Chen et al. 2021). For instance, the Baowu Group has announced its aim to peak emissions in 2023 and to reduce emissions by 30% by 2035 (Lin et al. 2021). The HBIS group even plans to peak emissions in 2022, following its "Low Carbon & Green Development Action Plan" of March 2021 (Lin et al. 2021).

The decarbonisation is mainly expected to be achieved through the **introduction of new technologies**, which can be distinguished between CO_2 management technology and CO_2 direct avoidance (Lin et al. 2021). With regard to **CO_2 management**, technologies like carbon capture, utilisation and storage (CCUS) have started to be implemented in China, with an expansion planned from the late 2020s. So far, CCUS technology has been used for small-scale demonstration (see good practices box), but cost-reduction might bring CCUS to a larger scale (Lin et al. 2021).

Hydrogen-based steelmaking is considered a key solution for **direct carbon avoidance** (Chen et al. 2021). Baowu, Jiuquan Iron and Steel, Jianlong Steel and other companies have launched cooperation programs with domestic and international partners in the field of hydrogen steelmaking that might become part of the primary route (Chen et al. 2021). The Baowu Group is also pursuing a pilot project for the introduction of hydrogen in blast furnaces that might reduce 30% of carbon emissions, even if China mainly uses grey hydrogen produced from coal (Lin et al. 2021). The transition towards renewable energies may result in a higher production share of green hydrogen that might reach a better decarbonisation rate.

Moreover, **energy efficiency and energy saving improvements** have been added to the agenda of Chinese steelmakers. Pursuing their goal of decarbonisation, Chinese steel industries have mainly focused on energy conservation and emission reduction (Lin et al. 2021). Since 2000, China’s comprehensive energy consumption per ton of steel has decreased by about 40% (Chen et al. 2021). Improved energy technology and energy management resulted in a decrease of energy intensity especially between 2010 and 2019, partly due to policies related to production control. Key methods for China’s energy efficiency improvements include the utilization of more efficient processing equipment, the increased recovery of by-products and waste, and the adoption of more efficient methods for casting and rolling (Lin et al. 2021). As a result, innovations in products and production processes have been implemented from the Chinese supply-side, even if further technological innovations for reaching the global advanced technological level are needed (Lin et al. 2021). The breakthrough and technology maturity of certain technologies such as coke dry quenching (CDQ) play a central role in the enhancement of energy efficiency (Lin et al. 2021).

Furthermore, Chinese steelmakers have **considered the use of scrap resources** and the possibility to focus on EAF steelmaking due to its large emission reduction potential (Lin et al. 2021). Overall, the total consumption of scrap resources by Chinese steelmakers increased from 90 million tons in 2016 to 230 million tons in 2016. This represents an average annual growth of 9.8%. Despite this increase, Chinese consumption of scrap steel remains rather low by international comparison (Chen et al. 2021). Chinese companies have increasingly upgraded their imports of scrap steel, thereby extending the steel supply chain: the import volume of recycled steel raw materials will reach about 10 million tons in 2025 and 20 million tons in 2030 (Chen et al. 2021). Nevertheless, the main supply of scrap steel stems from home scrap (generated in the steelmaking process) and societal scrap (generated in downstream products) which has risen sharply between 2016 and 2020 (Lin et al. 2021). Both domestically and globally, early used steel products gradually reach their end-of-life state, thereby releasing more and more available scrap resources to the market. The lower carbon intensity of the EAF method can make a major contribution to the decarbonisation of the steel supply chain in general (Chen et al. 2021). Steelmaking from scrap steel can lower the total emissions of the supply chains as the amount of extracted raw materials can largely be reduced.

In general, EAF steelmaking starts to rise in mid- and later-stages of the peak range of crude steel production: about 10 to 15 years are needed to increase the proportion from 10 to 20% of the total production rate (Chen et al. 2021). The boom in China’s scrap steel demand is likely to continue to support this transition, thereby expanding the Chinese import markets in different countries.

It is estimated that the production share of the EAF method will increase from 10% to about 60% by 2050 (Chen et al. 2021). As of yet, the potential of **material efficiency along the supply chain** has not been fully exploited (Lin et al. 2021) – as noted by the experts interviewed for this study. Indeed, material efficiency strategies can help reduce growth in global demand for steel while delivering the same material services (IEA 2020). After 2040, China may become a major green steel exporter and expand its role on a national and international level, as the demand for green steel on international markets will increase as well (Chen et al. 2021). Nevertheless, China’s dominance in global production declines from just over 50% today to 35% in 2050 according to the International Energy Agency’s policy scenario (IEA 2020), as India’s production more than triples to cater for booming domestic demand. Currently, China’s reliance on the energy-intensive BF-BOF steelmaking route slows down the decarbonisation process (Lin et al. 2021). According to our expert interviews, the decarbonisation technologies do not yet cover the broad production capacities of the Chinese steel industry due to their low maturity.

3.2.2 Industry approaches in the EU

The European Union is attempting to position itself as a leader in green steel production alternatives, with a number of innovative company initiatives as an alternative to traditional high-emission production routes. Hybrit, a Swedish steel producer, for example, plans to deliver the world's first "green steel" produced without using coal in 2026 (The Guardian 2021). However, decarbonisation technologies still need improvement before they can be adopted on a large scale (Fennell et al. 2022).

EU industry has recognized the importance of actively contributing to the **decarbonisation of steel supply chains**. Emissions from the EU steel industry have already declined by 26% since 1990, driven mainly by energy efficiency improvements and higher recycling rates (VUB 2018). A "business as usual" scenario without technological development is estimated to lead to a reduction of 10% of GHG between 1990 and 2050 (Eurofer 2019a). The development of a "current projects" pathway integrating a variety of production technologies will lead to a possible reduction of 74% in CO_2 emissions by 2050. However, this requires a "closed loop" with complete carbon capture, otherwise the emission reductions will be lower. To further reduce the remaining emissions in the core stream and downstream, CO_2-free energy is required (Eurofer 2019a). With green electricity and green gas applications in combination with "alternative pathways", reductions of up to 95% are possible.

Several technologies have been identified and assessed that might bring immediate gains: **improved insulation, better boilers and heat exchangers**, for example, are simple solutions for EU steel production (Fennell et al. 2022). Although numerous technologies have been identified for the EU steel industry, their availability and potential are very different (Roland Berger 2020): the main options include the use of hydrogen, carbon capture, use and storage as well as alternative methods for reducing iron ore.

Hydrogen-based, direct reduction processes and electrochemical reduction methods may replace coke or natural gas as an alternative reductant of iron ore (Roland Berger 2020). The **hydrogen-based shaft furnace direct reduction method**, for instance, has a lot of potential for the European steel industry and a relatively advanced state of readiness. However, the current dependence on iron ore pellets and high operating costs due to the importation of hydrogen need to be taken into account for the development of this method. (European Parliament 2021b). One leading project is HYBRIT – short for Hydrogen Breakthrough Ironmaking Technology – a joint venture between SSAB, LKAB and Vattenfall that aims to replace coal with hydrogen in the steelmaking process (HYBRIT 2022). Another method of steel production based on hydrogen is the **hydrogen-based direct reduced iron – fluidized bed:** in this case, the reduction occurs in a fluidized bed rather than a furnace (Roland Berger 2020). The production with green hydrogen for DRI could lead to an emissions reduction of 97% but is so far 2.5 times as using "grey" hydrogen (Fennell et al. 2022).

Carbon capture, use and storage (CCUS) has the potential to be easily installed, and infrastructures can also be shared with other industries (Roland Berger 2020). Nevertheless, carbon storage is still considered to be quite expensive and energy-intensive (Fennell et al. 2022). Indeed, the technology is not yet sufficiently in use but needs a 99.9% pure CO_2 stream to reduce costs for compressing and storing the gas, which requires further technologies to better isolate CO_2 (Fennell et al. 2022). Moreover, CCUS needs other technologies in combination, for instance the use of biomass instead of fossil fuels, or improved insulation in storing locations. The Swerea Mefos facilities in Luleå, Sweden, is operating a pilot unit for CCUS (European Parliament 2021b). German steelmaker Thyssenkrupp also launched the Carbon2Chem project in 2018, a CCU project which focusses on the reusing of CO_2 and other gases for the production of chemicals such as ammonia and methanol (European Parliament 2021b).

Biomass technologies might help to replace coal and coke with charcoal or other forms of biomass. Biomass can partially replace fossil fuels, natural gas or substitutes coke (Roland

Berger 2020). Their strength lies in their large availability and efficiency. However, the use of biomass could lead to conflicts with land needs for agriculture, constituting a high social risk (Fennell et al. 2022).

Furthermore, research on **plasma direct steel production** and **electrolytic processes** has been ongoing: their energy-efficiency is an advantage, but technologies are still at a very low stage so commercial feasibility is not yet guaranteed (Roland Berger 2020). Therefore, hydrogen-based direct reduced iron technologies have been identified as the most promising for the decarbonisation by European steelmakers (Roland Berger 2020).

The **use of fewer raw materials or the recycling of steel scrap** are two other solutions that are gaining traction in the EU steelmaking process (Fennell et al. 2022). Currently, the secondary route makes up 40% of the European steel production, where scrap metal is being heated in an electric arc furnace (EAF) with graphite electrodes to create steel (Roland Berger 2020). The growing integration of scrap metal is a central part of reduction strategies for CO_2 emissions (Eurofer 2019a). In addition, obsolete scrap from end-of-life products or applications might also be included, depending on available recycling technologies. Overall, the use of scrap-electric arc furnaces (EAF) and other “alternative pathways” may contribute to a total reduction of up to 80% of CO_2 emissions in the steel sector.

Nevertheless, when it comes to green hydrogen, rising gas prices could make sustainable hydrogen competitive sooner than expected. Analysts from Bloomberg New Energy Finance calculated that green hydrogen is already cheaper than “grey” hydrogen from natural gas in parts of Europe, the Middle East and Africa (Witsch 2022).

Examples of good practice

Companies in the EU and China have actively engaged in the development of technological approaches to meet the decarbonisation challenges of the steel supply chains. A number of good practices are advancing the decarbonisation of the steel production process and impact the carbon footprint of further downstream products.

In China, the utilisation of steel off-gases is at the core of a current key project concerning emissions reductions in the steel sector (IEA 2021a). A **joint venture between the Chinese iron and steel producer Shougang Group, US-headed carbon recycler LanzaTech and the New-Zealand investor TangMing**, focuses on the conversion of off-gases from the blast furnace steel production to biofuels. The first commercial plant at the Jingtang Steel Mill in Caofeidian in Hebei Province began its operation in 2018 in China, with a production of 60 000 tons of ethanol for sale between 2018 and 2021. Waste gases from oil refining and the manufacturing of steel are fermented into ethanol and chemically converted to ethylene glycol. The ethanol from recycled steel mill emissions is then directly sold to the road transport market in a low-carbon fuel blend or used for the fabrication of PET products such as bottles or t-shirts. About 100 000 tons of CO_2 could be avoided through this technology (Bioenergy International 2021). Valuable elements of the blast furnace gas are used for energy applications in other sectors, constituting new opportunities for supply chains linked to steel production (IEA 2021a).

Moreover, the **use of hydrogen** is a central strategy for Chinese steelmakers to boost decarbonisation. The country's second-largest steel company **HBIS Group** has been planning and started constructing a hydrogen-based steelmaking plant in Hebei, together with Tenova, an Italian company. The aim is to launch the production of 1.2 million tons of steel in the coming years, thereby renewing traditional metallurgical technologies. The integration of green energy from solar and wind power will be central to producing green hydrogen. Finally, the production process is to produce only 250 kg of CO_2 emissions per ton of steel (Zhong 2020).

On the EU side, the use of hydrogen for steel production is among the key technologies that are currently tested in the steel sector. German steel producer **thyssenkrupp** has been operating several test phases, injecting hydrogen in a blast furnace since 2019, replacing a proportion of injected coal (thyssenkrupp 2019). The Duisburg steelmaker launched a series of tests on the use of hydrogen in ongoing blast furnace operations, making use of electrolytic H2 blending in the blast furnace. The technology aims to sustainably reduce CO_2 emissions from steel production: by 2030, emissions from production and processes (scope 1 emissions) within the company and emissions from energy purchases (scope 2) are to be reduced by 30 %. While CO_2 emissions are produced when using injection coal, water vapor is produced when hydrogen is used. This means that CO_2 emissions can be reduced by up to 20 % at this stage of the production process. The project is funded as part of the *IN4climate.NRW* initiative launched by the state government with scientific support from the VdEH's Operations Research Institute (BFI).

Finally, the **use and integration of recycled steel** constitutes a major strategy of the European steel sector to downsize CO_2 emissions in the steel supply chain. The **Slovenian steel group SIJ** is a good example with its production sites in Jesenice and Ravne na Koroškem. The company has a particularly low carbon footprint due to the use of steel scrap exclusively and its efforts for energy efficiency which are aligned with the EU Taxonomy. The European Bank for Reconstruction and Development supports the SIJ group with EUR 25 million as part of a EUR 230 million debt facility in order to enhance the company's further decarbonisation for its specialised production of knives, bars and rolls (European Bank for Reconstruction and Development 2022).

4. Major challenges for the decarbonisation of the steel sector in the EU and China

4.1 Major challenges in the EU

To reduce emissions from the steel sector, the simplest option is to improve production efficiency. However, EU steel producers are already among the most efficient in the world and have improved efficiency to the highest possible degree. This leaves little room for further efficiency improvements that could lead to a reduction in CO_2 intensity. Therefore, achieving significant emission reductions in line with the EU's reduction targets will require large-scale industry transformation. However, the maturity and scale of new production methods are currently in the pilot phase and are only expected to be available on an industrial scale by 2040/2050. The European steel sector is targeting three major low-carbon steel production pathways, namely electrification, the use of hydrogen, and CCUS. However, most of these technologies are still at a moderate level of maturity, representing a key challenge for the decarbonisation of the steel sector.

Table 1: Technology Readiness Levels (TRL)* of major low-carbon steelmaking technologies

Pathway	Technology	TRL	EU R&D projects
Electrification	Increased recycling routes (EAFs)	mature	
	Iron ore electrolysis (+EAF)	4	Siderwin
Hydrogen	H-DRI: Hydrogen direct reduction (+EAF)	5	Hybrit, Salcos, tkH2steel
	Smelting reduction using hydrogen plasma	4	
CCUS	Integrated smelting process combindes with carbon capture and storage	6-7	Hisarna
	Capture and recylce waste gases from the BF-BOF route into synthetic fuels	8	Steelanol, Igar
	Capture and recycle waste gases from the BF-BOF route into chemicals	7	Carbo2Chem, Carbalyst
*TRL is a method to measure the maturity of a technology on a scale from TRL 1 (basic principles developed) to TLR 9 (system test, launch and operation)			

Source: (Adapted from European Commission 2021b; JRC 2022)

An alternative method currently under development is called **iron ore electrolysis**. This electrochemical process uses electricity to split iron ore, which is suspended in an electrolyte, into iron and oxygen. There are two promising technologies, alkaline iron electrolysis and molten oxide electrolysis. Since the electrolysis produces no direct CO_2 emissions, the process could be close to carbon-neutral if the electricity used is CO_2-free.

Among European steelmakers, the **increasing trend towards steelmaking based on the direct reduction of iron using hydrogen** (H-DRI) has led to the announcement of around 20 projects across Europe. The complete avoidance of fossil fuels and the possible market readiness by 2030 are among its major advantages, yet large quantities of low-CO_2 hydrogen and electricity are required for the process. European production capacities are probably not sufficient for this, which is why imports of green hydrogen from neighbouring regions will become necessary.

Finally, **carbon capture technologies** figure among the explored solutions for reducing CO_2 emissions in steelmaking, however the challenge is to employ extensive process modifications to achieve deep emission cuts. The decarbonisation process is partly held back by the lack of market readiness of technologies as well as the complex transformations of the production process.

Beyond technological obstacles, **financial aspects may slow down the decarbonisation process**: extensive investments in research and innovation are needed for the further development of low-carbon technologies. Moreover, with the current market situation, low-CO_2 production routes will increase production costs due to the high prices for hydrogen, green electricity and steel scrap (European Commission 2021b). For instance, according to the European Steel Association, the production of green steel through the primary route might cost EUR 110 to 320 more per ton compared to conventional steel, especially due to high electricity and hydrogen demands (European Commission 2021b). The European Commission analyses make clear that the development of green steel in Europe relies on necessary investments, long-term market confidence and a robust policy framework that focuses on effective carbon leakage measures and the protection against unfair trade practices (European Commission 2021b).

On a geopolitical and geo-economical level, **carbon leakage** represents a major challenge for the common decarbonisation between the EU and China. The protection from carbon leakage is among the EU's priorities to prevent unfair trade conditions between import and export countries and in order to enhance decarbonisation processes outside the EU as well (dena 2022). Indeed, the shifting of production volumes from the EU to countries with lower carbon standards might be seen as unfair since domestic steelmakers would face stricter carbon policies than non-European producers. The European Commission plans to replace free allocation by 2035 with a CO_2 border adjustment mechanism (CBAM), through which imports will be charged the same CO_2 price as intra-European production. As an alternative to unilateral CBAM, there is also talk of carbon clubs: these are alliances of different states or economic regions that agree on common or harmonised framework conditions for emissions recording and pricing (dena 2022). Both suggestions might be controversial for the EU-China steel relations: Chinese stakeholders may stick to joining the EU-promoted carbon clubs, on the other hand the CBAM policies might be perceived as an imposition of harming trade restrictions. Mutual understanding for carbon standards is therefore an important challenge in the EU-China trade relations in order to maintain the economic trust relationship in the steel sector, as expert interviews have shown.

4.2 Major challenges in China

As in Europe, the **low level of maturity of decarbonisation technologies** in the steel sector is a major obstacle in China according to the expert interviews. Many technologies are now in the development and testing stage and there is no reliable experience to draw on. The dependence on the traditional production pathway is still very high. Steel production based on blast furnaces, scrap and hydrogen is still in its infancy in China.

Experts also point out to the lack of reliable scrap. Indeed, a major obstacle for the decarbonisation is the **relatively low age of existing production capacity** which averages around 15 years compared to around 35 years in the United States and around 40 years in Europe. The average lifetime of emissions-intensive assets in the Chinese steel industry is around 25 years, which is 15 years less than the global average of 40 years. Therefore, the process change costs will be very high (IEA 2022). Other obstacles cited in the expert interviews are the limited domestic scrap supply, due to the immaturity of recycling systems. A third reason is the fact that breakthrough steelmaking technologies, such as hydrogen metallurgy, are still not mature. Internal data mention that Baowu, China's major steel producer, would need 23 years to reach carbon peaking.

Another challenge mentioned in the interviews is the **political sensitivity of steel**. Steel is a symbol of industrial capacity as well as national capacity, highly intertwined with military applications. This makes the issue of steel decarbonisation more sensitive than energy and electricity, for example. Steel production has been historically a key objective of the government's policy documents, so debates about steel decarbonisation may face some resistance.

Some interviewed experts also mention an **insufficient policy support** as an important obstacle in China. The policy system needs to focus more on issues such as: strengthening top-level design, improving the policy environment, stimulating innovation momentum, building cooperation mechanisms, and reducing systemic risks.

Finally, **economic barriers** are also highlighted in the interviews. The main economic barriers to the low carbon development of the steel industry are the low level of industry concentration in China's steel industry and the lack of incentive for the industry to invest in the technology and equipment needed for low carbon development. At the same time, the industry is facing high-cost pressures. Decarbonisation in the Chinese steel industry faces challenges such as the short average life of units and the large volume of investment in transformation. The technology route in China's steel industry is dominated by long processes. Low carbon technologies such as short process steelmaking and hydrogen energy (green hydrogen) reduction technologies have high-cost levels and require additional investment, slowing down the industry's low carbon transition.

4.3 Major challenges for the EU-China cooperation

Current political developments revolve less around increased transnational cooperation and more around growing conflicts: there is **great dissonance** between the EU and China on the subject of green steel. Against the backdrop of the high U.S. tariffs on Chinese steel in the past few years and the massive capacity ramp-up inside China after the 2009 fiscal stimulus – which have led to increased imports of cheaper Chinese steel into the European market – EU policy makers have already imposed several tariffs and duties on Chinese steel imports. European steelmakers recently called for a "Green Deal for Steel" and a carbon border levy to level the playing field on how CO_2 emissions mitigation affects competitiveness on the EU market – and by doing that also help to protect the domestic market from Chinese imports and support the sector's recovery after the COVID-19 crisis (Eurofer 2020b).

European steel makers call for **unified carbon cost constraints for EU- and non-EU producers to enable fair competition** (Simon 2020). The idea of introducing a CBAM alongside the EU ETS – the bloc's flagship climate policy – to prevent carbon leakage, protect industry competitiveness, and safeguard the EU's new climate targets (Kardish et al. 2021a) for carbon-intensive products entering the EU is put forward in the context of the European Green Deal – not trade protection. Facing the ever-growing high level of carbon price under the EU Emission Trading System, the EU proposed implementing CBAM, alongside the EU

ETS in order to prevent carbon leakage, safeguard industry competitiveness, and achieve the EU's new climate targets. Given the current trade relations between the EU and China on the proposed covered sectors under the EU CBAM[3], China is expected to be among the most exposed countries of the EU CBAM in absolute terms – although the initial coverage is only a fraction of China's exports to EU (Kardish et al. 2021b).

The perception among the majority of Chinese stakeholders is that the **impact of CBAM would be quite significant**. Especially at the early phase of the upstream value chain, where margins are not particularly high such as steel, Chinese manufactured products could lose their comparative price advantage (and with it, their appeal), making it more attractive for the European industry to source from other, "greener" partners. This is partly because sustainability standards are not accepted mutually between European and Chinese stakeholders. Another worry of the Chinese regarding the EU CBAM comes from its potential to expand further down the value chain, as proposed by some European stakeholders – such potential scope expansion overtime is also mentioned in the CBAM legislative proposal July 2021, although whether it will happen and how are still far from being clear.

In addition, a potential dispute point is the idea of the "**climate club**" put up by German chancellor Olaf Scholz during his G7 presidency. Even if the finally adopted concept steps away from aligning carbon pricing regimes as a condition for membership, it still mentions carbon leakage as a main threat to international trade relations (G7 Germany 2022). Depending on the exact design of the Club (which will be clarified over the course of 2022) and how Germany would actually pursue it (including how to align with its broader climate diplomacy work), there is still a risk that China may feel potentially isolated from or targeted by such a "climate club" – which adds another obstacle to advancing the EU-China climate partnership. Finally, given the geopolitical issues such as the tension between the United States and China, the climate relationship requires a stronger common understanding of policy and industry approaches for the decarbonisation of the steel sector.

Finally, **competition also rises around steel scrap**: scrap resources are crucial for EAF-based steelmaking, one of the technologies that might enhance steel decarbonisation. Both the EU and China might increase their imports of steel scrap, nevertheless the scarcity of scrap resources could lead to potential competition and less cooperation in the field (Chen et al. 2021).

Therefore, **coordinated and concerted** approaches at the policy and industry levels are required in order to reinvigorate the joint climate efforts of the two biggest emitters. Given that the two steel industries are strongly intertwined in their supply chains and trade volumes, concerted political action on decarbonisation is a challenge. On another level, joint efforts to promote green steel require resolving the potential for conflict and building mutual understanding.

[3] They are steel, cement, electricity, fertilizer and aluminium.

The automotive sector

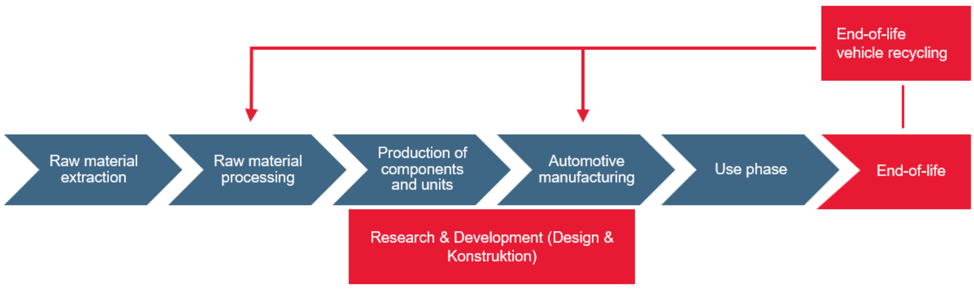
1. Background: The automotive sector in the EU and China

An important demand sector for steel products in both China and the EU is the automotive industry.[4] With global car sales growing to around 66.7 million automobiles in 2021 (Scotiabank 2022), the automotive industry reached a global market size of almost USD 2.8 trillion in 2022 (IBISWorld 2022). The most important industry segments include commercial vehicles and passenger cars. China is the largest automobile market worldwide, both in terms of demand and supply: new car registrations in China amounted to over 21 million units in 2021, followed by the USA with 14.9 million units and Europe with 11.7 million units (VDA 2022).

The most important automotive component segments in terms of markets size are the manufacture of the car body (with a market size of USD 173 billion in 2020) followed by the manufacture of internal combustion engines (ICE) (with a market size of USD 144 billion in 2020) (Coffman et al. 2021, p. 3). The automotive industry contributes significantly to global manufacturing employment. According to the UNIDO Industrial Statistics Database, in 2018, almost 5 million employees worked in the sector "Motor vehicles" (UNIDO 2022).

The value chain of the automotive sector can be briefly visualised as follows:

Figure 4: Simplified automotive value chain

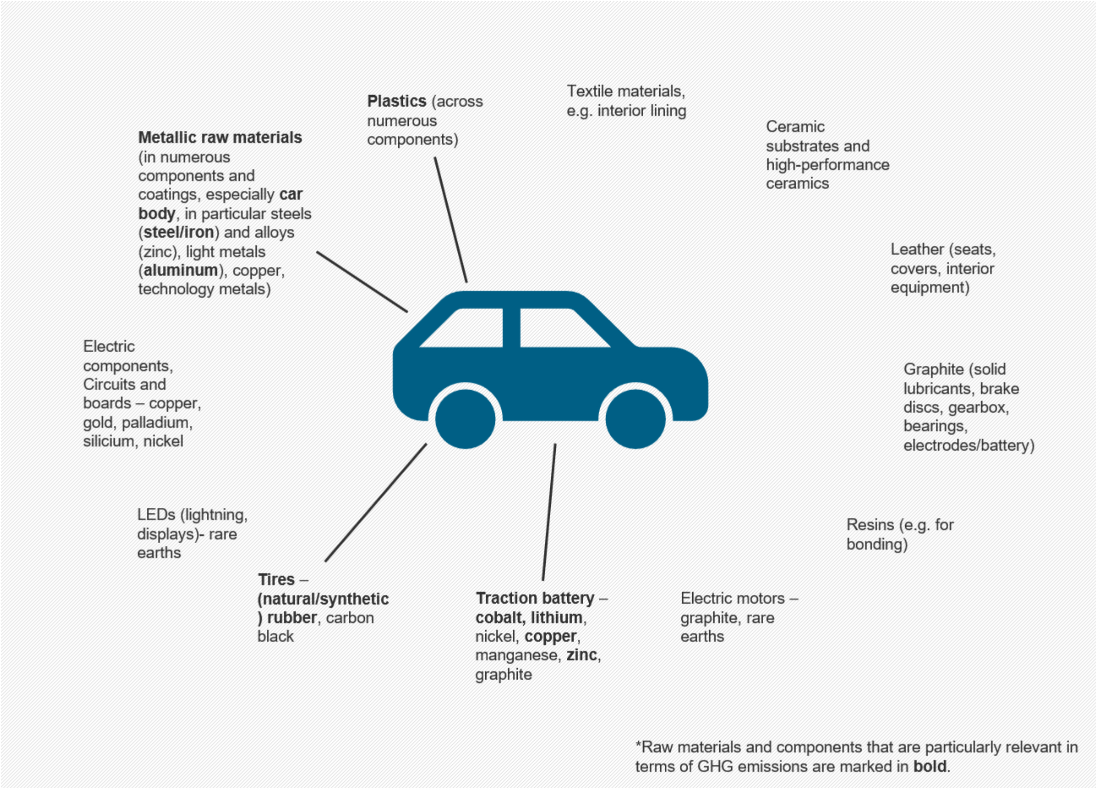


Source: Adapted from Braun et al. 2021, p. 11

The automotive value chain is highly complex, internationalised and includes many different raw materials and processes, some of which are associated with high GHG emissions. In addition, through its suppliers it is linked to other industrial sectors, including not only the steel sector but also the chemical, aluminium, electronics industry and the textile and leather industries (Weiss et al. 2022). A modern passenger car consists of several tens of thousands of individual parts that are manufactured by various supplier companies (Braun et al. 2021, p. 12).

[4] The automotive industry as defined within this study consist of companies and activities involved in the manufacture of motor vehicles, trailers and semi-trailers, covering the manufacture of parts and accessories for motor vehicles and the manufacture of trailers and bodies (Braun et al. 2021). The automotive sector and its upstream and downstream value chains will be the focus of this study, while the use phase of automobiles (usually defined as the "transport sector" [Braun et al. 2021]) will not be covered.

Figure 5: Simplified representation of central components and raw materials of an automobile



Source: Adapted from Weiss et al. 2022, p. 64

The automotive industry is very resource and GHG intensive. Between 50% and 60% of a car is composed of steel and aluminium, materials which are mainly used for the construction of the car body. Both metals account for the largest share of the automotive industry's raw material purchases in terms of volumes (Groneweg 2020, p. 5). At the same time, both of these materials account for a significant proportion of CO_2 emissions along the entire value chain of a car – according to the car manufacturer Daimler, the proportion is around 60% of the total emissions along the value chain (Groneweg 2020, p. 27). In 2018, the automotive industry consumed a total of 10.6 million tons of steel, 1 million tons of aluminium, 108,000 tons of copper, 47,6000 tons of zinc and 292,000 tons of lead (Braun et al. 2021, p. 14).

At the same time, the automotive industry is currently undergoing a comprehensive transformation towards electric mobility. The sales market for component groups associated with electrified vehicles (EVs) is growing at a rapid pace, while internal combustion engine (ICE) components are either stagnating or declining (Coffman et al. 2021, p. 4). This also has a massive impact on the value chain structure and hot spots for GHG emissions. New raw materials, especially lithium and cobalt, are increasingly in demand for the production of battery-electronic engines (Weiss et al. 2022). Lithium-ion battery packs are the most commonly used battery type in modern electric vehicles at 99% (Slowik et al. 2020, p. 17). Estimations show that with a predicted annual sale of 28 million electric vehicles in 2030, raw material demand will amount to about 100,000 tons of lithium, 70,000 tons of manganese, 82,000 tons of cobalt, 9,000 tons of phosphorous, 16,000 tons of iron, 600,000 tons of nickel, and 225,000 tons of graphite (Slowik et al. 2020, p. 20). While the switch to electric battery-powered mobility can greatly reduce a car's CO_2 emissions during the use phase, upstream CO_2 emissions caused during the production phase become more significant.

In addition to the restructuring driven by the e-mobility transformation, automotive supply chains have been under development pressure in recent years due to various external political and economic factors, such as the economic shutdowns in China and the EU caused by the COVID-19 pandemic, which halted production, created supply bottlenecks for semi-conductors and the risk of raw material shortages (Coffman et al. 2021, p. 8). The conflict in Ukraine negatively impacted automotive manufacturers, especially in Europe. In addition to falling sales figures, automotive manufacturers had to find replacements for their suppliers from Ukraine and Russia. Together with the continuing shortage of chips, this is having a severe impact on the ability of many European manufacturers to deliver. Sales figures of car manufacturers in China also declined in spring 2022 (in April 2022 sales fell by 1.2 % to 1.82 million in comparison to April 2021) (Deutsche Welle 2022).

The complexity and global interconnectedness of the automotive supply chain and its dependence on many energy and carbon-intensive upstream sectors (including steel) make the automotive industry a key sector for decarbonisation. At the same time, the complexity also poses a challenge for decarbonisation of supply chains, as it requires the cooperation of many different stakeholders.

1.1 The Chinese automotive industry

China has been the largest vehicles market in the world since 2019. According to data of the China Association of Automobile Manufacturers, 26.28 million automobiles were sold in China in 2021 (Xinhua 2022).

In 2020, China imported USD 42 billion worth of cars. This made the People’s Republic the third largest importer of cars in the world and cars the fourth largest imported product in China. The key import countries in 2020 were Germany (USD 16.7 billion), Japan (USD 8.69 billion), USA (USD 6.24 billion), UK (USD3.56B) and Slovakia (USD 1.98 billion) (OEC 2022).

Until recently, the majority of vehicles produced in China went into the fast-growing domestic market, with a production to export ratio of merely 4% as of 2019 (Sebastian 2021). However, China is taking on a growing role in the export of automobiles. In 2020, China exported USD 9.22 billion in cars, making it the 17th largest exporter in the sector worldwide. Main destinations for Chinese exports of cars in 2020 were the USA (USS 1.29 billion), Saudi Arabia (USD 1.1 billion), Russia (USD 456 million), Germany (USD 408 million) and Australia (USD 390 million). The fastest growing markets for Chinese car exports between 2019 and 2020 were Norway, Belgium and Saudi Arabia (OEC 2022).

The automotive industry in China has grown rapidly over the past 30 years and is composed of a mixture of global original equipment manufacturers (OEMs) and an increasing number of domestic brands. In 2015, over 21 million passenger cars were produced in China, accounting for almost a third of the global total in sales (Wenten 2020, p. 279).

Major automotive industrial clusters are located in coastal areas of China. According to the National Bureau of Statistics of China, in 2020 most cars were produced in the Guangdong region with about 3.1 million units; followed by Jilin and Shanghai with about 2.6 million units each and Hubei with almost 2 million units (National Bureau of Statistics of China 2021). Among the most important manufacturers in China are the so-called conventional “big four” – First Automotive Works (FAW), Dongfeng, SAIC and Chang’an (Wenten 2020, p. 283) – and the four largest independent automakers in China – Chery, Geely, BYD and Great Wall (Wenten 2020, p. 285). While the “big four” are state owned enterprises (SOEs), Chery is a public enterprise owned by the local government of Wuhu, Anhui province. BYD and Geely are fully private and the local government of Baoding, Hebei, has only a minority holding in Great Wall (Wenten 2020, p. 285). In 2021, SAIC was the leading Chinese automobile manufacturer, with a sales volume of 2 757 units, followed by Chang’an (1 755 units), Geely (1 328 units) and Great Wall (1 281) (CAAM 2022).

Before the growth of domestic brands, the Chinese automotive sector has long been characterised by joint ventures (JVs) between globally active foreign manufacturers and SOEs. Between the 1980 and 1990s, the automotive sector was one of the “pillar industries” subject to special political control. OEMs could only enter the market as JVs with Chinese companies (Wenten 2020, p. 281). In 1984 for example, German Original Equipment Manufacturer (OEM) Volkswagen (VW) and SAIC, as well as French manufacturer Peugeot and Guangzhou Automobile manufacturing, signed JVs, of which only Volkswagen Shanghai survived (Wenten 2020, p. 282). Foreign brands continue to dominate the market, with VW, for example, generating 40% of its profit from its China business in 2012 and 2013 (Wenten 2020, p. 285).

In the EV market in particular, however, the balance between global and domestic brands is shifting: BYD, originally a producer of lithium-ion batteries, holds a competitive advantage in EV battery production (Wenten 2020, p. 287). In the field of e-mobility – both EVs and batteries – China has also established a global leadership position: as of 2021, China is the world’s largest market for EVs with total sales of 1.3 million vehicles in 2020, more than 40% of global sales. The Chinese battery producer CATL controls around 30% of the global EV battery market, making it a key supplier for EV producers worldwide (Pattisson and Firdaus 2021). China’s share of global lithium-ion battery cell production capacity was 77% in 2020 (Weiss et al. 2022, p. 79). Due to growing demand for EVs in many economies worldwide, Chinese automotive and EV sectors are now increasing their export efforts, especially targeting the European market (Sebastian 2021).

China also occupies a key position in the production of automotive components: in 2019, the People’s Republic exported new tyres worth USD 14.6 billion, which accounted for 18.1% of global exports. China was thus the most important exporter of tyres worldwide (Weiss et al. 2022, pp. 100–101).

In addition to increasing export volumes of vehicles, China is also a key exporter of raw materials that are central to automotive production. For example, China plays a key role in the global zinc market: The People’s Republic is both a major mining country and the largest producer of refined zinc. In 2018, about 38% of the world’s mine production of zinc ore took place in China. China also ranked first in global refined zinc production in 2012, accounting for 38% of the total 12.64 million tons of refined zinc produced worldwide (Weiss et al. 2022, p. 90). In addition, China is the third largest producer of lithium, a key raw material for batteries, with an annual extraction volume of about 7,000 tons, behind Australia (60,000 tons) and Chile (18,000 tons) (Weiss et al. 2022, p. 75). It is estimated that in 2020 Chinese refineries provided 85% of the world’s battery-ready cobalt, which is a key component of lithium-ion batteries (Pattisson and Firdaus 2021). In the central cobalt mining country, the Democratic Republic of the Congo, 70% of the sector is dominated by Chinese companies (Pattisson and Firdaus 2021). Securing key raw materials for e-mobility is also being driven forward politically, for example by promoting public and private mining companies to secure access to essential primary resources abroad (lithium, cobalt etc.) and expanding capacities at home (Wenten 2020, p. 288).

Regarding the sourcing of raw materials by the Chinese automotive sector for production in China, one expert interviewed for the study explained that steel for automotive production would mainly be sourced from domestic companies. China is furthermore by far one of the leading producers in all segments of the aluminium value chain, including bauxite mining and aluminium recycling (OECD 2019, p. 49).

1.2 The EU automotive industry

The **EU automotive sector is central to the European economy,** generating a turnover of around EUR 936 billion in 2020. The automotive sector contributes to over 7% of the EU GDP and accounts **for 28% of total EU research and development (R&D)** spending. Of the total of EUR 62 billion R&D funds invested in 2019, automotive suppliers accounted for more than EUR 25 billion, producing an estimated two-thirds of the more than 9,000 patents filed by the automotive sector (Brown et al. 2021, p. 18).

With over 5.6 million vehicles exported annually to the rest of the world, the industry contributes a surplus of EUR 74 billion to the EU's trade balance (Brown et al. 2021, p. 18). In 2020, over 15% of motor vehicles globally were produced in the EU (12.1 million units). In terms of passenger cars, EU production amounted to over 16% of global production in 2021 (9. Million units) (ACEA 2022).

The sector is comprised of various business services and a total of 1.4 million companies. Moreover, the sector provides direct and indirect jobs to 13.8 million Europeans. For example, in manufacturing, the automotive industry makes up over 11% of EU employment (3.5 million people) (Brown et al. 2021, p. 18).

The EU is home to some of the world's leading automotive manufacturers as well as automotive suppliers. Among them are Volkswagen (#1 by 2020 sales), Daimler (#3), BMW (#7), Stellantis (#9). Also, non-EU automakers (such as Hyundai in Czech Republic) run assembly plants located throughout the EU (Brown et al. 2021, p. 18). Major automotive suppliers are Bosch as the biggest global player (2019), Continental (#2), ZF Friedrichshafen (#5), Michelin (#9) and Valeo (#10) (Brown et al. 2021, p. 19).

The automotive sector is the most integrated ecosystem in terms of intra-EU value chains. Over 45% of its production depends upon cross-border value chains within the EU, particularly in the Czech Republic and France, but also Italy, Spain, Austria and Poland (Brown et al. 2021, p. 20). This includes direct, indirect as well as upstream value chains, such as the automotive industry, the metal producing and processing industry, mechanical engineering, and the plastics processing industry (Weiss et al. 2022, p. 31). One of the most important production and sales countries is Germany, producing around 80% of all passenger cars sold in the premium segment (Braun et al. 2021).

In 2020, **Europe** surpassed China to become the **world's biggest market** in terms of both the number **of EVs** sold and the share of EVs in total car sales (Brown et al. 2021, p. 25). In 2020, EVs of all types accounted for 6% of the cars on Europe's roads in 2020 (Brown et al. 2021, p. 17). What should be noted is that, in contrast to other markets, the strategy of European carmakers for EVs in the next 10 to 15 years is relying on a balanced sales mix between battery electric vehicles (BEVs) and plug-in-hybrid electric vehicles (PHEVs). PHEVs are widely seen as a transitional technology, containing smaller batteries and being more profitable. Sales of PHEVs have therefore grown faster than BEVs in Europe, accounting for 54% of the EV market by June 2021. By comparison, in China the share of BEVs is significantly higher at 83% (Brown et al. 2021, p. 29)

As part of the **transition to electric mobility**, European initiatives for domestic **battery supply are increasingly emerging**. One example is Northvolt: a European battery production project relying on investments and supply agreements with manufacturers VW, BMW and Volvo, aiming for a share of 25% in the European EV battery market. European OEMs VW, Stellantis and Renault have also announced plans for pilot and large-scale plants to develop their own independent battery production capabilities internally or through joint ventures (Brown et al. 2021, p. 37). Strategic political decisions, such as the agreement of the Council of the EU from June 2022 to ban newly registered vehicles with combustion engines from 2035 onwards from the European market (Council of the EU 6/29/2022), will presumably accelerate the transition to e-mobility and development of corresponding domestic production capacities.

1.3 EU-China automotive trade relations

The automotive markets of the EU and China closely interconnected. European car makers depend on imports from China of raw materials such as aluminium, steel and lithium that are essential for car production (ACEA 2019). In addition, European carmakers increasingly scale up their China-based production with localised supply chains. Similarly, the Chinese automotive sector relies on European stakeholders. Chinese battery producers are increasingly investing in the EU and Chinese EV exports are focused on the European market (Sebastian 2021). These developments indicate that the automotive market will become more interconnected and companies in both countries will be increasingly present at all stages of the supply chain. In Germany alone, around EUR 4.8 billion of the value added in the upstream value chain of the automotive sector is generated in China. This is both at the level of direct suppliers and at lower supply chain levels (Weiss et al. 2022, p. 31). The **EU's main trade clusters with China** in the automotive sector concern **materials for vehicle bodies, mainly steel and aluminium, and finished products such as batteries**. With the shift to e-mobility, the demand for metals such as lithium, cobalt, graphite and nickel is also increasing (Power Shift, 2020 p. 5).

Regarding the production of raw materials for the cars body, in 2018, iron and steel made up for 6% of the EU's import of metal raw materials with 20% coming from China, 11% from Turkey, and 10% from Russia (DERA 2020, p. 31). The majority (94%) of the steel required by manufacturers is sourced in the European Union (Acea 2019). While there is no detailed data on the amount of steel imported from China that flows directly into European automotive production, China plays a key role as an exporter to the EU of **flat steel products**, which are most commonly used **in the automotive**, piping, appliance and machinery industries (International Trade Administration 2020, p. 6). In 2020, the EU imported around 16,6 million metric tonnes of flat steel products, making up over 78% of overall finished steel product imports (Eurofer 2021, p. 39). The largest share of flat products was imported from Turkey at 19.6% (3.3 million metric tonnes), followed by South Korea at 16.6% (2.8 million metric tonnes). Imports of flat products from **China were at 5,7%** (943 thousand metric tonnes) behind Russia, India and the Ukraine (Eurofer 2021, p. 43). Conversely, slightly fewer flat steel products were exported from the EU to China. Of the total 13.8 million tons of flat products exported by the EU in 2019, just under 5% (704 thousand tons) went to the Chinese market (Eurofer 2020a, p. 48). As pointed out by an expert interviewed for this study, Chinese auto manufacturers mainly source their steel from domestic producers.

Under the **EU steel safeguard measures**, tariff quotas are established for certain steel products based on the average volume of traditional imports during a given period. While the Regulation grants a separate quota to some steel products which are used substantially, but not exclusively in the automotive sector, the automotive sector is concerned that this could lead to an **inflationary effect** on steel prices and tight capacity of EU producers (ACEA 2019; Kinch and Rubin 2022). In 2019, Chinese suppliers exhausted their annual quota for imports of coated flat steel for the automotive industry into Europe only a few days after the start of the new quota period (Fastmarkets 2019).

The EU also sources significant quantities of **aluminium** from China. In 2021, 6.6% of the EU's imports of aluminium, which is used among others for manufacturing lighter vehicles, came from China (Kardish et al. 2021a). According to European Aluminium, China produces 54% of global primary aluminium (European Aluminium 2021). In Germany, the automotive sector makes up almost half of the demand for aluminium (Buchenau and Tyborski 2021). With the shift to electric vehicles, this demand will rise in the future. Aluminium weighs only about one-third as much as steel per cubic foot, making it very suitable for lightweight construction. This makes the material particularly important for BEVs, where the weight increase of the vehicle caused by heavy batteries must be offset to reduce energy consumption. BEVs use 45% more aluminium compared to ICE vehicles (Kong et al. 2021, p. 16). In October 2021, the European Commission imposed anti-dumping duties of 21 to 32 % on aluminium extrusions after identifying the sector as non-market-based (Reimers et al. 2021).

Trade relations with China are also of major importance regarding the European demand for finished **batteries and raw materials**. While Chile (40%), Australia (29%), and Argentina (16%) account for about 90% of global lithium mine production, China hosts the majority of the world's hard rock lithium refineries (45%) (Bobba et al. 2020, p. 19). China is also a market leader in other battery materials, such as nickel, cobalt, quartz and other rare earth elements. China provides 98% of the EU's supply of rare earth elements (REE) (European Commission n.d.). Combined, China, Africa and Latin America provide 74% of the world's battery raw materials (Bobba et al. 2020, p. 11), while the EU produces only 1% (Bobba et al. 2020, p. 19). The People's Republic is also almost the sole market leader in the production of batteries and battery components. More than 90% of all lithium cells that are used in batteries are produced in China (Hempel 2021). 60% of global lion-cells are manufactured in China while the EU's share is only 0,2% (Bobba et al. 2020, p. 20). In 2021, China accounted for 77% of global electric vehicle battery capacity and the largest manufacturing companies are from Asia (Brown et al. 2021, p. 36). With the EU initiatives to increase local EV battery production, European manufacturers are positioning themselves as market competitors, which will also increase global competition for battery raw materials (Reisch 2022, p. 2).

2. GHG emissions along the automotive supply chain

Global GHG emissions from the automotive industry in 2018 were around 4.8 gigatons of CO_2, which is approximately 9% of total global CO_2 emissions (Braun et al. 2021, p. 14). With this, the car industry's 2018 carbon footprint exceeded the EU's overall GHG emissions. According to a 2019 Greenpeace report, the top 5 emitters, Volkswagen (582m tons of CO_2), Renault Nissan (577m tons of CO_2), Toyota (562m tons of CO_2), General Motors (530m tons of CO_2) and Hyundai-Kia (401m tons of CO_2), were responsible for 55% of the industry's overall carbon footprint (Stephan et al. 2019, p. 2).

In China, the automotive industry is one of the three domains that see the fastest growth of GHG emissions, making it an essential sector for reaching Chinese climate goals (ADC 2020, p. 3). One interviewed expert pointed out that the Chinese automotive industry has not yet established a comprehensive life cycle carbon accounting system, which includes the acquisition of raw materials, vehicle production, vehicle sales, vehicle use, vehicle disposal and recycling, making it difficult to obtain reliable data on the GHG emissions of the automotive industry supply chain. However, calculations by Automotive Data of China (ADC) indicate that the life cycle emissions of all new passenger cars mass-produced in China in 2019 was 0.6 billion tons of CO_2 (ADC 2020, p. 46). It also should be noted here that **several efforts aimed at comprehensive life cycle accounting for the Chinese automotive industry's GHG emissions have been initiated in the past few years**, including the China Automobile Low Carbon Action Plan developed by the World Automotive Life Cycle Association (世界汽车生命周期联合研究工作组）in 2020 and a document on the technical specifications for life cycle carbon emission accounting of passenger cars (乘用车碳排放核算技术规范) published by the China Automotive Technology and Research Center (CATARC) in 2021. Both initiatives will be discussed further in the chapters highlighting policy and industry approaches to tackle supply chain emissions.

Data on the transport sector shows that it accounts for about 10% of China's **total carbon emissions**. Carbon emissions from road transport are the main source of carbon emissions from the transport sector and accounted for about 73% in 2018. Carbon emissions from the automotive industry accounted for about 97.8% of total road transport emissions in 2020, making the automotive sector a significant source of overall Chinese GHG emissions (Zhao et al. 2022, p. 1).

In the **EU**, passenger cars and vans are respectively responsible for around 12% and 2.5% of total EU emissions of CO_2 (European Commission 2022a).

On a **global average**, an **ICE vehicle** emits 202 g CO_2-eq/km, while well-to-wheel emissions of an **EV** are at 83 g CO_2-eq/km (IEA 2021b). Estimations by the ICCT from 2021 show slight regional differences for GHG emissions in the automotive industry: while ICE vehicles registered in Europe produced life cycle emissions of almost 250 g CO_2-eq/km, ICE vehicles registered in China were the source of around 255 g CO_2-eq/km. Life cycle emissions for EVs registered in Europe in 2021 are lower by 66% to 69% than a comparable gasoline car. In China, EV values are estimated to be 37% to 45% lower than ICE vehicles (Bieker 2021, p. i). Other data estimates that the amount of carbon emission in the automotive production stage in China amounts to about 0.06 and 0.07 billion tons of CO_2 per year (Zhao et al. 2022, p. 7). Calculations by ADC show that full life cycle GHG emissions from passenger cars (including ICEVs, hybrid vehicles, PHEVs and BEVs) in China have steadily decreased between 2010 to 2019 (from 243.6 gCO_2-eq/km in 2010 to 212.2 gCO_2-eq/km in 2019) (ADC 2020, p. 46).

Figure 7: Life cycle emissions of average medium-size ICEs and BEVs

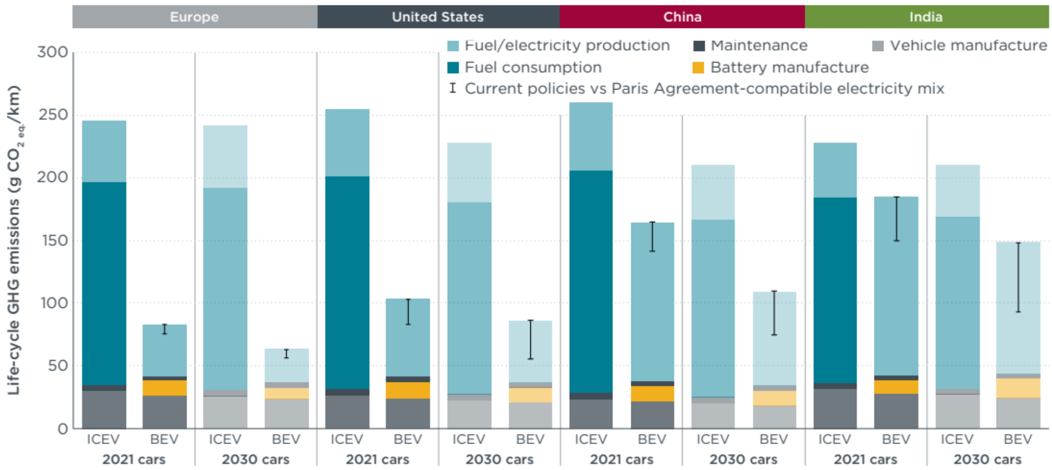


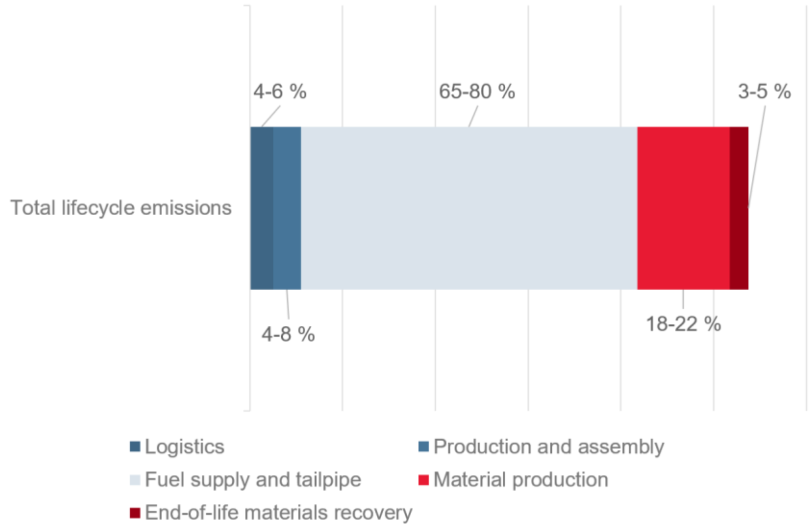
Figure ES.1. Life-cycle GHG emissions of average medium-size gasoline internal combustion engine (ICEVs) and battery electric vehicles (BEVs) registered in Europe, the United States, China, and India in 2021 and projected to be registered in 2030. The error bars indicate the difference between the development of the electricity mix according to stated policies (the higher values) and what is required to align with the Paris Agreement.

Source: (Bieker 2021, p. ii)

The numbers above reflect life cycle emissions, including production, use phase and end-of-life emissions. While 65% to 80% of the emissions of an automobile are tailpipe emissions, emitted during the use phase (and connected to indirect emissions from the fuel supply) (Hannon et al. 2020, p. 2), there are many hotspots for GHG emissions along the automotive value chain that stem from materials and processes in the production stages. Figure 8 also shows that while the average lifetime carbon intensity of ICE vehicles and EVs registered in China is higher than that of vehicles registered in Europe, this is mainly due to higher emission levels for fuel/electricity consumption in China, while vehicle manufacturing levels are similar in both countries/regions. According to the European Automobile Manufacturers' Association, the emissions per car produced by European manufacturers dropped by 33.1% between 2005 and 2020, while the overall figure of emissions form car production went down by 48.5% showing a slight tendency of lowering emissions also in the production phase (ACEA 2021b).

Hannon et al (2020) estimate that around 18-22% of the current life cycle emissions of ICE vehicles is emitted during the material production and around 3-5% during the end-of-life materials recovery phase. Both areas, that OEMs have so far tended to overlook in their decarbonisation efforts (Hannon et al. 2020, p. 2).

Figure 8: Percentage distribution of total emissions from ICE vehicles over various life cycle stages



Source: Adapted from Hannon et al. 2020, p. 2

Against the background of a reduction in tailpipe emissions due to a shift towards electric mobility and alternative drives, it is estimated that emissions at the material and production level will continue to rise in both relative and absolute terms. Hannon et al. (2020) estimate that emissions from material production may grow from 18% of life cycle emissions in 2020 to 60% by 2040 (reaching a higher level than tailpipe emissions, which will account for 40% of overall life cycle emissions) (Hannon et al. 2020, p. 3). ADC (2020) describes that although the total life cycle emissions of passenger cars manufactured in China have decreased between 2010 and 2019, this is mainly due to the reduction of GHG emissions during the fuel cycle, while GHG emissions in the vehicle cycle have increased, mainly due to the use of CO_2-intensive lightweight materials and electrification (ADC 2020, p. 46). Electrification in this way leads to an increasing relevance of the supply chain in the overall decarbonisation efforts of car manufacturers. The German car manufacturer BMW estimates that the supply chain footprint of an all-electric vehicle could almost double that of an ICE vehicle if no appropriate decarbonisation measures are introduced, which would nearly erode all GHG emission savings from the use phase (BMW 2022a, p. 79).

What are the GHG emission hotspots in the automotive supply chain? In light of the complexity and differentiation of the supply chain, which is due to the different components and raw materials used in automotive production and differences in the production of different types of ICE vehicles and EVs, each supply chain has to be considered individually for hotspots. However, some overarching hotspots can be identified, which apply to vehicles produced in China and the EU. These result on the one hand from a high carbon intensity of the respective materials/components or processes and a high use in the automotive industry. Overall, high GHG emissions occur at various upstream stages (direct suppliers and upstream suppliers) of OEMs: the automotive industry, for example, obtains numerous products from the metal-producing and processing industry, which is associated with high GHG emissions due to a mostly high energy requirement and the use of fossil fuels. This is particularly relevant in China due to the high proportion of coal-fired power in the energy mix. The same applies to electricity generation and the extraction of energy sources at the level of direct suppliers and upstream suppliers. In addition, the automotive industry purchases products from the chemical industry, which is associated with high GHG emissions, and direct suppliers of automotive parts are also responsible for GHG emissions in their production. GHG emissions also occur in the automotive supply chain during the transport of materials and components (Weiss et al. 2022, p. 37). GHG hotspots within the automotive supply chain include: Steel, aluminium and battery materials (components and cell production). Zinc, plastic (used to manufacture various components in the vehicle) and tyres are also associated with high GHG emissions.

2.1 Steel

The automotive industry is an important consumer of steel and steel products. As described in Chapter 1, steel production is highly energy- and carbon-intensive. The production of one ton of steel causes approx. 1.8 tons of CO_2 emissions, which is mainly due to the operation of blast furnaces in smelting plants. The extraction of the iron ore required for steel production is also associated with a high energy demand (Weiss et al. 2022, p. 84).

On average, for ICE vehicles produced in the EU, 34% of the total GHG emissions generated during production and in the supply chain are due to the steel required. For EVs produced in the EU, 27% of production and supply chain emissions are due to the steel used (Material Economics 2021, p. 11).

The production of automotive sheet from steel requires fine-tuning of the parameters (of the proportion of some rare elements) in iron smelting. As highlighted by an expert interviewed for this study, this means that the reduction of emissions in the production of automotive sheet can be traced back to the upstream areas, so that the reduction of emissions from automotive steel could promote the overall reduction process in the steel industry.

2.2 Aluminium

Next to steel, aluminium is one of the most frequently used raw materials in a vehicle. The production of aluminium and aluminium products is also associated with high CO_2 emissions, which is due to a high energy requirement during the smelting process (which is responsible for about 60% to 79% of overall CO_2 emissions from aluminium production) (Hannon et al. 2020, p. 4; International Aluminium Institute 2021, p. 3).

In 2018, the global aluminium sector emitted 1.1 billion tons of GHG, amounting to about 2% of total global emissions. 90% of this carbon footprint stem from primary production processes (International Aluminium Institute 2021, p. 3).

2.3 Battery materials

Of the total life cycle emissions of most EVs, between 10% and 75% of the manufacturing energy and between 10% and 70% of the manufacturing GHG emissions are due to battery production. Despite the wide range of data, the majority of EV LCAs conclude that the majority of GHG emissions are due to battery cell production (European Environment Agency 2018, p. 24).

Due to the high energy consumption, the production of battery cells causes a large amount of GHG emissions: nickel manganese cobalt oxide cell types, which are one of the different types of lithium-ion battery technologies, emit between 61 and 106 kg CO_2-eq/kWh of battery capacity. This is mainly due to high temperature processes (calcination, graphitisation) and drying processes using fossil fuels. Depending on the proportion of coal in the mix in the country of manufacture, the GHG emissions may be higher or lower (Weiss et al. 2022, pp. 68–69).

In China, where battery cell production is mainly located in the provinces of Guangdong and Jiangsu, the electricity mix has a coal content of about two-thirds (Weiss et al. 2022, p. 80). As a result, 35% to 50% of the total emission of battery production in China arise from the electricity consumption (European Environment Agency 2018, p. 29). LCAs calculate that cell manufacturing and battery assembly account for anything between 3% and 80% of total battery production (European Environment Agency 2018, p. 24).

The rest arises from raw material extraction and processing, which occur at the beginning of the EV battery supply chain: the energy-intensive smelting and refining of cobalt, especially in China (due to the high proportion of coal-fired electricity), emits significant amounts of carbon dioxide. The mining and processing of copper is also associated with high GHG emissions, depending on the energy source. Depending on the method of extraction, lithium mining produces between 5,000 kg CO_2 per ton (extraction from salars) and 5,000 kg CO_2 emissions per ton (extraction from rock) (Weiss et al. 2022, pp. 71–75). Given the EU's high dependence on China for imports of key battery raw materials, China's high share of coal-fired power also strongly impacts the European automotive industry's ability to reduce supply chain GHG emissions (Christmann 2021, p. 198).

2.4 Further sources of GHG emissions in the automotive supply chain

Other areas and supply chain sections of automotive production are also associated with significant GHG emissions. For example, depending on the electricity mix, the energy-intensive processes of welding and wrought-iron forming in **car body** production generate high emissions, which is again particularly relevant in view of China's high share of coal-fired electricity (Weiss et al. 2022, p. 93).

Zinc has a primary energy demand of 37,500 MJ/t and a climate impact of 2600 kg CO_2-eq per ton of zinc. About 65% of the emissions are caused by smelting, 30% by the mining and production of zinc concentrate and 5% by the transport of zinc concentrate. As China is an important zinc producing country, coal-fired power again plays an important role in the energy-intensive processes (Weiss et al. 2022, p. 91).

Large amounts of CO_2 are also emitted in the production of **tyres and rubber**; the production of a 10 kg tyre causes about 334 kg CO_2-eq (Weiss et al. 2022, pp. 104–105).

In addition, numerous **plastic parts** are installed in automobiles, which is associated with emissions of 0.36 ton of CO_2 per vehicle in the case of an exemplary ICE car (Hannon et al. 2020, p. 4).

3. Approaches to the decarbonisation of the automotive industry

There is growing demand for a decarbonisation in both the EU and China for the decarbonisation of automotive supply chains. Policy and industry stakeholders in both regions also face similar challenges resulting from the complexity and length of the automotive supply chain, a corresponding lack of comprehensive GHG emissions data, and broader geopolitical challenges. Regulatory measures have already led to a shift towards e-mobility and, as a result, to a reduction of emissions in the use phase of vehicles. Policies and financial incentives in the EU and China are now increasingly focusing on the emissions along the entire value chain, for example by taxing emission-intensive manufactured products.

The public demand for green products has also reached carmakers and is reflected in decarbonisation targets – and strategies that have been comprehensively developed in recent years, especially by European carmakers. While the decarbonisation of the automotive sector has also become a widely accepted relevant topic in the industry, most industry stakeholders do not yet adequately record their scope 3 emissions. To close data gaps and improve cooperation along the supply chain in recording CO_2 emissions, some companies are discussing options for standardised data exchange, for example via blockchain solutions. Similarly, cross-industry initiatives aim to bring together stakeholders from different parts of the supply chain to share knowledge on CO_2 reduction opportunities and are also working on uniform standards for CO_2 accounting.

3.1 Policy approaches

In recent years, the main focus in reducing emissions in the sector has been on emissions in the use phase. In this regard, **regulatory pressure** in both China and the EU, for example the setting emission limits or offering financial incentives for BEV's have led to a **shift in the sector towards e-mobility** (Schäpe and Tsang 2021, p. 9). Moreover, **customer preferences** in both markets also accelerate the expansion of the EV market. There is growing demand for low-carbon vehicles.

In the EU, the ETS and the phasing out of free allowances, the proposed CBAM and the tightening of reporting requirements for GHG emissions are policies that will increase the pressure to account for CO_2 emissions along the entire value chain. It is also expected that the method used in the EU to calculate vehicle emissions will in future cover emissions over the entire life cycle.

In order to sufficiently **record full life cycle emissions of passenger vehicles**, China has stepped up to develop technical standards and limit values for GHG accounting (ADC 2020, p. 3). Although **China does not yet have a policy targeting full life cycle emissions for vehicles**, the ambitions of international automakers to full life cycle GHG neutrality are putting pressure on engine manufacturers and suppliers in China. Chinese automakers, on the other hand, still lack knowledge in technology and managerial experience. Mostly, there is lack of compliance with international standards and trends (ADC 2020, p. 4). Considering that the automotive sector is intertwined and that both European and Chinese downstream players have an interest in the EU market, there is a good potential for cooperative policy approaches to harmonise life cycle emissions accounting standards.

Table 3: Central policy approaches in the EU and China

	China	EU
Key strategy	• 1+N: peak emissions by 2030, achieve climate neutrality by 2060 (1+N政策体系: 2030碳中和，2060碳中和) • 30:60 target addressing also the automotive sector (30:60 双碳目标也强调了汽车行业) • “dual circulation” growth strategy (“双循环” 新发展格局)	• European Green Deal (“Fit for 55” package): setting binding EU-wide climate targets for 2030 (55% reduction of GHG emissions) and 2050 (carbon neutrality) • Renewable Energy Directive (REDIII)

Limiting/Lowering fleet emissions	• New Energy Vehicle (NEV) Program (新能源汽车项目) • Parallel Management Regulation for Corporate Average Fuel Consumption (CAFC) (乘用车企业平均燃料消耗量并行管理办法) New Energy Vehicle (NEV) Credits (新能源汽车积分)	• Regulation (EU) 2019/631 • Requirements for efficiency of electric motors • Plan to allow only for zero emission cars from 2035 onwards
Import/export restrictions	• Export restrictions in the form of export quotas or export taxes on primary raw materials e.g. on cobalt and copper (European Commission, Trade Barriers n.d.) (以出口配额或出口税的形式对钴和铜等初级原材料进行出口限制（欧盟委员会，贸易壁垒)) • Restriction on foreign battery companies in the domestic market (在国内市场限制外国电池企业)	• Carbon Border Adjustment Mechanism (CBAM)
Emissions trading	• Automotive/Transport sector is not participating in national ETS (全国碳排放权交易市场)	• EU ETS (indirect effect through automotive suppliers)
Due Diligence Regulation	• none	• Proposal for a Directive on Corporate Sustainability Due Diligence
Green finance	• Unified system of standards and statistics for green finance and instruments; examples: 2015 Green Bond Approved Projects Catalogue; 2019 Green Industry Guiding Catalogue (绿色金融和工具的统一标准和统计系统； 比如：绿色债券支持项目目录（2015年版）; 绿色产业指导目录（2019年版)) • Guidelines on Environmental Information Disclosure for Financial Institutions issued by the People's Bank of China (中国人民银行《金融机构环境信息披露指南》)	• EU Taxonomy for sustainable investments • VAT Directive • GPP criteria • Urban Mobility Package
Cooperation with companies	• State owned auto manufacturers such as China FAW Group Corporation	• EU Battery Alliance • European Automotive Manufacturers Association

		• European Council for Automotive R&D (EUCAR)
Circular economy	• 2016 Action Plan for the Circular Economy (2016年循环发展引领行动) • Circular Economy Promotion Law (updated last in 2018) (中华人民共和国循环经济促进法（2018修正)) • Electric Vehicle Battery Recycling Technology Policy (电动汽车动力蓄电册回收利用技术政策) • Management Measures for the Gradual Utilisation of New Energy Vehicle Power Batteries (工信部发布《新能源汽车动力蓄电池梯次利用管理办法》)	• Circular Economy Action Plan • Directive for end-of-life vehicles 2000/53/EC • Commission Decision 2005/293/EC setting vehicle recycling quotas etc. • Regulation (EU) No 566/2011 and (EC) No 595/2009 dealing with access to repair etc. • Battery Directive (Directive 2006/66/EC)
Standards	• Unified standards by the China Securities Regulatory Commission (中国证监会统一标准)	• Unified EU labels for benchmarks (climate, ESG disclosures) by the EC and the EU Technical Expert Group on Sustainable Finance
International cooperation	• China is securing access to key battery raw materials abroad	• Minerals Security Partnership (MSP)

Source: Own table based on the policy documents mentioned in this chapter

3.1.1 Policy approaches in the EU

The automotive industry has already been in transformation for several years with European policy makers introducing various policies to lower CO_2 emissions of the sector. In the EU, central climate framework policies such as the **Green Deal** and the EUs binding target of achieving **climate neutrality by 2050** through the implementation of the **Fit for 55** package set an ambitious and clear goal to decarbonise industries, including the automotive sector as one of the key ecosystems for the EU industrial leadership. There is a lot of attention on the automotive sector, both in terms of **limiting vehicle emissions and in terms of improving the circularity of vehicles** and batteries. The last aspect is central to the **Circular Economy Action Plan (2020**), which promotes more circular business models (Brown et al. 2021, p. 78).

On the one hand, the automotive industry has to deal with a growing demand from consumers and politics for greener production, and on the other hand, is itself a major demand player for low-carbon products in supply chains. The CO_2 efficiency of products has now become a key **competitive advantage** that automakers increasingly want to exploit (Böttcher and Müller 2013, p. 478).

The key policy instruments **relevant to the supply chains** of the automotive industry include the **ETS**, which puts a price on carbon and lowers emissions caps for certain sectors. The automotive industry in Europe is not directly involved in the ETS. However, as many of its suppliers participate in the system, it is indirectly affected (ACEA 2021a). The influence of the

ETS on the industry will only increase as Phase IV progressively removes free allowances from the system and the value of carbon certificates increases (ACEA 2021a).

Additionally, the automotive sector, as a major downstream consumer of high carbon raw materials such as steel and aluminium, would be affected by the proposed **CBAM**. There could be high and increasing taxes in the future for key components and raw materials (approx. EUR 75 per metric ton of CO_2 emissions). In addition, CBMA is accompanied by increased administrative burdens for manufacturers, such as measuring emissions in supply chains and product lines. This will encourage the sector to actively seek out less carbon-intensive inputs to avoid paying the higher costs (Titievskaia et al. 2022).

The focus on the carbon emissions of products along the supply chain could even intensify in the future. While globally, the regulation of supply chains via due diligence legislation is increasing, the European Commission recently published its **proposal for a directive on Corporate Sustainability Due Diligence.** The current draft of the directive provides for all companies to adopt a climate transition plan in line with the Paris Agreement, including short- medium-, and long-term reduction targets (European Commission 2/23/2022).

These overarching policies that aim at accelerating the decarbonisation of supply chains are supported by **legally defined CO_2 limits and requirements for the EU vehicle fleet**. EU-wide regulations focusing on reducing the in-use phase CO_2 emissions of the automotive sector have already brought about a **shift towards EVs and increased the demand for low carbon vehicles**. Examples of legislation in the past include the introduction of mandatory CO_2 standards for passenger cars**, for example through Regulation (EU) 2019/631**, which entered into force on 1 January 2020 and the requirements for efficiency of electric motors (Commission Regulation (EU) 2019/1781 of 1 October 2019 laying down ecodesign requirements for electric motors) (Böttcher and Müller 2013, p. 483). This has already led to an emissions decrease by 20% in 2020 compared to the year before (Directorate-General for Climate Action 2021). Regulation (EU) 2019/631 sets maximum emission targets for passenger cars (95 g CO_2/km) and vans (147 g CO_2/km) for the period 2020-2024. In addition, specific emission targets are set annually for each EU manufacturer, based on the EU-wide targets. From 2025 and 2030 the EU fleet-wide CO_2 emissions targets for passenger cars will be strained by 15% from 2025 on and by 37% from 2030 onwards (European Commission 2022e). While these EU GHG emission standards formulate strict regulations, **they neglect calculation of the full life cycle emissions of a vehicle** (ADC 2020, p. 2). In order to map and reduce full CO_2 emissions, which increase proportionately in the supply chain, especially in the production of EVs, it is necessary to also account for the raw materials and manufacturing phases. This fact is taken into account in the existing Regulation (EU) 2019/631 through a clause that requires the European Commission to thoroughly review the **effectiveness of the regulation** by 2023 and consider the possibility of taking into account **life cycle emissions** of vehicles for subsequent CO_2 regulations (Mock 2019). The corresponding adjustment of the regulation from 2023 and expansion to include Life Cycle Analysis (LCA) emissions would significantly increase the pressure on the industry.

In addition to emission limits, there are various financial incentives aimed at decarbonising the automotive supply chain. These include, among others, the EU ETS, the VAT Directive, EU GPP criteria, the EU Taxonomy and the Urban Mobility package. According to the European Commission, approximately EUR 350 billion investment per year is needed to adopt to the climate targets by 2030 (European Commission 2020b). Therefore, the Sustainable Finance Action Plan (partly in force since March 2021) and the EU Taxonomy (in force since 12 July 2020) are concentrated on mobilising investments. The EU Taxonomy is a classification system for sustainable economic activities (Teubler and Söndgen 2020, p. 7). It sets criteria for around 80 subsectors, including the automotive sector, to determine if they are sustainable (Schütze et al. 2020, p. 974). Moreover, it provides for the European Commission, together with experts, to draw up a list of environmentally sound activities based on technically detailed assessment criteria. The European Commission proposed the delegated Act “EU Sustainable Finance Taxonomy” in early February 2022 (European Commission 2/2/2022). The act stipulates that only carbon-neutral vehicles such as BEVs, hydrogen and fuel cell vehicles will be classified as sustainable in the taxonomy, as a CO_2 threshold is set at 50 g CO_2/km. This would put the allowed taxonomy threshold below the current EU fleet limits of 95 g CO_2/km (Schütze et al. 2020, p. 976). When considering GHG emissions in value chains, the final production of vehicles is not explicitly covered by the EU taxonomy, but the production of the materials used is. Accordingly, the supplier for products could use public funds explicitly to restrict its purchasing to low-emission or emission-free steel (Teubler and Söndgen 2020, p. 15). The taxonomy regulation contains **disclosure requirements** for EU member states, financial market players and companies. This includes, among other things, the obligation to disclose the proportion of taxonomy-compliant investments in the portfolio of financial products. Potentially, this also covers data of companies, including the value chain, if they have business partners that are affected by the reporting obligation (Teubler and Söndgen 2020, p. 9).

There are **also regulations that indirectly target decarbonisation** by reducing the automotive industry’s dependence on primary materials (Material Economics 2018). The supply bottlenecks which became apparent during the recent COVID-19 pandemic and Ukraine conflict made automakers become more aware of the need to use recycled materials. The EU aims to make the dismantling and recycling of end-of-life vehicles more environmentally friendly.

The circular economy aims to decouple growth from environmental impacts by optimising resource use, minimise waster and pollution. The **EU Circular Economy Action Plan,** adopted on March 2020, focuses on closing resource loops through several strategies as remanufacturing and recycling (Baldassarre et al. 2022, p. 38). Incentives for recycling are set by the EUs regulation on recycling of automotive parts. The **Directive on end-of-life vehicles (2000/53/EC)**, together with Commission Decision 2005/293/EC of 1 April 2005 laying down detailed rules on the monitoring of the reuse/recovery and reuse/recycling targets set out in the Directive, deals, among other things, with the transfer, take-back and environmentally sound disposal of end-of-life vehicles. It defines clear reuse and recycling quotas (85%) for vehicles as well as reuse and recovery quotas (95%), and stipulates the obligation to transmit data to the European Commission (Braun et al. 2021, pp. 12–13).

In order to identify knowledge and governance gaps in **advancing a global circular economy**, the EU proposed a global alliance (GACERE) in its 2020 Circular Economy Action Plan (European Commission 2022e). China is not a member of the alliance.

Additionally, Regulation (EU) No 566/2011 and (EC) No 595/2009 deal with access to repair and maintenance information for consumer (Braun et al. 2021, p. 13). Batteries and vehicles are among the key value chains selected to increase **sectoral actions** aimed at expanding the market for circular products (Brown et al. 2021, p. 78).

In the context of the debates about an improved circularity of the European automotive sector, batteries play a central role. Making **batteries more sustainable** throughout their life cycle is a key goal of the European Green Deal. The **Battery Directive (Directive 2006/66/EC)** regulates the placing on the market, collection and environmentally sound disposal of batteries and accumulators in the EU (European Commission 12/10/2020a). In 2020, the European Commission proposed a **new Batteries Regulation** to replace Directive 2006/66/EC and improve the sustainability of batteries placed on the European market. The draft, which has yet to be adopted, would require all automotive, industrial and electric vehicle batteries to be fully collected at the end of their life cycle. This would require battery manufacturers to accept such battery types form the end-user and take them back free of charge. In addition, the proposal foresees the mandatory introduction of a specific carbon footprint declaration for all electric vehicle batteries[5] placed on the EU market (European Commission 12/10/2020b). This

[5] This is further specified: with internal storage and a capacity above 2 kWh.

intended harmonisation of the rules for calculating the carbon footprint for batteries in the EU is meant to enable the Commission to introduce maximum carbon footprint thresholds for batteries, aiming to support the achievement of the EU objective of reaching climate neutrality by 2050. The proposal provides for the introduction of a mandatory maximum carbon footprint value over the entire life cycle of batteries for electric vehicles and rechargeable industrial batteries from July 2027 (European Commission 12/10/2020c). The introduction of such a mandatory CO_2 life cycle emission limit for vehicle batteries would greatly increase the pressure on battery cell manufacturers in the EU and China to decarbonise their production. However, experts interviewed for this study claimed that **the carbon footprint of battery production** is not yet sufficiently addressed in the current draft. While the European Parliament has proposed to include resources such as the aluminium raw material bauxite, copper and iron as well as key battery raw materials such as cobalt, graphite, lithium and nickel in the new battery regulation, the member states in the European Council want to remove these materials from the list (Reckordt 2022b). In addition, researchers emphasise that, in order to ensure an efficient circular economy for batteries, imported batteries and the management of battery waste exported outside the EU should be subject to the same requirements as new and used batteries produced within the EU (Thomaset 2022, p. 8). In this respect, there is still potential for strengthening the decarbonisation potential of the proposed regulation.

In addition, the EU, together with ten other Western countries[6], has taken further steps to green supply chains for key battery raw materials by establishing the **Minerals Security Partnership (MSP)** in June 2022. The main goal of the partnership is to ensure that critical minerals such as cobalt, lithium and nickel can be sourced, processed and recycled in a way that allows member countries to share their geological resources with like-minded countries. The main goal is to build robust and responsible commodity supply chains that meet Green Deal standards, including climate benchmarks. This is also accompanied by an effort to reduce the current dependence on Chinese imports. If the MSP achieves its goals, the EU and other member states would no longer be dependent on Chinese imports of the selected raw materials. A central idea of the initiative is that compliance with climate and environmental standards in supply chains is easier to achieve in cooperation with similar political systems than in a trade partnership with China (Maihold 2022, p. 8).

3.1.2 Policy approaches in China

Various regulatory, financial and market factors aim to accelerate the decarbonisation of automotive supply chains in China. One expert interviewed for this study highlighted approaches to LCA emissions accounting, environmental product declarations, ESG targets, CSR, carbon footprint, and the EU carbon offset tax in particular as influential factors.

With the 14th Five-Year Plan (第十四个五年计划), outlined in the first part of this study, China has committed to **peak carbon emissions by 2030** and achieving **carbon neutrality by 2060.** The automotive sector is responsible for high carbon emissions and is therefore a key sector addressed in the 30:60 target (30:60 双碳目标) (Zhao et al. 2022, p. 6). Additionally, China's provinces have issued individual carbon peak planning (碳中和计划). The plans set out more detailed targets and pathways for achieving peak and neutral carbon in various areas, such as power, steel and non-ferrous metal, petrochemical, chemical, building materials, construction, transportation and other industries and sectors that are highly relevant to the automotive industry. The 14th Five-Year-Plan foresees a continued opening up of the Chinese market in a "dual circulation" growth strategy ("双循环" 新发展格局). One priority is the development of self-reliant and secure supply chains, by increasing the competitiveness of

[6] Australia, Canada, Finland, France, Germany, Japan, South Korea, Sweden, United Kingdom and the United States.

new materials and in the electric vehicles sector. Moreover, it encourages critical supply chains to remain within the country (Schäpe and Tsang 2021).

Similar as in the EU, China has gradually developed a concrete policy package to support the **shift to e-mobility** through successful pilot programs, long-standing central subsidies, and emission standards (Zhang and He 2022). Among those are the New Energy Vehicle[7] (NEV) Program (新能源汽车项目） (introduced in 2009) as well as the Parallel Management Regulation for Corporate Average Fuel Consumption (CAFC) and New Energy Vehicle Credits (乘用车企业平均燃料消耗量与新能源汽车积分并行管理办法）, both established in 2018, which punish the production of fossil fuel cars and reward the production of EVs (Chen and He 2022). The rapid growth of the Chinese EV market is largely attributed to these incentivizing policies. In comparison with the EU and the US, China has the fastest growth rate and is also home to the world's largest stock of electric vehicles, with 4.3 million cumulative electric passenger vehicle sales by August 2020, accounting for 47% of the global total (Jin et al. 2021). According to an analysis, the share of EVs in light duty vehicle sales will grow to 11% in 2022 and about 22% in 2025, if manufacturers comply with the dual credit policy requirements (Chen and He 2022, p. 2). Additionally, EV sales will depend on factors like consumer demand, model availability and other factors (Chen and He 2022, p. 2). Despite the success of the policy, it remains unclear what happens if a company fails to meet the credit requirements in China. There is no publicly available information on which companies have failed in the past and whether their failure had any consequences (Chen and He 2022, p. 2). There is also criticism that the dual credit policy of the CAFC and NEV dual credits policy was not directly linked to carbon emissions control (Zhao et al. 2022, p. 9). Targets that address the **full life cycle emission**s are not covered by these EV policies. However, in order to achieve the dual carbon target outlined in chapter 3.1.1 in the transformation of the energy sector, the Ministry of Industry and Information Technology is currently planning to set carbon emission standards for vehicles as soon as possible and to consider introducing such standards for the entire life cycle of vehicles. It also aims to promote environmentally friendly supply chains and products with green designs, as well as environmentally friendly, low-carbon solutions throughout the industrial chain (Aoki 2021).

The dual credit policy has been supplemented since 2021 by the **Chinese carbon trading policy** (碳排放权交易政策), which was already addressed in Chapter 3.1.1 on the policy approach for decarbonisation of the Chinese steel sector. The transport sector is not yet explicitly covered by the Chinese carbon market. Researchers call for the Chinese government to prioritise the creation of a single carbon trading market and conduct relevant research for the inclusion of the transport sector in the Chinese ETS (Zhao et al. 2022, p. 10). In addition, it is recommended that tax and fiscal incentives should be based on consideration of the entire life cycle of a vehicle. This would include a shift from double-credit policies to carbon control policies (Zhao et al. 2022, p. 10).

Similar to the EU, **financial regulations and incentives** are influencing the growing demand for decarbonisation in the automotive supply chain in China. Experts interviewed for the study emphasised that, in addition to growing international requirements for ESG reporting, the demand for green investments triggered by the dual carbon target has led to progress in environmental disclosure by financial institutions. In recent years, various policy documents have been published that aim to set uniform standards for the disclosure of climate and environmental information by listed companies – similar to the EU taxonomy approach (Sausmikat 2021). In 2015, the People's Bank of China published the Green Bond Endorsed Project Catalogue (绿色债券支持项目目录）, which lists projects that are eligible for green bond issuance and aims at reducing investments in non-sustainable projects through green bonds. While the EU Taxonomy is aimed at financial market participants (mainly investors) the Chinese Green Bond Endorsed Project Catalogue is aimed at green bond issuers and does

[7] In Chinese government documents, the term "New Energy Vehicles (NEVs)" refers to plug-in EVs eligible for public subsidies and includes battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs) and fuel cell electric vehicles.

not include a carbon emission threshold. Fossil fuels are also not excluded from its scope (Dai and Xie 2019, p. 2). Furthermore, the Green Industry Guiding Catalogue (绿色产业指导目录) which was established in 2019 by the central planning body National Development and Reform Commission aims to direct investments into green industries. Compared to the EU taxonomy, the catalogue focusses on pollution prevention and control instead of climate change and does not provide details on the policy basis (Dai and Xie 2019, p. 3).

In 2021 the People's Bank of China issued official Guidelines on Environmental Information Disclosure for Financial Institutions (金融机构环境信息披露指南), requiring financial institutions to disclose their environmental information at least once a year. The guidelines focus on carbon disclosure and incorporate principles from the international industry-led Taskforce on Climate-Related Financial Disclosures initiative. The guidelines incorporate standards with specific requirements for environmental management, risk analysis and impact assessment of their own operations and financing activities (People's Bank of China 2021). According to an expert interviewed for this study, environmental disclosure requirements in the financial sector will further strengthen green preference for investment and increase willingness to reduce carbon emissions in the automotive supply chain. Additionally, in 20202, the Hong Kong Green Finance Association proposed some principles (香港绿色金融协会) that market authorities and market participants should consider when defining the operational framework for climate transition financing (Zhu et al. 2022). Among those are transparency and format requirements, such as disclosure of plans aligned with the Paris Agreement and constraints on engaging in low carbon activities with evidence.

Similar to the EU, China is also focusing on improving the circularity of industry. China has developed a **Circular Economy Strategy** (循环经济发展规划) over the last twenty years, implementing a comprehensive concept that aims to align environment and industrial growth (Bleischwitz et al. 2022). While the EU strategy focuses more on the waste hierarchy and product policy, Chinese policies take a holistic approach, covering a range of economic, environmental and social indicators. Water and air pollution were made a core issue (Bleischwitz et al. 2022, p. 3). While the relevant policy documents do not set specific targets for the automotive sector, they also have an indirect impact on the sector and associated value chains. The 2016 Action Plan for the Circular Economy (2016年循环发展引领行动) published by the National Development and Reform Commission (NDRV) includes general proposals for applying the circular economy approach to the entire value chain and developing new business models based on circular economy principles. The plan was complemented in 2020 by a proposal for a "dual circulation" (双循环) (domestic-international circulation) strategy, which envisages closing loops domestically to become independent of the unstable international trade. In addition, the circular economy approach is also taken up in the current 14th Five Year Plan and elaborated in legislation such as the Circular Economy Promotion Law (中华人民共和国循环经济促进法) (originally from 2008), which was updated in 2018 (Bleischwitz et al. 2022, p. 3). The Chinese circular economy policies are face criticism for measuring resource productivity, which is often only measured on the basis of individual material flow systems and lacks standardised accounting methods. In addition, the issue of decarbonisation is not directly addressed and there is a lack of cross-company, cross-sector and cross-regional coordination (Bleischwitz et al. 2022, pp. 6–9).

In addition, specific policies have been developed to increase the **recycling and reuse rates of EV batteries**. The Electric Vehicle Battery Recycling Technology Policy (电动汽车电池回收利用技术政策) (in force since 2016) provides guidance to Chinese companies on the design, production and recycling process for EV power batteries and makes recommendations for the establishment for a battery recycling system which links upstream and downstream supply chain actors. The policy provides for companies to assume responsibility for environmental and resource-related aspects at all stages of the life cycle (including design, logistics, consumption, recycling and disposal) of their products in the sense of an "extended producer responsibility" (Muyi and Wenbo 2021). The policy was supplemented in 2018 by an interim policy (试行政策） that makes NEV manufacturers responsible for recycling the batteries in their vehicles and, among other things, requires them to set up collection points for old batteries and increase their cooperation with recyclers (Muyi and Wenbo 2021). The 14th Five Year Plan foresees the development of a more complete battery recycling system by 2025 and several policy documents published in 2021, such as the "Management Measures for the Gradual Utilisation of New Energy Vehicle Power Batteries" (《新能源汽车动力蓄电池梯次利用管理办法》） (published in August 2021 by the Ministry of Industry and Information Technology), include measures to improve the environmental protection, traceability and accountability of the secondary utilisation of EV batteries through improved collaboration of national and regional departments and industry stakeholders. Several selected regions and cities are implementing pilot projects on the improved battery recycling and reuse (Hampel 2022).

The Chinese government is therefore supporting the decarbonisation of the automotive industry through a mix of subsidies for the production of green products, requirements to increase circular economy capacities, and demand-side measures such as the establishment of green finance standards. Often, the automotive industry is not (yet) specifically mentioned in the relevant policies, but is indirectly affected through the regulation of its supply industries (such as the steel sector). In China, these measures must also be seen in the context of the state's close involvement in the automotive industry in the form of state-owned enterprises. The specific corporate structure of SOEs entails special obligations to the government and restricts, for example, the disclosure of information by the companies (García-Herrero and Ng 2021, p. 2).

Overall, as the automotive industry is critical to both the economy and national security, it is of strategic importance to the Chinese central government and is therefore heavily subsidized (Brown and Grünberg 2022). The government has invested an estimated USD 58.7 billion in the sector between 2009 and 2017, massively supporting the transition to electric mobility and the growing dominance of Chinese players in global EV value chains (Sebastian 2021).

3.2 Industry approaches

The automotive sector and individual companies have been increasingly addressing their environmental impacts and also the reduction of their GHG emissions (Böttcher and Müller 2013, p. 479). To achieve their GHG reduction targets also in the supply chain, car manufacturers are already implementing various measures – at the individual and sectoral levels. Emission reductions can be achieved through improved management, product design or the development and application of new technologies, processes and materials.

Transparency: reporting supply/value chain emissions

An important prerequisite for reducing GHG emissions in the supply chain is reliable recording, also along complex and global value chains. Emissions and resource transparency along the entire value chain will enable suppliers abroad to produce in an essentially climate-friendly manner (dena 2021, p. 136). The majority of the large car manufacturers report emission values as well as reduction target values for scope 1 and 2 emissions – emissions generated in their own plants and through energy procurement (Agora Verkehrswende 2022, p. 3). Many automotive manufacturers from the EU and China refer to the Greenhouse Gas Protocol (GHG Protocol), which was created by the World Business Council for Sustainable Development (WBCSB) and the World Resource Institute as a key reference **GHG accounting standard** for their emissions reporting (BMW 2022b, p. 22; Volkswagen AG 2022b, p. 46).

However, it should be noted that most Chinese car manufacturers do not publicly disclose their carbon emission reduction measures (in the supply chain). This study therefore mainly refers to overarching literature and examples from European manufacturers. This lack of information and transparency was explained by an expert interviewed for this study as being due to the fact that the Chinese automotive industry has not yet implemented a full life cycle carbon accounting system covering raw material sourcing, vehicle production, vehicle sales, vehicle use, vehicle disposal and recycling, and therefore the GHG emissions of the entire automotive industry chain are not yet known.

One stakeholder working to close these data gaps is the China Automotive Technology and Research Center (CATARC), a third-party auditor covering all related areas of the Chinese automotive industry, and its subsidiary Automotive Data of China Co, Ltd (ADC), which focuses on Chinese industry data. In 2018, ADC established the **World Automotive Life Cycle Association**, which launched the China Automobile Low Carbon Action Plan and conducted research in 2020 together with experts from various domestic and international organisations to account for the full life cycle GHG emissions of vehicles produced in China (ADC 2020). CATARC further published a document on the technical specifications for life cycle carbon emission accounting of passenger cars (乘用车碳排放核算技术规范) in 2021. The document sets out specific rules and standards such as the test range, the components required for the life cycle emission calculation and the emission calculation formula (China Automotive Technology and Research Center Co., Ltd. 2021). In the same year, CATARC, together with the National Technical Committee of Auto Standardization, issued the China Electric Vehicle Standardization Roadmap (Version 3.0) (中国电动汽车标准化工作路线图), which however does not mention life cycle emissions (National Technical Committee of Auto Standardization and China Automotive Technology and Research Center Co., Ltd. 2021).

While data on scope 1 and 2 emissions are already disclosed by many companies, scope 3 emissions – emissions that occur in the rest of the value chain – are less consistently recorded and reported, and few targets are set for reducing GHG emissions in the supply chain. This is despite the fact that CO_2 emissions from the supply chain account for up to 10% of total emissions for most manufacturers and suppliers (Agora Verkehrswende 2022, p. 3). In addition, some car manufacturers have already recognised that with the shift to electric mobility, supply chain emissions will play a more important role: although CO_2 emissions from the use phase are continuously decreasing due to the shift towards e-mobility, the importance of emissions in the supply chain is increasing proportionally. Furthermore, due to a change in the demand for components and parts, the relevance of the supply chain has increased in the decarbonisation plans of industrial stakeholders (cf. amongst others BMW 2022a, p. 79; SAIC 2022, p. 8; Volkswagen AG 2022b, p. 41). Several major European automakers have announced targets to reduce GHG emissions not only in their production but also in their supply chain: Volkswagen will phase out the production of combustion engine vehicles between 2033 and 2035 (Volkswagen AG 2022b). In September 2021, BMW announced that it would reduce its life cycle CO_2 emissions by 40% by 2030. Daimler aims to produce in a climate-neutral manner from 2023 onwards (BMW 2022a). Swedish manufacturer Volvo Cars aims to reduce its overall carbon footprint per vehicle by 40% between 2018 and 2025 and achieve a company-wide carbon footprint of zero by 2040 (Volvo Cars 6/16/2021).

The recording of emissions at scopes 1, 2 and 3 is the first measure at company/industry level to achieve reduction targets. Through systematic recording and ongoing screening, the risk areas and hotspots for CO_2 emissions are recorded in sub-areas. Based on the information, reduction targets are formulated and systematically anchored at all management levels (Muslemani et al. 2022; Volkswagen AG 2022b, p. 41).

In addition to applying reporting and accounting standards such as those provided by the GHG Protocol or the Science Based Targets Initiative, some companies are experimenting with **digital approaches** in order to exchange data across borders and industries on standardised data exchange platforms for market communication between providers, suppliers and consumers. This is intended to enable the transition from what is often only a rough estimate of emissions to a reliable recording of real emissions along the entire supply chain. Great hopes are placed on distributed ledger technologies, e.g. blockchain (dena 2022, p. 20). For example, the Catena-X Automotive Network – an association of international partners in the automotive supply chain – is working on an open, scalable, decentralised network for cross-company and secure information and data exchange, with which a digital image of the core processes of automotive value creation is to be created and real CO_2 data in the supply chain measured and made comparable (Catena-X 2022).

Few automotive companies also ask their suppliers to participate in transparency programmes such as the Supply Chain programme of the Carbon Disclosure Project (CDP), the core of which is annual reporting on, among other things, climate aspects, reduction of CO_2 emissions or increasing the share of renewable energy[8]. OEMs can incorporate the results of the CDP ranking for their suppliers into their purchasing processes and reflect them in supplier meetings and supplier management strategies. BMW uses the CDP ranking results of its suppliers to determine the group of bidders in awards, among other things (BMW 2022a, p. 79).

Incentivising the use of low-carbon energy sources

An important lever for CO_2 reduction in the supply chain is the use of green electricity. This plays a particularly crucial role in the energy-intensive production of battery cells for vehicles (Hannon et al. 2020, p. 4). Car manufacturers can influence their suppliers, for example by contractually agreeing that only renewable energies will be used for the production of battery cells. Car manufacturers, such as BMW, Volkswagen AG, Volvo Cars also sign contracts with suppliers of battery cells and other energy-intensive inputs to use green electricity (BMW 2022a, p. 79; Volkswagen AG 2022b, p. 41; Volvo Cars 6/16/2021). For electricity shares that are needed for production and that cannot yet be covered by renewable energies, lower-CO_2 energy sources such as biogas, hydrogen and renewable electricity can be used (BMW 2022a, p. 72).

The use of low-carbon energy also plays a central role in energy-intensive steel production in order to reduce process emissions. Approaches to this from the steel industry were described in detail in Chapter 1. Here, too, car manufacturers are already using their power as important buyers by large-scale upfront investments in green steel production pilot projects or making the use of clean energy a procurement criterion and contractually obliging suppliers to comply. Various European and Chinese car manufacturers are collaborating with steel producers to test the production of steel with hydrogen or to promote the use of other low-carbon energy sources (see box on page 51-52).

Various car manufacturers have already made or are planning to make CO_2-reduction measures a criterion for awarding contracts to their suppliers.[9]

Development of joint standards at industry level, e.g. through business/industry initiatives

Both of the above approaches are carried out by OEMs on an individual level with their suppliers, but are also worked on in various cross-sectoral initiatives. Some initiatives are working to develop international standards for, among other things, the identification and reduction of GHG emissions along the supply chain of highly energy intensive raw materials and products, e.g. ResponsibleSteel, the Aluminium Stewardship Initiative and Drive Sustainability (Aluminium Stewardship Initiative 2022; ResponsibleSteel 2018; Drive Sustainability 2021). Internationally uniform standards would make it easier to compare the CO_2 performance of international suppliers and facilitate the recording of scope 3 emissions for OEMs (Muslemani et al. 2022, p. 6).

Cross-sector initiatives can also generate knowledge that a single company could not compile on its own. For example, the Drive Sustainability initiative developed the *Raw Material Outlook Platform*, a publicly accessible online platform that lists the key raw materials in automotive production and their associated environmental, social and governance risks along the entire

[8] https://www.cdp.net/en/supply-chain

[9] BMW has introduced a corresponding award criterion since 2020 BMW 2022a, p. 79; VW plans to make CO2 emissions a central award criterion for relevant supplier contracts in the future Volkswagen AG 2022b.

value chain, including GHG emissions (Drive Sustainability). Such reports can be used by many companies in the sector to identify GHG hot spots in the supply chain (BMW 2022a, p. 77).

Individual companies often have no direct contact with suppliers at the lower levels of the supply chain and also have little market power, for example at the mining level, where they have only small market shares (Stiftung Klimawirtschaft and Better Earth 2022, p. 18). By joining forces in sector initiatives, companies can pool their power as buyers and exert greater influence on suppliers.

Companies often commit to additional reduction targets and criteria sets by joining cross-industry initiatives. For example, Swedish car manufacturer Volvo Cars joined the SteelZero initiative. Here, automotive companies commit to procuring 100% net zero steel by 2050. The initiative, run by the Climate Group and ResponsibleSteel, aims to harness the collective purchasing power of different organisations from sectors that procure significant amounts of steel to push towards a decarbonisation of steel production (SteelZero 2022).

Initiatives also organise exchange formats that bring together OEMs and suppliers to discuss decarbonisation approaches. The Drive Sustainability initiative, for example, organised a dialogue with 25 Chinese Tier 1 suppliers in 2018 with its China partners BMW; Volvo Cars, Volvo Group, Volkswagen, Daimler, Jaguar Land Rover and Scania. The focus was on how OEMs and their tier 1 suppliers can develop a common approach to improve sustainability beyond tier 1, down the supply chain (Drive Sustainability 2018). One expert interviewed highlighted that such formats are also developing into training modules that are used by large OEMS for training their suppliers, including on the topic of decarbonisation. According to the interviewed expert, training and knowledge building on CO_2 management is particularly relevant and in demand among suppliers in China, because many suppliers there have less knowledge of CO_2 reduction measures than in the European context, for example, and often little support for emission reduction measures comes from the management level in supplier companies.

Circular economy approaches/ improvement of product and material efficiency

In addition to collaborating with suppliers, sharing data and setting incentives to reduce emissions in supplier processes, for example through procurement criteria, OEMs are reducing CO_2 emissions in their supply chain by increasing the resource efficiency of their vehicles.

On the one hand, this is achieved by increasing material efficiency, for example by designing and manufacturing products that use less material, such as lightweight construction or reducing the oversizing of vehicles (dena 2021, p. 134). Lightweight construction is an essential approach to reducing the life cycle emissions of vehicles, for example through the increased use of aluminium (hybrid car bodies), carbon and other composites instead of heavy metals such as steel. The weight of a vehicle is decisive for the CO_2 emissions during the use phase. A lower weight leads to lower fuel consumption and therefore lower CO_2 emissions. This is particularly relevant due to the long service life of vehicles. For the European automotive sector, the use of lightweight construction has the potential to save 9 million tons of CO_2 per year (Braun et al. 2021, p. 21).

In addition, emission savings can be achieved, also along the automotive supply chain, by increasing recycling and reuse quotas, reducing the use of primary raw materials (dena 2021, p. 143). The recycling of aluminium and the use of aluminium recyclate offer great potential for CO_2 savings, particularly in the use of aluminium in automotive construction. Only about 5% of the energy required to produce the metal as a primary raw material is needed to melt down used aluminium (Braun et al. 2021, p. 17). The use of secondary material for aluminium can save around 80% of CO_2 emissions compared to primary material. In the case of steel, the savings potential is 70%. In addition, environmental risks and damage associated with the extraction of raw materials are also reduced (BMW 2022a, p. 71).

Synthetic material components are also recycled into high-quality granulate, which in turn can be used to produce new components. This can save up to 2 tons of CO_2 per ton of plastic (depending on the recycling process) (Braun et al. 2021, p. 18). Other sources speak of an emission saving potential of 34% through the increased use of recycled plastic materials such as polypropylene or polyethylene in car parts, which are usually not visible (Hannon et al. 2020, p. 3).

In order to fully exploit the potential for CO_2 emission savings through the increased use of secondary raw materials, it must be ensured at the product design stage that materials can be recycled and reused without significant loss of quality (Braun et al. 2021, p. 17; dena 2021, p. 137).

Particularly with regard to the energy-intensive manufacturing process of battery cells, recycling approaches are also being specifically developed further by automotive manufacturers, as there is great potential for GHG savings in the life cycle if important raw materials such as lithium, nickel, manganese and cobalt, as well as aluminium, copper and plastics can be recovered and recycled as secondary materials. In recycling processes that do not require energy-intensive melting in a blast furnace, up to 1.3 tons of CO_2 can be saved per 62-kWh battery (Volkswagen AG 2022b, p. 62). In China, piloting of EV-battery recycling already started in selected cities in 2018 (Brown et al. 2021, p. 38). Currently, there are about 47 battery recycling companies in China that are whitelisted by the government. Two of these large companies – Brunp and GEM – account for about 50% of the total official battery recycling business in China. Brunp is a subsidiary of CATL, the world's largest manufacturer of batteries. In October 2021, CATL also announced that it will build its own recycling plant (Hampel 2022). In Europe, too, initial attempts to recycle EV batteries, albeit to a much smaller scale, are also underway (Brown et al. 2021, pp. 37–38).

Substitution of resources and materials

Another approach to reducing CO_2 emissions along the automotive supply chain is to avoid the negative impacts of finite raw materials, materials and products as far as possible and to use renewable raw materials: many renewable raw materials have a better CO_2 balance than fossil raw materials, such as hemp, kenaf, cellulose, cotton and wood. For example, substituting dandelions for rubber can save transport distances, as dandelions grow close to industrial areas. This can reduce transport emissions. However, the potential for CO_2 savings through substitution is still immature and strongly dependent on the processes and materials used (Braun et al. 2021, pp. 26–27).

Examples of good practice

European car manufacturers are working together or investing in key technologies for CO_2-free or low-carbon production of key raw materials and components, especially steel. This enables them to reduce CO_2 emissions in their supply chains.

In June 2021, the Swedish **Volvo Cars Group** became the world's first car manufacturer to announce a collaboration effort **with steel producer SSAB to explore the development of fossil-free high-quality steel** for use in the automotive industry. SSAB's HYBRIT initiative is investigating processes to replace carbon in the steel manufacturing process with green energy and hydrogen. SSAB plans to supply the market with fossil-free steel at a commercial scale from 2026. Volvo Car pledged to use the fossil-free steel in its own production, thereby also reducing emissions from the supply chain (Volvo Cars 6/16/2021). In addition, Volvo Cars has converted its largest manufacturing plant in China to 100% renewable energy in 2020. This was achieved through a new electricity supply contract, under which the majority of the plant's energy is sourced from hydropower, with the remainder coming from solar power, wind power and other renewable sources (Volvo Cars 6/16/2021).

Volkswagen Group China has taken several measures to reduce GHG emissions in the supply chain and during production in parallel with the Group's push to accelerate electric mobility in 2021. For example, Volkswagen Group China is **encouraging its suppliers to use renewable energy** and is working with partners and suppliers in China to create a roadmap for using 100% renewable electricity by 2030, including both ICE and EV suppliers. Suppliers to the Group are committing to switching to electricity from renewable sources by signing **commitment letters**. In addition, a project at the Volkswagen Anhui plant in 2023 will produce VW models equipped with **battery cells made with 100% renewable electricity**. Volkswagen Group China is also implementing the so-called S-rating programme in China, a **mandatory assessment of supplier sustainability performance**, which has also included the production of electric vehicles since 2021. The Group further aims to **increase the use of recycled content in new battery cells** and strengthen responsible sourcing of raw materials for batteries, particularly nickel, cobalt and manganese (Volkswagen AG 2022a). Car manufacturers also enter into contracts with suppliers for the purchase of low-emission products for other components and materials: in the production of new electric car models, for example, **battery housings and rims made of green aluminium** and **low-emission tyres** are used. With the targeted use of more sustainable focus components, VW wants to improve the CO_2 balance of its electric car model series by around 2 tons of CO_2 per vehicle (Volkswagen AG 2022b, p. 41).

Manufacturers of vehicle parts that supply OEMs are also entering into cooperative ventures with metal producers and other companies to achieve their own decarbonisation targets and meet the demand from OEMs for low-carbon components and parts. For example, the Spanish metal processor Gestamp (specialised in forming technology), which is a key supplier for the European automotive industry and also operates some plants in China, signed an agreement with the steel manufacturer ArcelorMittal in 2021 to use its green steel certificates for the production of automotive components. Gestamp says it is the first tier 1 supplier in the automotive sector to offer OEMs products with a lower carbon footprint based on project-based CO_2 savings achieved through ArcelorMittal's decarbonisation initiatives (Gestamp 2021).

4. Major challenges for the decarbonisation of the automotive production in the EU and China

There are several challenges in decarbonising supply chains in the automotive industry, mainly due to the complexity and global interconnectedness of the sector. Some of these challenges apply to the automotive sector as a whole, while other challenges are specific to the transformation of the Chinese or European sector and their supply chains. The global automotive industry has faced particular challenges in recent years: economic shutdowns due to the COVID-19 pandemic, supply difficulties for semiconductors and the Ukraine conflict have put particular financial pressure on the sector (Deutsche Welle 2022). While this has contributed to increased focus on supply chain issues in the automotive industry, it is unclear whether these developments will slow or accelerate decarbonisation efforts. However, in both countries, uniform legal targets for greenhouse gas reductions in the sector's supply chains are still developing. This also complicates political cooperation between China and the EU with regards common targets and harmonisation of the decarbonisation policies, strategies and standards. Additionally, there are various technological challenges, e.g. in improving resource efficiency to reduce CO_2 emissions and securing the availability of green energy.

4.1 Major challenges in the EU

The **automotive supply chain is highly complex, internationalised and includes many different raw materials and processes**. This poses major challenges for automakers in the first and central step of decarbonising the supply chain: creating **transparency** and recording all relevant emissions along the supply chain. OEMs and their suppliers need to understand the CO_2 intensity of different components and processes and recognise the value of reduction potential (Hannon et al. 2020, p. 5). To achieve this, it is necessary to create transparent carbon footprints along the entire value chain, for which **common reporting standards** must be established and correctly applied (dena 2021, p. 19). However, many European car manufacturers struggle to record scope 3 emissions in a reliable and comparable way. While manufacturers already have tools in place to capture their scope 1 and 2 emissions, the collection of emissions data from indirect and direct suppliers remains largely incomplete (Muslemani et al. 2022, p. 6). One expert interviewed for the study attributed this primarily to a lack of a uniform standard within the EU for measuring supply chain CO_2 emissions. While many European car manufacturers already base their emissions accounting and reporting on voluntary standardised methodologies such as the GHG Protocol and Science Based Targets Initiative, there is still a lack of standardised options for allocating emissions to individual products at supplier and sub-supplier level. The development of a uniform, efficient standard for data exchange along the supply chain would allow an individual calculation of CO_2 emissions per vehicle instead of calculating the CO_2 footprint based on average values.

While the EU GHG **emissions standards for vehicles do not yet cover the full life cycle emissions**, an examination of the possible extension of Regulation (EU) 2019/631 to life cycle accounting is expected by 2023 (Mock 2019). Such a revision of the existing standards could greatly tighten the reporting requirements for European automakers in the future. The requirements of the EU taxonomy on carbon-neutral vehicles are already putting financial pressure on the automotive sector to step up efforts to record and reduce supply chain emissions.

Another challenge arises from the automotive industry's **dependence on green steel products**. Despite the trend toward lightweight construction, a passenger vehicle still consists of a significant proportion of steel. Reducing emissions from the steel input is therefore central to decarbonising automotive supply chains as a whole. Some European automakers have launched pilot projects with steel producers for green products. However, most of these are not yet available at scale (Hannon et al. 2020, p. 5). This leaves automotive manufacturers dependent on a solution to decarbonise their supply chains, most of which is currently still in the pilot phase. Scaling up to industrial level requires investment and research and development, which SMEs in particular are often not able to do on their own (dena 2021, p. 146, 2022, p. 12). This offers potential for increased cooperation between European OEMs and Chinese steel producers, as a significant proportion of flat steel products are imported into the EU from China, and at the same time many European manufacturers (especially from Germany) are expanding their production capacities in China. In order for the automotive sector to decisively advance decarbonisation in the steel sector through demand for green products, cooperation between automotive manufacturers and steel producers must be expanded and also extended to the international context.

In addition to the low availability of green steel, there is often a **lack of sufficient green energy** to guarantee carbon-free production. In central production sites of the European automotive industry (key locations for many direct suppliers, upstream sectors and plants), coal accounts for a large share of the local electricity mix, resulting in particularly high GHG emissions. For example, coal-fired electricity accounted for 74% of the electricity mix in Poland in 2019. In the Czech Republic, the share of coal-fired electricity was around 45% (Weiss et al. 2022, pp. 39–40). In China, where many European OEMs have major production sites, coal also accounts for a large share of the electricity mix (64% in 2019) (Weiss et al. 2022, p. 40).

This means that the decarbonisation of the supply chain of European manufacturers is also dependent on the energy transition to renewable energy sources in China.

Another challenge for reducing GHG emissions in the supply chain stems from the fast-moving **transformation of the automotive sector towards e-mobility**, which will accelerate even more for European manufacturers, especially against the backdrop of the ban on combustion engines as of 2035. While the shift to e-mobility will reduce use phase emissions, it will create new hotspots for GHG emissions in the supply chain – especially through the increased use of CO_2-intensive aluminium (for light-weight constructions) and battery materials. While Chinese stakeholders clearly dominate the global market for automotive batteries, the EU is now trying to increase its own battery production capacity. Standards for the most CO_2-efficient production possible should be jointly defined at an early stage so that the increasing competition between European and Chinese battery manufacturers does not lead to a lowering of environmental standards in order to achieve competitive advantages.

In addition, the European automotive sector is under increased pressure to **improve circularity**, partly due to policies such as the EU Circular Economy Action Plan. However, major technical challenges remain, especially with regard to **recycling processes**. While the increased use of secondary raw materials offers high GHG savings potential (Weiss et al. 2022, p. 131), there are still numerous technical challenges: the recycling of metals such as steel, aluminium and copper, which are important for the production of automobiles, often leads to downcycling. This means that the recycled raw material does not have the same quality as the primary material. This is often due to the fact that copper and steel or different aluminium alloys are mixed together during the shredding of end-of-life vehicles. As a result, reuse in the automotive industry in particular is often no longer possible. Shredding the so-called "light fraction" and plastics can also lead to a loss of quality during recycling (Braun et al. 2021, p. 15). One expert interviewed for this study highlighted this aspect as a major challenge, pointing out that alloys in particular often pose a problem, as separation by type is necessary for the production of high-quality raw materials. With regard to the plan to ramp up European battery production for e-vehicles, it should also be noted that recycling methods for batteries are still at an early stage and so far, dominated by Chinese players. Here, an early exchange of knowledge could lead to a quicker adaptation of the best available techniques.

4.2 Major challenges in China

Chinese automotive manufacturers are also faced with the challenge of decarbonising their processes due to the **complexity of their supply chains**. This problem is exacerbated by the fact that there is no widely applied unified life cycle carbon accounting system in China, resulting in a lack of information on GHG emissions in the automotive supply chain. A review of sustainability reports from major Chinese automotive manufacturers[10] also reveals a lack of transparent reporting on scope 3 emissions. One expert interviewed for the study noted that despite the rapid growth in the e-mobility market, consumer demand for green products in China is not yet as strong, resulting in a lack of incentives to improve CO_2 reporting and recording.

As in the EU, Chinese automakers continue to rely heavily on steel products and on **decarbonisation in the steel sector** to reduce their own supply chain emissions. So far, however, green steel products are not sufficiently available in China. The Chinese automotive industry needs to make more use of its potential as a driver of decarbonisation in the steel industry and, for example, initiate cross-industry pilot projects, as some European OEMs have already done.

In addition to the lack of widely available low carbon material and breakthrough technologies, Chinese automakers also face the challenge of the **availability of sufficient green energy**.

[10] SAIC 2021 Corporate Responsibility Report and Chongqing Changan Automobile Company Limited 2021 Semi-annual Report.

Due to the high share of coal in the electricity mix, this is a particular challenge in China, which was also pointed out by experts interviewed. Carmakers and suppliers are dependent on the availability of sufficient clean energy and the necessary infrastructure to meet the high energy demands of low-carbon processes (Zhao et al. 2022, p. 6).

China has taken **circular economy measures** such as the 14th five-year Circular Economy Strategy (“十四五” 循环经济发展规划) and electric vehicle battery recycling technology (电动汽车动力蓄电池回收利用技术政策), but there is a lack of action leading to coordination between companies, sectors and regions. While there are some industry pioneers taking a holistic and ambitious approach to the circular economy, this has not been achieved on a larger scale. There is a need for new indicators for the productivity of circular economy and its contribution to decarbonisation, monitored by frameworks at different levels (Bleischwitz et al. 2022, p. 10). As China is a leading manufacturer of EV batteries, one focus of improved circularity in automotive supply chains is the recycling and reuse of EV batteries, which theoretically offers great potential for reducing supply chain emissions. However, recycling and reuse rates of lithium-ion batteries are very low. One of the reasons for this is uncertainty about the economics of recycling, which today is often still more costly than the production of new batteries due to low raw material prices. In addition, other types of batteries may be developed in the future, making long-term investment in lithium-ion battery recycling uncertain (Jacoby 2019).There is still a great need for R&D in this area (European Environment Agency 2018, p. 46). China has also seen the development of a large number of unofficial, smaller recyclers that offer cheaper recycling services than the officially licensed recyclers. However, these unofficial battery recyclers do not always reliably recover all valuable resources, such as cobalt and nickel, and often improperly dispose of the valuable – and environmentally harmful – materials (Hampel 2022).

4.3 Major challenges for EU-China cooperation

Due to the strong economic linkages between the EU and China in the automotive and related sectors, the development of **consistent data exchange on GHG emissions** from products and raw materials as well as the development of uniform **standards for the reduction of GHG emissions** are key challenges. Both China and the EU lack uniformly prescribed and applied standards for recording and reducing life cycle emissions, even though many European manufacturers use international standards such as the GHG Protocol on a voluntary basis. One expert interviewed for the study pointed out that Chinese and European stakeholders along automotive supply chains would often use differing standards, making the exchange of information and development of aligned decarbonisation strategies even more difficult.

Another challenge for the reduction of supply chain emissions in the German-Chinese relationship arises in relation to **aluminium**: China is a key global provider of aluminium, and the EU imports large quantities of the CO_2-intensive material from China. While OEMs are already working extensively on reducing emissions from steel production, aluminium still plays a subordinate role in most decarbonisation strategies. One way to facilitate exchange between Chinese and European stakeholders on the emission reduction potential of aluminium products could be the US-EU *Global Arrangement on Sustainable Steel and Aluminium*, which focuses on common production standards and their decarbonisation. The agreement is open to other countries that aim to engage in common standards for the trade of low-carbon metals (European Commission 2021d). Stronger cooperation with China on issues of sustainable steel and aluminium production would be of key importance in view of China’s central role as an exporter.

A final challenge in the decarbonisation of automotive supply chains against the specific background of Chinese-European trade relations arises with regard to the production of **EV batteries.** Despite attempts to diversify its import sources, the EU is heavily dependent on imports from China, especially lithium and battery-ready cobalt. This dependency could further increase if European stakeholders increase EV battery production capacity in the EU as planned. Even though China seems willing to adopt more sustainable production methods and do more to protect the environment in the extraction and processing of battery raw materials, environmental standards in China are still generally lower than in the EU, which can lead to high CO_2 emissions (Wrede 2022). To enable the most environmentally friendly production of EV batteries in the EU, European stakeholders should increase cooperation with Chinese suppliers and policy stakeholders on decarbonisation strategies in the raw materials and components sector. As one expert interviewed for the study pointed out, there is a large **knowledge and reporting gap about emissions in the mining sector** as a whole. As of 2021, the majority of large mining companies has not even set carbon-reduction targets that match the UN goal of limiting global warming to 2 degrees Celsius above pre-industrial levels (Durao 2021).

Current geopolitical developments such as the COVID-19 pandemic or the Ukraine conflict, which have in some cases led to supply difficulties, as well as the growing political demands within the EU for compliance with environmental and social standards along supply chains, have led to a trend of **"reshoring" supply chains** for critical raw materials and sectors. Reshoring refers to a process in which production is moved back or closer to the home market, for example, to avoid supply chain disruptions (Suzuki 2021, p. 2). This is reflected in European efforts to expand domestic production capacities for electric cars and batteries, for instance. These include the construction of European battery cell factories for electric cars or the establishment of factories for the production of semiconductors, such as a new Intel plant in Magdeburg, Germany (Piller and Theurer 2022). At the same time, European policy initiatives such as the MSP serve the goal of becoming independent of Chinese raw material imports – with potentially strong implications for EV battery and raw material supply chains. An underlying idea of the MSP is that climate targets as well as social and environmental standards in supply chains are easier to achieve when importing battery raw materials from democratic, Western-oriented countries than in trade relations with China (Maihold 2022, p. 8). Since the outbreak of the COVID-19 pandemic, there has also been a growing trend in China towards the relocalisation of central value chains. The announcement of the "Dual Circulation" strategy, for example, reinforces the importance of local consumption over overseas exports and imports as a driver of economic growth and key domestic policy goals (Suzuki 2021, pp. 4–5). These developments could make cooperation between the EU and China more difficult in the future, including in the area of decarbonisation of supply chains.

Opportunities for greening the EU and China value chain for the steel and automotive sectors

Recent crises such as the COVID-19 pandemic or the conflict in Ukraine have led to the collapse of global trade flows and delayed the delivery of key goods. This has shown policy makers worldwide how vulnerable global supply chains can be and led to a trend of re-shoring. This also applies to trade relations between China and the EU. In a resolution from September 2021 on a new EU-China strategy, the EU Parliament calls on the European Commission to critically review the EU's dependence on China "in certain strategically important and critical sectors" (European Parliament 2021a) and to reduce "undesired dependencies" (European Parliament 2021a).

As this study shows using the example of the steel and automotive industries, the European and Chinese economies are currently strongly interlinked through complex supply chains. This link is likely to remain in place in the long term, despite efforts to diversify supply chains. This is because demand is growing in both sectors in China and the EU, and building alternative supply chains is a lengthy process.

This makes Sino-European supply chains central to achieving global climate goals. As shown, the production of steel and automobiles generates large amounts of GHG emissions. A significant amount of these emissions occurs in the global supply chains – for example in the extraction of raw materials, the production of components or transport. Both the EU and China have developed ambitious policies and industry approaches to reduce emissions from steel and automotive production. However, the emissions that arise in the EU-China supply chains have not yet been sufficiently addressed. For these reasons, this study identifies areas where stakeholders from the EU and China should cooperate in order to reduce emissions in the steel and automotive supply chains in a targeted manner.

One of the key findings of the study is that China and the EU share many common policies and challenges in the decarbonisation process of the steel and automotive sectors.

Regarding the **steel sector**, both China and the EU have set ambitious sectoral targets and are focusing their efforts on developing the maturity and scale of new production methods, especially hydrogen-based steelmaking as a decarbonisation strategy. Major challenges include the low maturity of current decarbonisation technologies and the need for substantial investment in research and innovation for the further development of low-carbon technologies.

In the **automotive sector**, both the EU and China have embarked on a transition towards e-mobility, placing even greater emphasis on supply chain GHG emissions in decarbonisation strategies. Policy makers and industry stakeholders face challenges in appropriately calculating vehicle life cycle emissions due to the complexity and length of automotive supply chains, and are therefore developing approaches to uniform standards. Other challenges include the insufficient availability of "green" materials (e.g., green steel), which have not yet been able to fully meet the demand of the automotive sector, and the lack of availability of green energy. In addition, both China and the EU have identified improving the circular economy, particularly for electric vehicle batteries, as a key approach to reducing environmental impacts in the automotive supply chain.

This results in the following **areas of action for policy and industry stakeholders, where there is great potential for GHG emission reduction through improved dialogue and cooperation between European and Chinese stakeholders**. The areas for action are based on common challenges and areas where China and the EU are already pursuing similar approaches[11]:

Areas for policy action

1. ***Ensure sufficient funding for the development of pilot and demonstration projects for current decarbonisation technologies*:** investment is needed in both China and the EU to make existing low-carbon technologies market-ready. The exchange of effective research and innovations funding can help to accelerate the development of mature technologies in the foreseeable future. The possibility of funding joint pilot projects, for example related to the low-emission production of electric vehicles, should also be explored. Discussion could entail the promotion of finance approaches to green steel. Joint finance mechanisms could be developed that are available to both European and Chinese stakeholders. This also concerns an alignment of the taxonomies on sustainability standards that serves as a basis for private investments and for decisions on the allocation of public funds.
2. ***Facilitate the dialogue between policy makers in the EU and China on CBAM and "Carbon Clubs":*** policy ambitions and fears on both sides need to be taken seriously regarding possible carbon border adjustment policies. Policy makers on both sides need to communicate their intentions to increase the mutual understanding of policy approaches. This requires appropriate dialogue formats for an exchange: multilateral and bilateral platforms between the EU and China could be used to dialogue on carbon and trade policies as well as on respective decarbonisation ambitions. With clear communication, the EU and China can jointly move towards an inclusive "climate club" based on mutual trust and common climate ambitions rather than exclusion.
3. ***Develop a common price signal:*** both the EU and China use carbon pricing mechanisms, especially emissions trading schemes, in order to enhance the shift towards low carbon technologies. Cooperating on carbon pricing in the steel and automotive sector in the form of policy dialogues helps to establish a long-term and increasing price signal for CO_2 emission reductions on different levels of the supply chain. Mutual learning from ETS experiences can support the convergence of both carbon pricing approaches and generate a clearer and more consistent policy framework for businesses and investors along the supply chain. Therefore, policy dialogues on emissions trading and carbon pricing could enhance a regulatory framework which empowers industry actors to contribute to joint climate objectives.
4. ***Enable a level-playing field for joint ventures and common industrial approaches:*** a multi-stakeholder and cross-sector approach needs to be applied that brings together companies, business associations, NGOs and research institutes both from China and the EU to exchange information on decarbonisation pathways that also include scope 3 emissions. Public-private partnerships can build on the demand for green steel and cars and help transfer technologies between sectors and countries. These exchanges must ensure that successful technologies become accessible to all actors at reasonable conditions. Carbon leakage can be strongly reduced if policy approaches provide common incentives to use near-zero emission production

[11] The results of this study will serve as input for workshops with European and Chinese experts from business, politics, science and civil society. Based on the overview of the study and the identified areas for action, recommendations for an enhanced EU-China cooperation on decarbonisation of supply chains in the steel and automotive sectors will be developed.

technologies. Public funding for the research and development sector as well as for the digitisation of the industry should complement the stakeholder dialogues.

5. ***Take action to develop joint standards for the decarbonisation process:*** the development of joint standards for the calculation and reporting of carbon footprints and life cycle emissions should also include scope 3 emissions and cover the full sectors. Political and economic stakeholders from the EU and China should work together on the development of internationalised standards that include, for example, secondary steel and steel scrap. For this, the necessary control and compliance mechanisms need to be established that can be applied by auditors. The joint standards can cover, for instance, the establishment of data platforms, supplier evaluation metrics, the alignment of fuel consumption standards, and scenario modelling. In the automotive sector, new initiatives for comprehensive life cycle accounting of GHG emissions of the Chinese automotive industry, such as World Automotive Life Cycle Association, should be encouraged to refer to existing international standards (e.g. the GHG Protocol) and exchange with international partners should be supported to ensure international comparability of standards.

Areas for industry action

1. ***Set clear decarbonisation targets for the supply chain***: automobile manufacturers can drive the shift to green steel as they play a key role in the introduction of steel products. As a starting point, both Chinese and European OEMs need to set decarbonisation targets for their supply chain, which can then be communicated in the form of clear requirements to suppliers of steel or even batteries. The steel industry and the companies themselves could also establish clear decarbonisation plans with explicit targets (e.g. based on science) and can learn from the experience of the automotive industry.

2. ***Strengthen cross-sector collaboration***: sector and industry initiatives such as Drive Sustainability, ResponsibleSteel, Aluminium Stewardship, etc. provide a framework for cross-sector exchange on the development of common standards for the transfer of GHG emission levels, the exchange of best practices and lessons learned. In addition, they help identify shared potential for influencing stakeholders in the deeper supply chain (e.g. mining companies) towards improved decarbonisation efforts. Chinese and European companies from both sectors – steel and automotive – should increasingly join such initiatives and engage in direct exchange.

3. ***Increased investment in joint R&D pilot projects***: there are already some examples of major automotive OEMs supporting research on decarbonisation pathways in the steel sector with investments and commitments to reduce emissions along their own supply chain. Such collaborations should be expanded and collaborations on decarbonisation technologies between Chinese and European industry actors should be strengthened. R&D investments should also cover the topics of improved circularity, material efficiency and recycling, especially in the areas of steel, battery (materials) and aluminium.

4. ***Improve the sharing of knowledge on decarbonisation with suppliers*****:** many suppliers do not yet have the same know-how on decarbonisation strategies as large OEMs. Offers for knowledge transfer, such as training courses for suppliers on CO_2 management, should therefore be stepped up. Here, a special opportunity arises from the fact that many large European OEMs have joint ventures in China; through these business relationships, training and knowledge exchange formats can be established

between OEMs and steel producers in China. Initiatives such as the CDP Supply Chain programme offer existing structures for entering into an intensified exchange on the topic of decarbonisation with the company's own suppliers.

5. ***Jointly increase transparency on GHG emissions along the supply chain***: there is still a need to improve the collection of GHG emissions data, especially for scope 3 emissions in the lower supply chain. This can be achieved by developing common standards (across countries) as described in the policy measures. Another solution, which some companies are already working on, is the development of digital exchange platforms through which emissions data can be shared among suppliers and customers in a standardised and simple way. Here, companies in the automotive and steel sectors should exchange information to ensure the usability of technical solutions along the entire supply chain. Here, too, the existing joint venture business relationships in the automotive sector offer potential for exchange between Chinese and European stakeholders.

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