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Which automakers are shifting to green steel?

An analysis of steel supply chains and future commitments to fossil-free steel

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EXECUTIVE SUMMARY

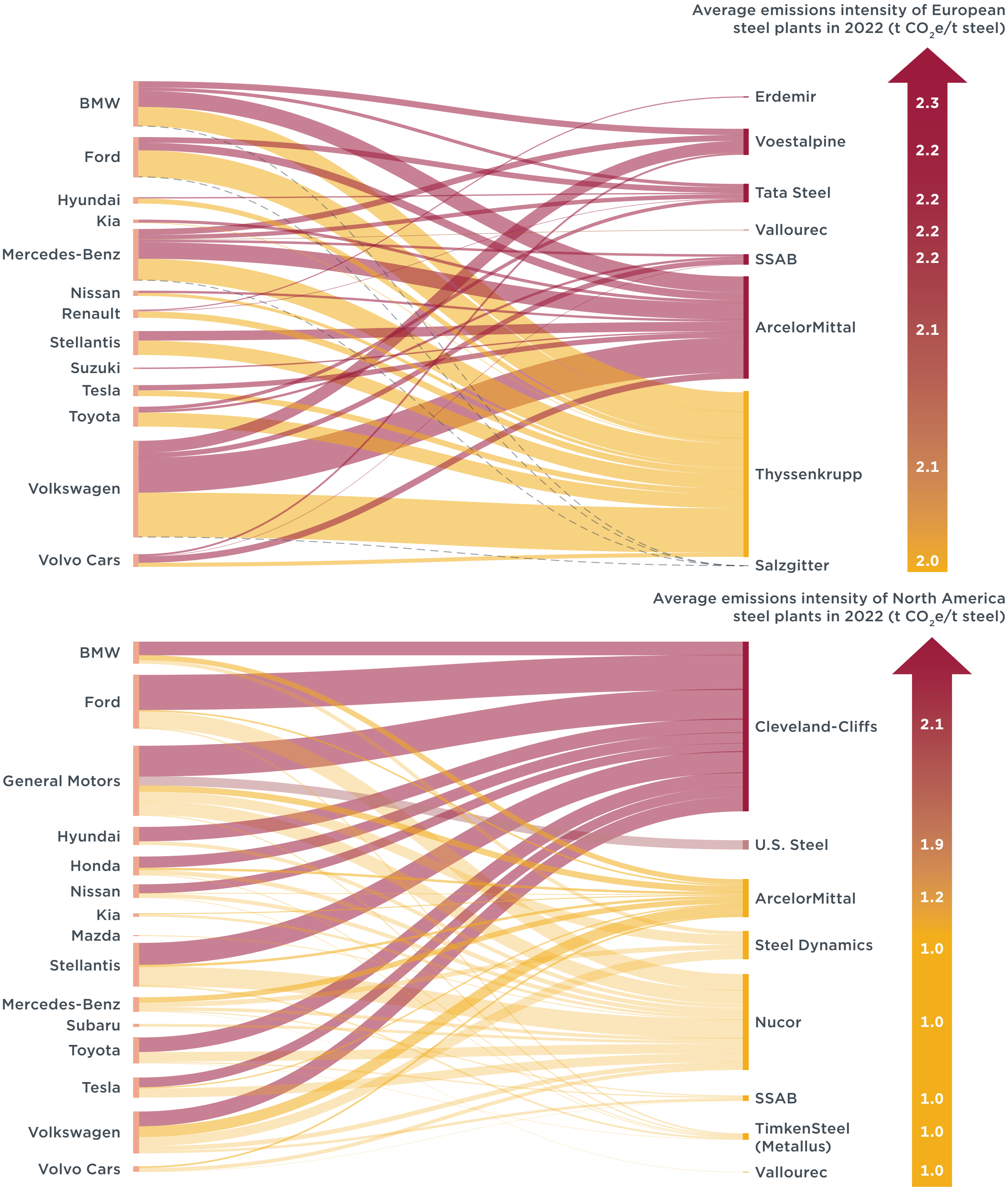
Steel manufacturing is responsible for 7% of global greenhouse gas (GHG) emissions, the highest percentage among all industry sectors. According to the International Energy Agency's Net Zero scenario, the steel industry will need to expand fossil-free steel production capacities and reduce its GHG emissions by 25% by 2030 to be on a pathway to achieve climate neutrality by 2050. The automotive industry, the second-largest consumer of steel at 12% in 2022, is uniquely positioned to support investments in fossil-free steel production. This is because of its high demand for primary steel, usually characterized by a higher quality and higher cost compared to other sectors, its higher exposure to consumers and public pressure, and the relatively low impact of higher steel costs on the total vehicle price.

This study estimates the GHG emissions intensity of steel supplied to 17 major automakers selling and manufacturing vehicles in Europe and North America, based on analyses of steel production pathways and automakers' supply chains for steel. The study also estimates the selected automakers' current steel-related GHG emission intensities at regional and global levels, and identified if these automakers have made public commitments to buying fossil-free steel or steel produced with fewer emissions in 2030. The study closes with recommendations for automakers and policymakers on ways to reduce emissions from the production of automotive steel.

Figure ES1 shows the identified economic connections between automakers and steel producers in Europe and North America.

Figure ES1

Average GHG emissions intensity of steel producers for their plants in Europe and North America in 2022 and the automakers supplied by these steel producers



Notes: Line thickness is proportional to the revenue received by steel companies from specific automakers. Dotted lines are used when revenue data is not available. These estimates are based on supply chain data from Bloomberg L.P. (2024).

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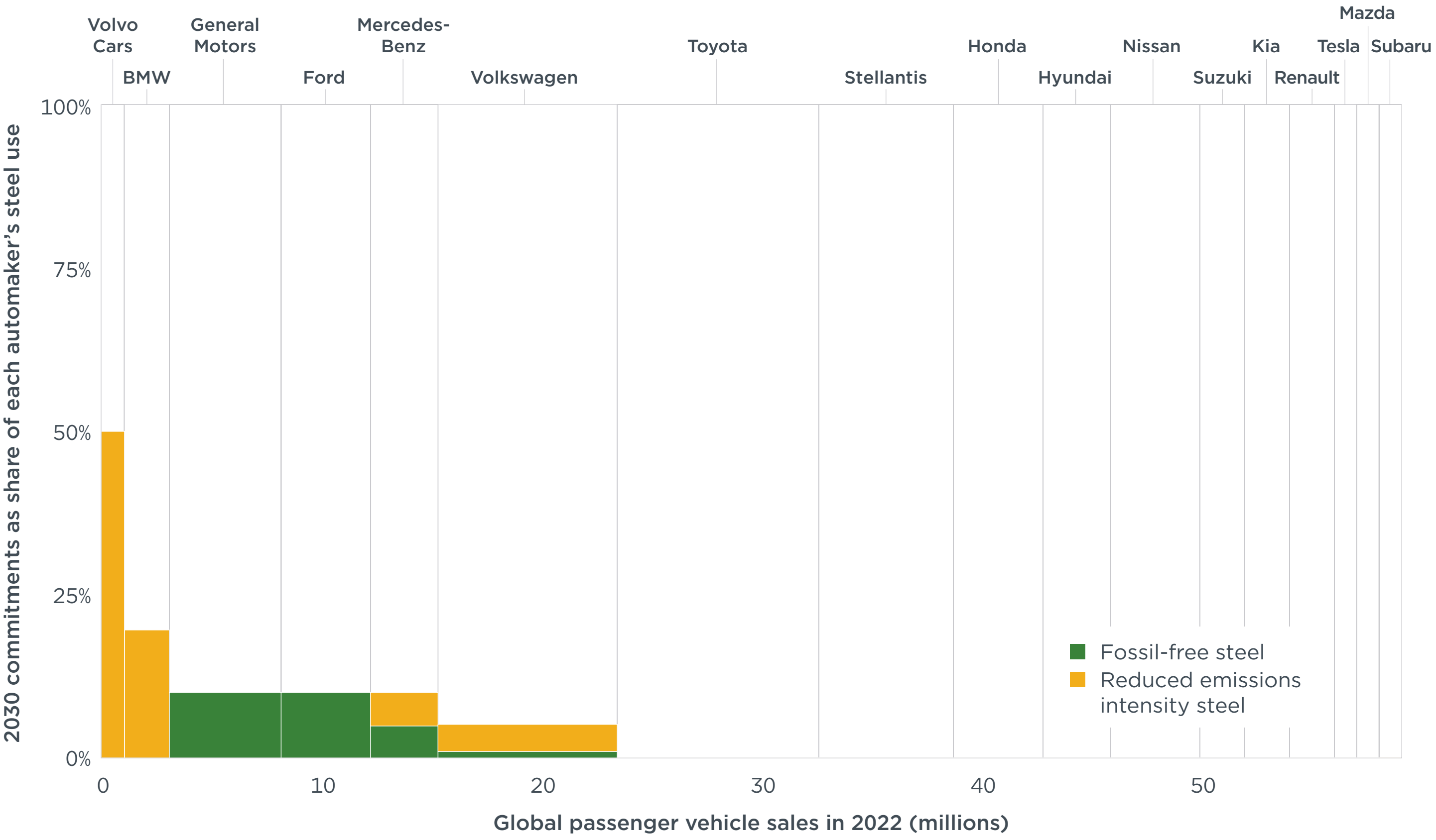
Automakers in Europe procure steel from companies with a disproportionately large share of steel produced through the blast-furnace–basic oxygen furnace (BF-BOF) pathway, which generates much higher GHG emissions than the electric arc furnace (EAF) pathway typically used to produce recycled steel. This may be explained by the higher quality steel demanded by the automotive sector. For the European companies identified as supplying steel to automakers, 97% of the installed steelmaking capacity is based on the BF-BOF pathway compared to the European average of 56%, with the remainder being EAFs. This results in a GHG emissions intensity equal to or above 2.1 tonnes of CO_2e per tonne of steel (t CO_2e/t steel). In North America, steel producers supplying the automakers, on average, have a BF-BOF share of 31%, in line with the North American steel industry average. Due to the high quality requirements of automotive steel, however, the BF-BOF share in the steel these companies deliver to the automakers will be higher. Further, the biggest automotive steel supplier in North America, Cleveland-Cliffs, is also one of the highest-emitting at 2.1 t CO_2e/t steel.

The study further estimates the GHG emissions intensity of steel purchased by the selected automakers on a global level. A central estimate shows global average values of 1.8–2.2 t CO_2e/t steel, depending on the automaker; a lowest emissions intensity sensitivity shows 0.9–1.7 t CO_2e/t steel; and a highest emissions intensity sensitivity shows 2.0–2.5 t CO_2e/t steel. Despite the uncertainty of results for individual automakers, the GHG emission intensities of steel used in automaking are higher than industry average in most of the considered regions.

Fossil-free steel production is not yet available at a commercial scale, but automakers can make commitments to procure fossil-free steel to support investments of steel producers. As of today, however, as presented in Figure ES2, the fossil-free steel commitments for 2030 correspond to only 2% of all the steel used by the 17 selected automakers. Adding the commitments to buy steel with a reduced GHG emissions intensity raises that share to just 4%. These are important first steps, but If the automotive steel demand is to be aligned to the International Energy Agency's Net Zero pathway for decarbonization of the steel sector, at least 25% of steel procured by automakers should be fossil-free by 2030.

Figure ES2

Share of the automakers' global steel demand for passenger vehicle production to be fossil-free or reduced GHG emissions intensity in 2030, based on automakers' public commitments



Note: Commitments up until 2030 are calculated as a share of total steel demand for each automaker without considering material utilization losses; only public commitments are included. The width of each section corresponds with global passenger vehicle sales.

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Based on the results of this study, we identify actions that automakers and policymakers can take that could lower the GHG emissions intensity of automotive steel.

Automakers could consider the following options to reduce steel-related GHG emissions of vehicle production:

» **Demonstrate demand for fossil-free steel.** Commit to fossil-free steel procurement by signing pre-purchase agreements, directly investing in companies developing fossil-free steel capacities, or by joining industry initiatives such as SteelZero or the First Movers Coalition at the maximum level of ambition with specific timelines, steel quantities, and emissions reduction goals.

» **Make vehicles easier to recycle.** Increase the availability of high-quality recycled steel by optimizing vehicle design for recyclability and reducing the contamination of steel with copper and other elements during the recycling process.

» **Increase disclosure of steel emissions intensity and recycled content.** Require environmental product declarations from steel producers, track and disclose emissions intensity and quantities of pre- and post-consumer scrap in the purchased steel.

» **Make vehicles lighter.** Increase lightweight designs to reduce the quantity of steel in a vehicle.

Policymakers could consider the following policy options to reduce the GHG emissions of steelmaking in general and steel used in vehicle production in particular:

- **Provide subsidies to scale up fossil-free steel production**. Subsidies could help to encourage further investment into clean technologies that for now entail higher costs.
- **Introduce an emissions trading system covering the steel sector**. This market-driven approach can incentivize companies to reduce GHG emissions and invest in energy efficiency and decarbonization.
- **Incentivize the use of fossil-free steel in vehicle production.** Some automakers have made commitments, but these are voluntary. Requiring a fossil-free steel quota or an average GHG emissions intensity threshold for steel used in new vehicles could boost demand and thereby promote investments by steel producers.
- **Require vehicles to be designed for recycling and increase the supply of automotive-quality secondary steel.** Measures to increase the supply of high-quality secondary steel for automotive applications include ensuring the collection of end-of-life vehicles, improving the sorting of metal parts during vehicle dismantling and shredding, and requiring a recycled steel quota in newly built vehicles.

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LIST OF ACRONYMS

AHSS	Advanced high-strength steel
BEV	Battery electric vehicle
BF	Blast furnace
BOF	Basic oxygen furnace
DRI	Direct reduced iron
EAF	Electric arc furnace
EPA	U.S. Environmental Protection Agency
FMC	First Mover Coalition
GHG	Greenhouse gas
OHF	Open hearth furnace
PV	Passenger vehicle
UHSS	Ultra-high strength steel

INTRODUCTION

The total life-cycle greenhouse gas (GHG) emissions of battery electric vehicles (BEVs) are significantly lower than for their internal combustion engine vehicle (ICEV) counterparts (Bieker, 2021). As both the share of BEVs and renewable energy sources increase, the emissions from vehicles during operation will diminish over the long term. As a result, the emissions from the production of vehicles will increase in relative importance. It is thus important to turn our attention to reducing the emissions from vehicle manufacturing.

The production of materials is a significant contributor to the energy consumption and GHG emissions related to vehicle manufacturing. Indeed, steel accounts for roughly 27% of the manufacturing GHG emissions of ICEVs, and about 15% of the manufacturing emissions of BEVs (Bui et al., 2024). Steel is also the most-used material in vehicle production, and makes up roughly 60% of the weight of an ICEV, and about the same of a BEV when excluding the weight of the battery (Wang et al., 2022).

The steel industry as a whole is associated with a high environmental and social impact, as it is responsible for 7% of global GHG emissions.[1] It is also the largest industrial consumer of coal (Hasanbeigi, 2022b). Current steel production is connected to air pollution and its impact on public health, especially for the population living close to or working in steel plants (Mozaffari et al., 2023). In order to be compliant with the Paris Agreement's target of limiting global warming to 1.5 °C, the steel sector would need to reduce its emissions 25% by 2025 and 90% by 2050 compared to current levels, according to the pathways set out by the International Energy Agency (International Energy Agency, 2021).

As lined out in recent studies, however, the steel sector has the potential to reach net-zero emissions before 2050, and possibly by 2040, with a combination of strategies such as deploying key technologies, phasing out coal, developing a green iron trade, establishing an adequate regulatory framework, and increasing international cooperation (Witecka et al., 2023). This reduction in emissions is despite the expected growth of global steel demand by more than a third in 2050 compared to 2019 (International Energy Agency, 2020).

Fostering the rapid decarbonization of the steel sector is also advisable from an economic perspective. As the steel sector is highly asset intensive, with assets typically having a long operational lifespan, failing to invest in low-emission steel technologies now will produce stranded assets in the longer term (Agora Industry, 2021). In particular, blast furnaces—the main technology for primary iron production used in the conventional steel industry—have a typical lifetime of 40 years. Blast furnaces also need to undergo substantial and very costly maintenance work approximately every 25 years. As the production capacity-weighted global average age of traditional blast furnaces is about 13 years (International Energy Agency, 2020), there is a window of opportunity to promote investments in more sustainable ironmaking and steelmaking within the next few years.

Several technologies for decarbonizing primary iron and steel production are under consideration, with varying levels of market readiness.[2] These include direct reduced iron (DRI) using green hydrogen produced from renewable electricity instead of fossil fuel-based syngas, and molten oxide electrolysis (MOE) using renewable electricity. These technologies are not yet available at a commercial scale and require investments to make them fully operational. For green hydrogen-based DRI, the deployment of

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[1] When looking at CO_2 emissions only, the steel industry is responsible for 11% of global emissions.

[2] Primary iron and steel is produced from iron ore instead of from scrap.

additional infrastructure and ancillary services, such as green hydrogen from renewable energy sources, is needed (Swalec & Grigsby-Schulte, 2023). MOE is still in a pilot phase and is expected to require several years of research and development before it can be used commercially. Secondary steel production, such as producing steel from steel scrap in electric arc furnaces (EAF), can be decarbonized by the use of renewable electricity. The scalability of secondary steel production is dependent on the availability and quality of steel scrap. Although these can be improved, the increasing demand for steel globally will ultimately limit the role of secondary steel production alone in decarbonizing the sector. It is thus important to foster investments in scaling up technologies for the decarbonization of primary steel production.

Investments in the decarbonization of steel production can be facilitated by creating lead markets for decarbonized primary steel (Material Economics, 2019). The automotive sector accounts for 12% of global steel demand, making it the second largest market after the building and infrastructure sector (World Steel Association, 2023a). In Europe and the United States, the automotive sector absorbs 17% and 26% of steel demand, respectively (Eurofer, 2023; U.S. Geological Survey, 2023). The sector appears as an ideal lead market for green steel, as automakers tend to purchase high-quality and high-cost primary steel products produced by the blast furnace–basic oxygen furnace (BF-BOF) pathway. In addition, being a consumer-facing industry, automakers are more likely to respond to supply chain decarbonization pressure than other sectors. Finally, it is estimated that using green steel would increase the purchase price of vehicles by less than 1% (Bui et al., 2024).

This study analyzes the status quo of supply chains and of the GHG emissions intensity of steel used in the automotive industry. Building on this assessment, the study compares automakers based on the estimated GHG emissions intensity of the steel they procure, their use of recycled steel, and their commitments to reducing the GHG emissions of future steel procurements. The study is focused on the global performance of the main automakers selling cars in Europe and North America.

The first part of the study provides an overview of the global steel production and trade, current production technologies and their GHG emissions intensity, and steel use in the automotive sector. Next, the supply chain and current emissions intensity analysis methodology and results are presented. In a third part, the automakers' commitments to reducing steel-related emissions in the future are analyzed. The study closes with conclusions from the results, followed by recommendations.

BACKGROUND

GLOBAL STEEL PRODUCTION AND TRADE

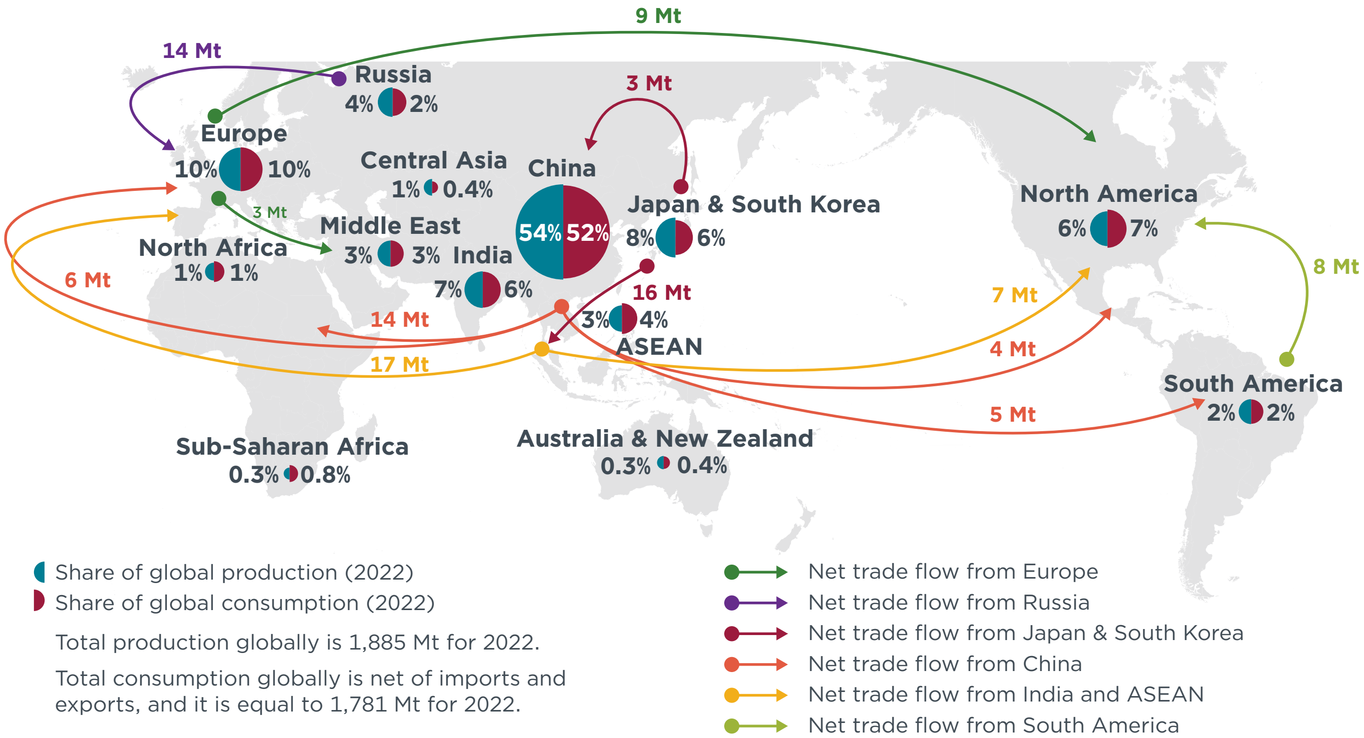
Steel is a globally traded commodity, with about 1,885 million tonnes being produced in 2022 for domestic consumption or export. As presented in Figure 1, the most important steel manufacturing country is China, which is home to more than half of global steel production (World Steel Association, 2023b). This production is used mostly to meet domestic demand, but China is also the largest global exporter of steel. Other major steel producing countries are, in decreasing order of production volume for 2022, India, Japan, the United States, Russia, South Korea, Germany, Türkiye, Brazil, and Iran. The European Union's aggregated yearly production accounts for 7% of global steel production (Eurofer, 2023). The number increases to 10% when additional European countries are considered, making it the second-largest steel-producing region after Asia (World Steel Association, 2023b).

About 25% of steel produced globally is traded between countries (International Energy Agency, 2020). In addition to China, other net exporters of steel are Japan, Russia, South Korea, Brazil, Oman, and India. A large share of the global steel trade occurs between countries in the same region. Interregional trade connections, the most important of which are displayed in Figure 1, correspond to around 13% of global steel production (Worldsteel Association, 2023b).

In the European Union, five corporations account for more than 57% of total crude steel production (International Energy Agency, 2020). Sixty percent of EU steel production is in the form of sheets or plates, known collectively as flat products (Eurofer, 2023). The European Union is an overall net importer of steel, although individual Member States are net exporters—such as Austria, Belgium, Luxembourg, and Germany—when considering intra-EU trade. The most relevant partners for steel imports into the European Union are Türkiye, Russia, India, and Ukraine. Germany is the largest producer of steel in Europe, accounting for 26.2% of EU production, followed by Italy, Spain, and France.

Figure 1

Global steel production, consumption, and net trade in 2022



Data source: World Steel Association (2023)
Notes: Only annual trade flows greater than 2 Mt are shown.

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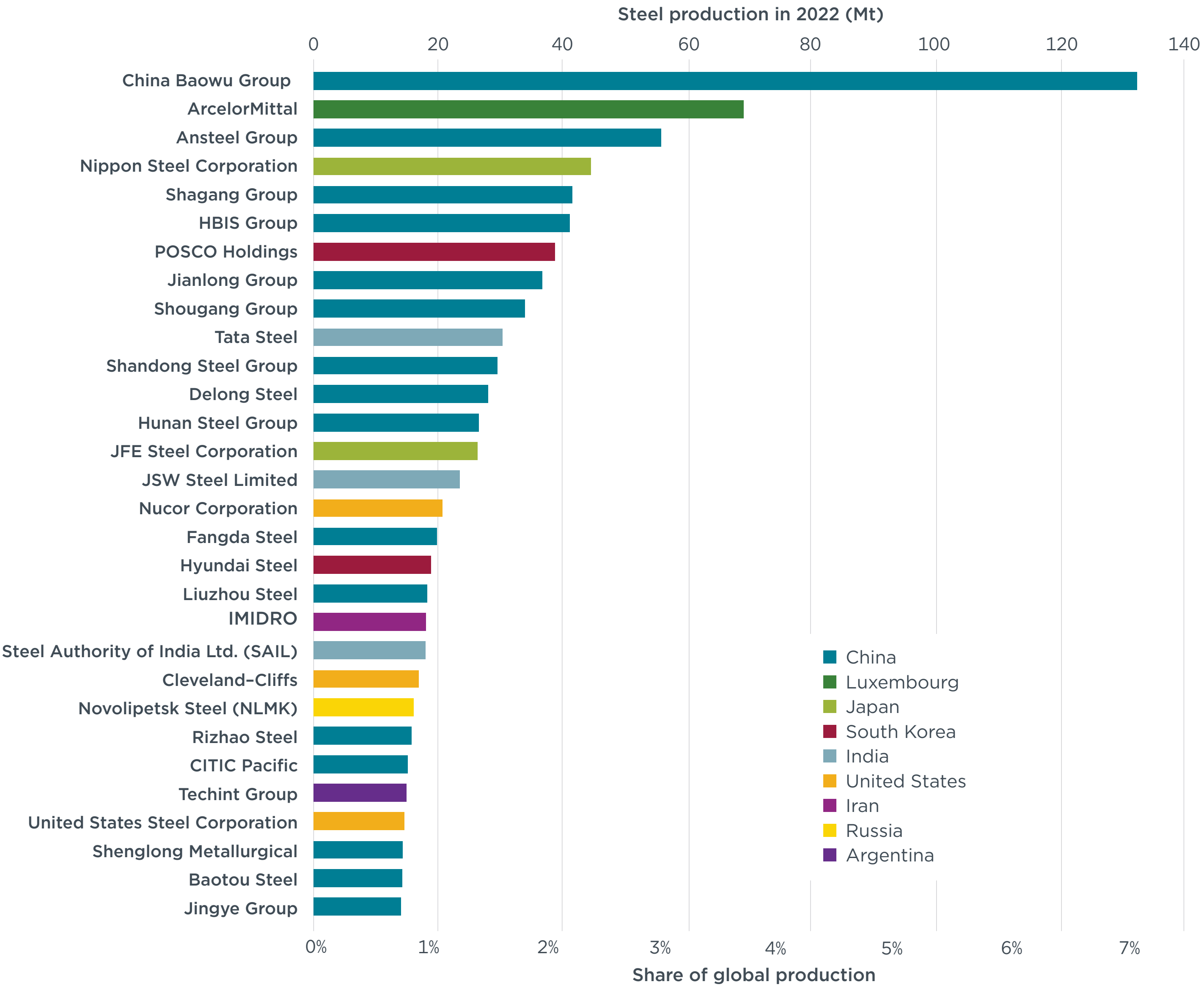
The United States produced approximately 80.5 Mt of steel in 2022, about 4% of world production. However, up to 90% of U.S. steel production is consumed domestically (Watson, 2022). The steel exported by the United States consists mainly of high-quality products, such as advanced high-strength steel or lightweight steel for automotive uses. The United States is also a big importer of steel, with imports equal to about one third of domestic production (U.S. Geological Survey, 2023). Sources of steel imports include Canada (21%), Brazil (15%), Mexico (14%), and South Korea (9%).

Figure 2 shows the 30 largest steel manufacturers by volume in 2022 (World Steel Association, 2023b).Together, these companies represent 48% of global production. Many of the largest steel corporations have plants in several regions of the world; ArcelorMittal, for example, has production plants in Europe, North America, South America, Africa, and Asia. Sixteen of the 30 largest steel producers have their headquarters in China. Of the other 14 largest steel producers, India and the United States are home to three each, followed by South Korea and Japan with two each.

Figure 2
Largest global steel producers



Data source: World Steel Association (2023)

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STEEL PRODUCTION TECHNOLOGIES

Steel is an alloy of iron and carbon plus additional elements, such as chromium, nickel and manganese, which are added to give the final products the desired characteristics. Steel production follows four steps: raw material preparation, ironmaking, steelmaking, and steel finishing (Bataille et al., 2021; International Energy Agency, 2020). While the following paragraphs provide an overview of the key processes for making iron and steel, a more comprehensive description of the processes and alternative production routes are provided in Bui et al. (2024).

About 70% of the world's steel is produced through the BF-BOF pathway (International Energy Agency, 2020). The main inputs in the BF-BOF route are iron ore and coke. Mined iron ore is a mixture of different-sized components. The larger lumps can be directly used in ironmaking, but the smaller fines must be subjected to heat and pressure to form nodules (sintering) and pebble-sized particles (pelletizing). Coke is produced from a grade of hard coal with a high carbon content, known as coking coal, by heating it in the absence of air in a coke oven.

Scrap can also be added, after being sorted and prepared. First, metallic scrap is separated from nonmetallic scrap. Larger pieces of scrap are shredded into smaller pieces for transport and to facilitate sorting. The scrap is then subject to several additional processes to remove other materials and impurities. Typically, some materials are not completely separated at this point and polluting elements can remain in the scrap metal. Some contaminants, such as silicon, manganese and aluminum, can be removed because they oxidize and dissolve in the slag—a liquid that floats to the top of during smelting of ores and metals—or, as in the case of zinc, because they can evaporate once subjected to the high temperatures. However, several elements, including tin, copper, antimony, and lead, cannot economically be removed with common processes. In this latter category of pollutants, copper poses the greatest concern because of its widespread presence in products ready for recycling or disposal (Cooper et al., 2020). For this reason, steel scrap is often downcycled into lower-quality products.

In traditional BF-BOF plants, iron ore (mainly iron oxide) is inserted into a blast furnace along with coke and limestone. Preheated air is blown into the furnace, burning the coke and producing heat and carbon monoxide (CO). The CO reacts as a reducing agent, removing oxygen from the iron ore to produce both liquid pig iron and carbon dioxide (CO_2). This stage of the process is responsible for the largest share of CO_2 emissions from steel production. Pig iron is then fed into a basic oxygen furnace (BOF) to produce crude steel. At this point, pig iron can be blended with the scrap steel. Globally, scrap forms an estimated 20% of the metallic input into BOFs (International Energy Agency, 2020). The steel is finally finished in continuous casting machines to produce flat products, such as hot rolled wide strips or quarto plates, or in ingot casting machines to produce long products, such as wire rods, rebars or merchant plates.

The BF-BOF pathway is energy and GHG-emissions intensive, and it presents limited opportunities for reducing emissions. In a best possible configuration, Bui et al. (2024) estimate that emissions from the BF-BOF route could be reduced by 25% in the United States and by 18% in the European Union, mostly due to efficiency improvements in downstream processes.

The most common alternative pathway for steelmaking uses electric arc furnaces (EAFs) to melt steel scrap, primary iron, or a blend of both inputs to produce new steel products. This route accounts for about 25%–30% of global steel production (International Energy Agency, 2020). Electricity is the main energy source used in this type of furnace, but natural gas may also be used as an additional energy input to help the smelting process (Somers, 2022). The primary iron used for EAF steelmaking is usually produced via a direct reduced iron (DRI) process that requires less heating than the blast furnace process. DRI typically uses syngas, a mixture of CO and hydrogen (H_2) that is produced from natural gas or coal (Somers, 2022). When the syngas reacts with iron ore, it produces CO_2 and water (H_2O) and reduces the ore to metallic iron. When using natural gas-based syngas in the DRI process and the current average electricity mix in the EAF, the GHG emissions of the DRI-EAF route are about 11% lower than the BF-BOF route in Europe, and about 3% lower in the United States (Bui et al., 2024). Hydrogen can be used instead of syngas in the reducing process, resulting in only water and iron ore. When green hydrogen produced solely from renewable electricity is used in the DRI, combined with an EAF running on renewable electricity, up to 95% of the GHG emissions can be avoided compared with the BF-BOF route (Bui et al., 2024). Other studies in the literature also find that green hydrogen-based DRI-EAF can save up to 97% of CO_2 emissions compared with BF-BOF (Fennell et al., 2022; Vogl et al., 2018).[3] The emissions intensity of the EAF route depends largely on the share of inputs from steel scrap versus DRI, the electricity mix used in the EAF, and whether the DRI process uses fossil fuel-based syngas or renewable electricity-based hydrogen.

Table 1 shows the GHG emissions intensity of the pathways mentioned above, for steel production in the EU and United States. These intensities can vary widely from country to country and depend on which processes, from producing raw materials to steel finishing, are included in the pathway.

Table 1

Emission intensities for producing steel through different pathways in the European Union and United States

Process		EU average emissions intensity ($t\ CO_2e/ t\ steel$)[a]	U.S. average emissions intensity ($t\ CO_2e/t\ steel$)[a]
Ironmaking	Steelmaking		
Blast furnace	Basic oxygen furnace	2.08	2.27
Natural gas direct iron reduction	Electric arc furnace	1.85	2.20
Green hydrogen direct iron reduction	Electric arc furnace	< 0.10	0.10
	Electric arc furnace using steel scrap	0.70	0.97

[a] System boundaries include iron ore mining, coke making, sintering, blast furnace, basic oxygen furnace, steam generation, uses and losses, DRI mining, pelletizing, DRI, EAF, and downstream processes (hot rolling, skin mill, cold rolling, galvanizing, and stamping).

Source: Based on Bui et al. (2024)

Figure 3 shows the installed production capacities of the 20 largest steel manufacturers (Swalec & Grigsby-Schulte, 2023). The BF technology accounts for 95% of global ironmaking capacity. BOF technology accounts for 82% of steelmaking capacity while 17% of steelmaking capacity is based on EAFs. Some steel producers have an especially high share of EAF technology, such as Nucor Corporation, which is 100% EAF, and Hyundai Steel and JSW Steel Limited, which are each about 50% EAF.

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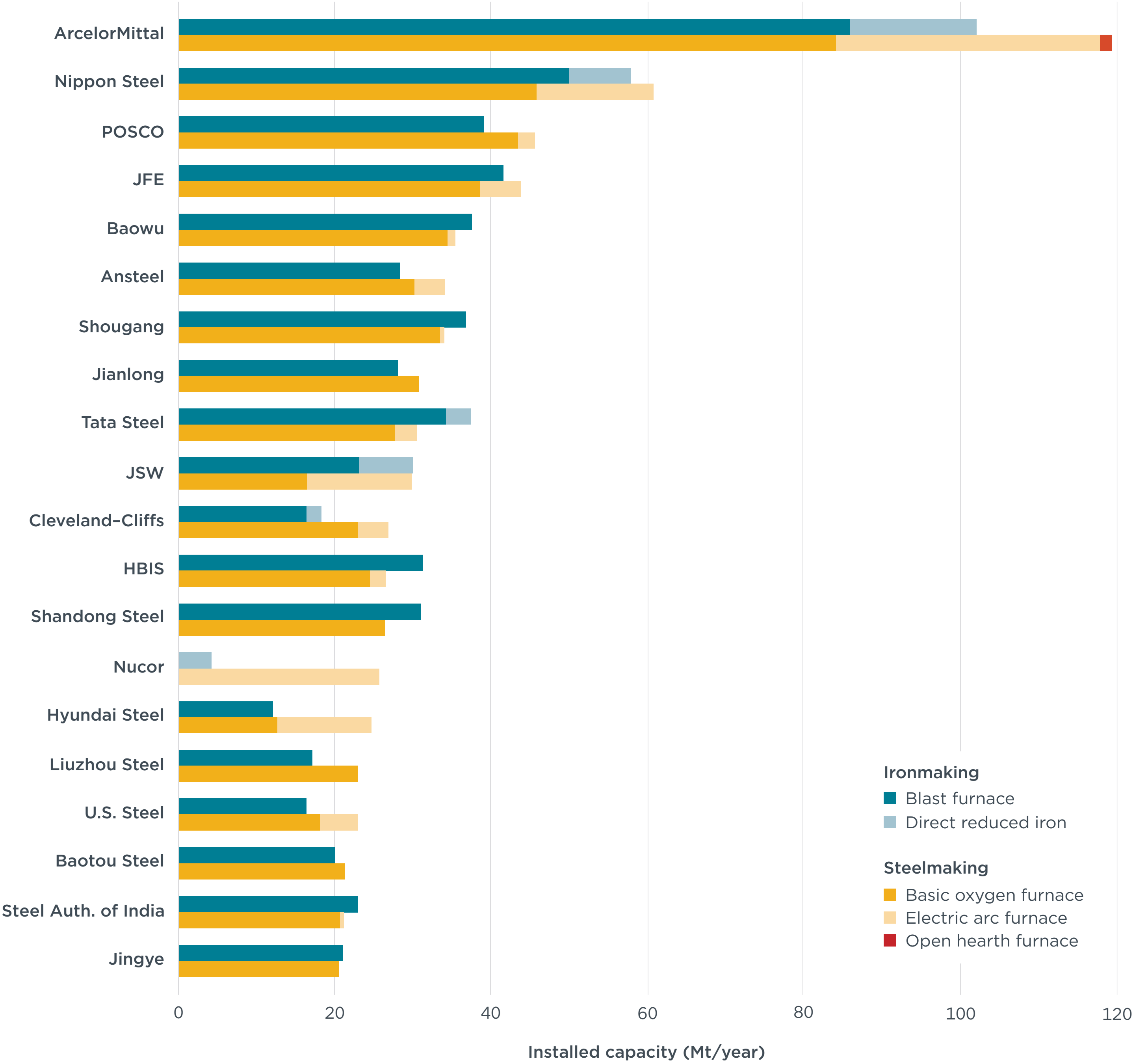
[3] This estimate of emissions reduction considers the main steps for ironmaking and steelmaking, including the extraction and generation of iron ore and limestone, but excludes downstream emissions from steel finishing.

Figure 3

Annual ironmaking and steelmaking capacities by process of the 20 largest steel producers



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Although there has been a slight shift towards EAFs over the past few years, the industry is still far from being aligned with global decarbonization efforts. A significant share of new steelmaking capacity, either announced or under construction, relies on the BF-BOF pathway. As of March 2023, roughly 60% of new announced capacity follows the BF-BOF pathway, while only 40% would be EAFs (Swalec & Grigsby-Schulte, 2023). This development also reflects the increasing availability of steel scrap globally, particularly in emerging markets.

STEEL SUPPLY CHAINS

Iron ore is the main raw material for making steel. Iron mines are concentrated in a few countries, with Australia and Brazil being the largest iron ore producers, accounting for roughly 38% and 18%, respectively, of global production (U.S. Geological Survey, 2024). The European Union imports iron ore mostly from Brazil, Canada, Ukraine, South Africa, and Russia (TrendEconomy, 2023). The European mining industry has been declining over the years; Sweden and Norway are the only countries where a significant amount of iron ore is still mined (European Commission, 2023a), but are responsible for just around 1% of global iron ore production (World Steel Association, 2023b). In the United States, the iron ore used in steel production is mostly sourced domestically (Watson, 2022), especially in Michigan and Minnesota. Only a small amount of iron ore is imported, mainly from Brazil, Canada, and Sweden (National Mineral Information Center, 2023). For context, U.S. iron ore mining accounts for about 2% of the global total. U.S. iron ore comes in a relatively low-grade form, taconite, which must be ground and rolled into pellets. Sometimes, iron ore mines are owned by steel producers themselves. For example, ArcelorMittal owns iron ore mines in Canada and Liberia (ArcelorMittal, 2024).

The second important input for steelmaking in the BF-BOF pathway is coal in the form of coke. In the European Union, only Poland and the Czech Republic are still mining the hard coal used to make coke. The European Union's imports of coking coal come mainly from Australia (24%), the United States (20%), and Russia (8%) (Eurostat, 2022). This concentration of supply prompted the European Union to include coking coal in the updated critical raw material list of 2023 (European Commission, 2023a). The United States, on the other hand, is a net exporter of coking coal, which is mined and produced especially in the Western region. Coke is imported into the United States mostly from Canada, Poland, Colombia, and South Africa (U.S. Energy Information Administration, 2023).

Steel scrap inputs are also very important, especially for the EAF pathway. Scrap is generally classified as post-consumption—namely the scrap that is generated from end-of-life products—or pre-consumption, the scrap that is generated during production and fabrication. Production scrap is created during the steelmaking process, while fabrication scrap results from the transformation of steel into different products (Dworak & Fellner, 2021).

Steel produced in the European Union has an estimated recycled steel content of 56%–60%, on average (Eurofer, 2023). During the steelmaking process in the European Union, about 9% of steel ends up as production scrap (Dworak & Fellner, 2021). This share has decreased over the years as the efficiency of plants has increased. Fabrication scrap, in contrast, increased significantly, mainly because of the more dominant use of flat products (such as hot rolled wide strips or quarto plates), which have a lower material efficiency in the fabrication process compared to long products (such as wire rods, rebars or merchant plates). The automotive sector alone is responsible for the generation of 30% of the total fabrication scrap in the European Union. In the United States, the share of recycled steel going into new steel production is about 60%–70% (American Iron and Steel Institute, 2019). Almost all scrap used in U.S.-based EAFs comes from domestic supply. Both the European Union and the United States export significant quantities of scrap, mostly in the form of post-consumption scrap (Dworak & Fellner, 2021).

AUTOMOTIVE STEEL USE

Steel is the most used material in vehicle production, accounting for roughly 60% of the weight of an average vehicle (Wang et al., 2022). On a global average, there is 800–900 kg of steel in a vehicle, distributed among the body (40%), the drivetrain (23%), the suspension (12%), and other components such as wheels, tires, fuel tank, and steering and braking systems (World Steel Association, 2023a).

Automotive-grade steel is usually of higher quality than that required for other applications. The use of recycled steel in automaking is limited because of the polluting elements often found in recycled steel. Some automakers disclose that the recycled content of steel in their vehicles is around 10%–15% (e.g. Volvo Car Group, 2022), but this information is seldom made public. Some steelmakers report that the recycled content of their automotive-grade flat steel is around 60%, which is lower than for other applications (Nucor, 2023c). The use of recycled steel in cars is thus highly dependent on the quality of the available scrap. There is potential to increase the quality of scrap—and therefore the share of recycled steel in cars—with better auto design and end-of-life vehicle practices, such as improving the sorting of metal parts during vehicle dismantling and shredding (Diener & Tillman, 2016). There are already examples of companies managing to produce automotive-grade steel from 100% scrap (Zong, 2023).

The steel present in vehicles today is of different types depending on the specific function. Mild steel—which has a lower tensile strength, a lower cost, and is easier to shape during manufacturing—is typically used in the body structure and trunk closure. High-strength steel is normally used where energy-absorbing performance is important. Advanced high-strength steel (AHSS) and ultra-high strength (UHSS) have an even greater strength-to-weight ratio. These materials can reduce the weight of vehicles, resulting in reduced fuel consumption and GHG emissions during vehicle operation. Originally, AHSS was used only for the chassis, suspension, and the frame and body components, but it is now also used for doors and other body panels (Hu & Feng, 2021).

The main strategies for reducing the life-cycle emissions related to steel in vehicles include using less and lighter materials, using more recycled steel, and switching to steel made through processes with lower GHG emissions (Bui et al., 2024). The most significant reduction in steel-related emissions is obtained by using a combination of these strategies. For example, Bui et al. (2024) estimates that the steel-related emissions of a typical passenger vehicle could be reduced by 95% in the European Union and the United States by switching from the coal-based BF-BOF pathway to using DRI-EAF technology.

In the study, the results show that using conventional blast furnace-basic oxygen furnace technology, producing the steel needed for a typical internal combustion engine passenger car would result in emissions of 1.4 tonnes of CO_2e in the European Union, and 1.9 tonnes of CO_2e in the United States. Producing automotive steel with 75% of recycled content via an electric arc furnace (EAF) in combination with DRI for the remaining 25%, and using the current average electricity mix, cuts the emissions to 0.8 tonnes of CO_2e per vehicle in the European Union, and 1.2 in the United States. To avoid a potential displacement of recycled steel use in other applications, this needs to be accompanied with an increase in automotive-grade recycled steel supply. Fossil-free steel, produced either from iron ore using renewable energy and hydrogen, or by recycling steel with renewable electricity can reduce the steel-related emissions to below 0.1 tonnes of CO_2e per vehicle for typical vehicles both in Europe and in the United States.

STUDY METHODS

This study identifies the most important steel suppliers for major automakers and estimates the GHG emissions intensity associated with the steel used in vehicle production. The following sections introduce the methodology used to assess steel supply chains and GHG emissions, followed by a presentation of the results.

IDENTIFYING THE AUTOMOTIVE INDUSTRY'S STEEL SUPPLIERS

This part of the analysis focuses on automakers selling passenger vehicles in Europe and North America but encompasses the global vehicle production of these automakers. The 17 automakers selected for the study cumulatively represent 86% of passenger vehicle (PV) sales in Europe and 98% of sales in North America in 2022 (MarkLines, 2023).[4] The automakers are BMW, Ford, GM, Honda, Hyundai, Kia, Mazda, Mercedes-Benz, Nissan, Renault, Stellantis, Subaru, Suzuki, Tesla, Toyota, Volkswagen, and Volvo Cars.[5]

As discussed in the background section, the steel in an average passenger vehicle is mostly in the body (40%) and powertrain (23%) (World Steel Association, 2023a). These components are typically produced by automakers themselves. Our supply chain analysis focuses only on the steel that automakers directly purchase from steel producers. Therefore, the steel used in components that automakers buy from suppliers is not covered in this analysis.

Automotive steel suppliers were identified through supply chain data available from Bloomberg L.P. (2024). The data identify customer-supplier relationships and provide the monetary value equivalent to both the buyer's spending and the seller's revenue. For all selected automakers, a consistent trend was observed: The majority of automakers spend 2.0%–3.5% of their cost of goods sold with steel producers.[6] Although the data do not display the exact types of products exchanged between companies, we assume that this spending points to the tonnes of steel supplied.

Based on the identified relationships between automakers and steel suppliers at a global level, the analysis next considers regional production capacities for both steel and passenger vehicles. Data on the steel production plants is sourced from the global steel plant tracker, posted online by Global Energy Monitor (2023), which provides the number, size, and locations of plants, as well as the installed capacity and the technologies used. Information on where automakers produce their vehicles comes from MarkLines (2023).

As discussed in the background section, the interregional trade of steel is low when compared to total production and consumption. Therefore, the analysis assumes that automakers buy steel from plants in the same region where the vehicles are manufactured. Areas of the world where both steel and vehicles are made include North America, South America, Europe, North Africa, Sub-Saharan Africa, the Middle East, Central Asia, India and Pakistan, the ASEAN (Association of Southeast Asian Nations) region, China, Japan, and South Korea, Pacific countries, and others. Table A1 in the appendix displays the assignment of countries to these regions.

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[4] Europe in this study includes the 27 EU Member States plus the United Kingdom, Norway, Switzerland, Türkiye, and Ukraine.

[5] When possible, subsidiaries have been considered separately from the parent group to capture more detailed information on the behavior of companies. For example, Hyundai and Kia—both part of Hyundai Motor Group—have been analyzed separately. Similarly, Volvo Cars is examined apart from its majority shareholder, China's Zhejiang Geely Holding Group.

[6] The cost of goods sold is the sum of all direct costs associated with making a product. Three automakers deviated from the range of spending with steelmakers, with Kia spending 1.9% of cost of goods sold, Tesla spending 1.4%, and Renault spending 1.1%. Although some variations among the cost of goods sold for different companies is expected, the lower value for these companies could have other explanations, such as spending more with steel companies not covered by the Bloomberg data or purchasing a lower share of steel directly purchased from steel manufacturers.

The assignment of steel production plants to automakers' regional demand for steel is based on the following steps:

- First, we determine the percentage of steel each automaker sources from individual steel producers globally. This was calculated by adding up the spending of each automaker on all steel producers and then dividing the spending on individual steel producers by the automaker's total spending.
- Second, we match regions where automakers produce PVs with the plants operated by their steel suppliers in those regions. If a steel producer identified as having a connection to an automaker has steel plants in only one region of the automaker's vehicle production, the total share of steel provided by that steel producer to the automaker is allocated to that region.
- Third, when a steel producer has plants in multiple regions where an automaker also manufacturers PVs, we assume that the amount of steel supplied to the automaker by region is split proportionally based on the steel producer's installed capacity in those regions.

There are several limitations to this approach. As previously noted, the monetary value displayed in Bloomberg's supply chain dataset does not allow us to deduce the exact types of products exchanged between companies. Our analysis assumes that the share of spending with a steel company is proportional to the share of steel supplied. These business connections and spending totals are based on disclosures by companies or estimated by Bloomberg. Therefore, the information may be incomplete. This is especially the case for smaller, nonpublic steel companies that might not be required or willing to share as much information on their customers as larger, public companies. Relationships between automakers and steel suppliers may also be obscured when intermediate companies provide products such as semifinished or finished parts.

In some cases, the Bloomberg dataset provides information on the existence of a relationship but does not report related spending and revenue. For example, Bloomberg does not provide such quantitative data for steel companies in China. China is an important country both for steel production—as it hosts over half the world's steel production—and for PV production. Among the analyzed automakers, several have a considerable share of their PV production in China, such as Tesla (53%), General Motors (39%), Volkswagen (38%), and Volvo Cars (32%).

ESTIMATING THE GREENHOUSE GAS EMISSIONS INTENSITY OF AUTOMOTIVE STEEL

Building on the results of the supply chain analysis, we estimated the regional and global average GHG emissions intensity of the steel purchased by the automakers. As a first step, average emission intensities for each steel producer were determined at the regional level. This was done by combining a steel producer's installed capacity by country and by technology with the country-level average emission intensities of steel produced via the BF-BOF and the EAF pathways. In a second step, the automakers' regional GHG emission intensities were calculated as an average of the average emission intensities of their steel suppliers in the respective region, weighted by results of the supply chain analysis. Finally, the automakers' global emission intensities were calculated as the average emissions intensity in each of the regions where they have PV production, weighted by the number of vehicles produced in the regions.

Country- and technology-specific emission intensities

The country-level average GHG emission intensities for the different steel production pathways are based on the emission intensities reported in literature. Hasanbeigi (2022a) was selected as a recent and comprehensive study on emissions intensity in different countries, with values for the BF-BOF and the EAF routes. This study was chosen because it covers several major steel-producing countries and is a well-established reference in literature. Table A2 in the appendix presents other evaluated sources for comparative purposes.

The system boundaries of the Hasanbeigi (2022a) study include direct (Scope 1) and indirect (Scope 2) CO_2 emissions for coke making, pelletizing, sintering, ironmaking, steelmaking, steel casting, hot rolling, cold rolling, and processes such as galvanizing or coating. The embodied emissions in net imported pig iron and DRI are also included. The system boundaries of the cited study do not include emissions related to the mining of iron ore and coal or any emissions related to the processing of steel scrap before being added to an EAF. Our study considers a broader scope of emissions, including those from coal mining (coking coal and thermal coal) and iron ore mining. Material losses, such as waste and scrap, specifically related to automotive hot rolling, cold rolling, galvanizing, and stamping are also included. In addition, we have also included non-CO_2 emissions from the main production steps of iron and steelmaking, notably methane and nitrous oxide. The emissions from these additional sources were calculated using inputs from the GREET model (Wang et al., 2022).

Our study modifies the country-average emissions intensities of steel produced via the EAF route by Hasanbeigi (2022a) to the specific quality requirements of steel used in the automotive sector. As discussed in the background section, automotive-grade steel has a lower tolerance for contaminants from scrap steel than other applications. Therefore, the shares of scrap steel versus primary material produced through DRI were adjusted for the EAF pathway. In particular, we assumed that the scrap share in EAF steel used for vehicles currently does not exceed 60%, as disclosed by some steel producers (Nucor, 2023c). Hasanbeigi (2022a) reported the combined CO_2 emissions intensity for both the scrap EAF and DRI-EAF pathways. The underlying country-average shares of scrap in the EAF pathway can be significantly higher than currently observed for EAF steel used in the automotive sector. By comparing DRI production, imports, and exports with the total steel production from EAF in a country or region—all provided by Hasanbeigi (2022a)—we estimated that the share of scrap in EAF steel was above 90% in most countries. For China, India, and Mexico, however, scrap shares of below 50%–60% are reported.

After breaking down emissions for the scrap-EAF and DRI-EAF components, an average emissions intensity for DRI ironmaking was calculated based on GREET (Wang et al., 2022) and assumed to be equal for all countries. We then estimated the country-specific emissions intensity values of the EAF steelmaking process by itself. Next, we weighted the emission intensities of the DRI-EAF and scrap-EAF pathways by a maximum scrap share of 60%. We eventually recombined the values to determine country-level average emission intensities for both DRI-EAF and scrap-EAF steel suitable for the automotive industry. For a selection of major steel producing countries, Figure A1 in the appendix displays the GHG emission values of different steel pathways based on Hasanbeigi (2022a), with the larger scope of emissions and with the adjusted scrap shares.

To ensure methodological consistency and comparability among different regions, we used the same system boundaries in the Hasanbeigi (2022a) study for countries not covered in that study. Consequently, when the emissions intensity values for a country were missing, we used values from another country in the same region with similar characteristics. For example, we used the Brazil emissions intensity values for

Argentina, and the values of Vietnam for Thailand. For Morocco, we used the emissions intensity values for Spain, and Türkiye's emission values were used for Iran. The European Union values were used for all countries in the European region, including the United Kingdom, Norway, and Switzerland.

As a limitation for this part of the analysis, note that the considered shares for BF-BOF and EAF routes are based on installed capacity rather than on actual production. The relation of production and installed capacity, called capacity utilization rate, may vary for the BF-BOF and EAF pathways. While the utilization rate of EAFs and BOFs is quite similar in Europe, North America, South America, and in some Asian countries like Japan, some other countries show a much higher BOFs utilization rate compared to EAFs. This is the case, for instance, in China and South Korea (Global Energy Monitor, 2023; Worldsteel Association, 2023b). This means that there is an even stronger reliance on the conventional BF-BOF production route in some countries than considered in this study.

Regional and global automaker-specific emissions intensities

As a second step, the GHG emission intensities by steel production pathway and country were aggregated to determine the average emissions intensity of steelmakers' plants in a given region. For each steel producer with identified connections with an automaker, we weighted the GHG emission intensities of the BF-BOF and the EAF pathways in the different countries of a region based on the steelmaking capacities of the steel producers' plants in that region.

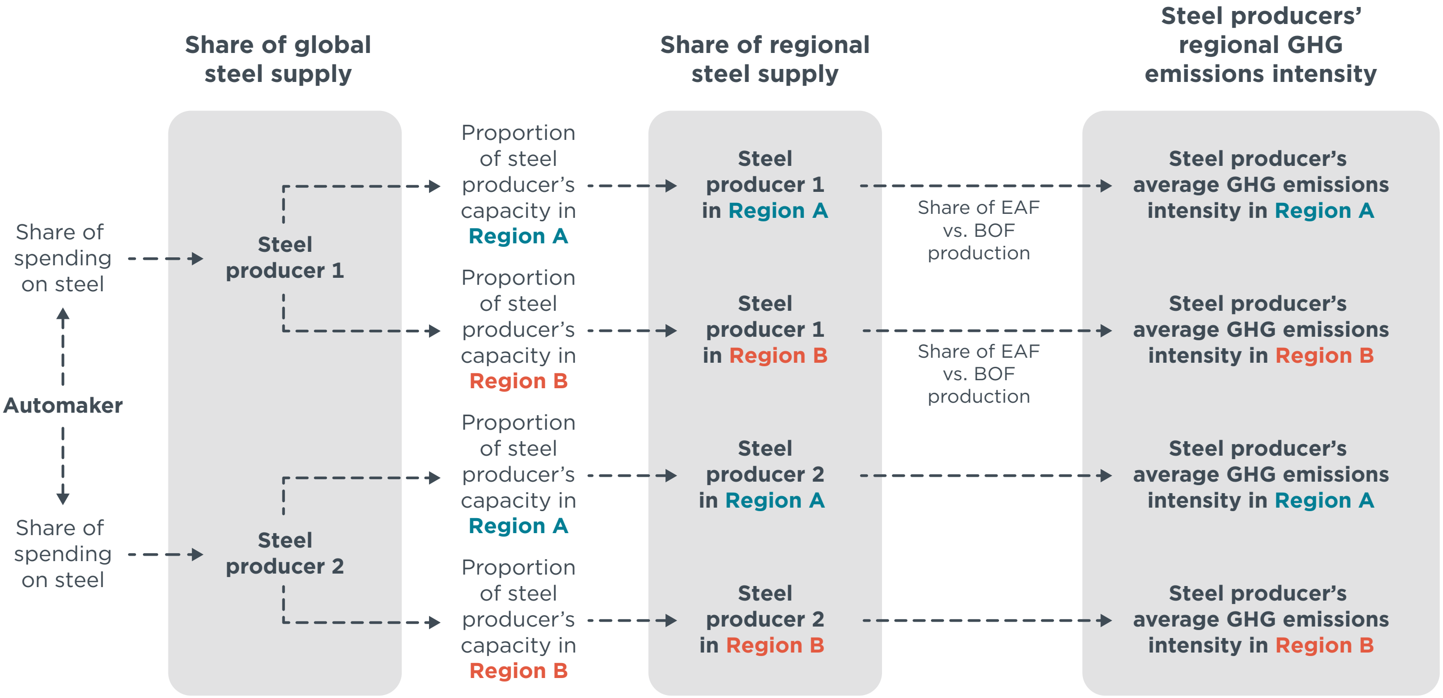
To determine the automakers' average GHG emission intensities in each region, we weighted the steel producers' regional average emission intensities by their share of supply to the automaker in the same region. For regions where there was no steel plant available for the analysis—either because there were no quantified supplier relationships in the Bloomberg dataset or because no operating steel plants were in the Global Energy Monitor dataset, the average emissions intensity for the country was used. This was always the case for China because no quantified relationships with steel suppliers are shown in the Bloomberg dataset.

Finally, the global average emissions intensity of automakers was calculated by weighting the automakers' regional average emission intensities by the number of PVs produced in each region.

A graphical representation of this process is shown in Figure 4.

Figure 4

How the regional and global average GHG emissions intensity of steel is calculated for each automaker



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RESULTS

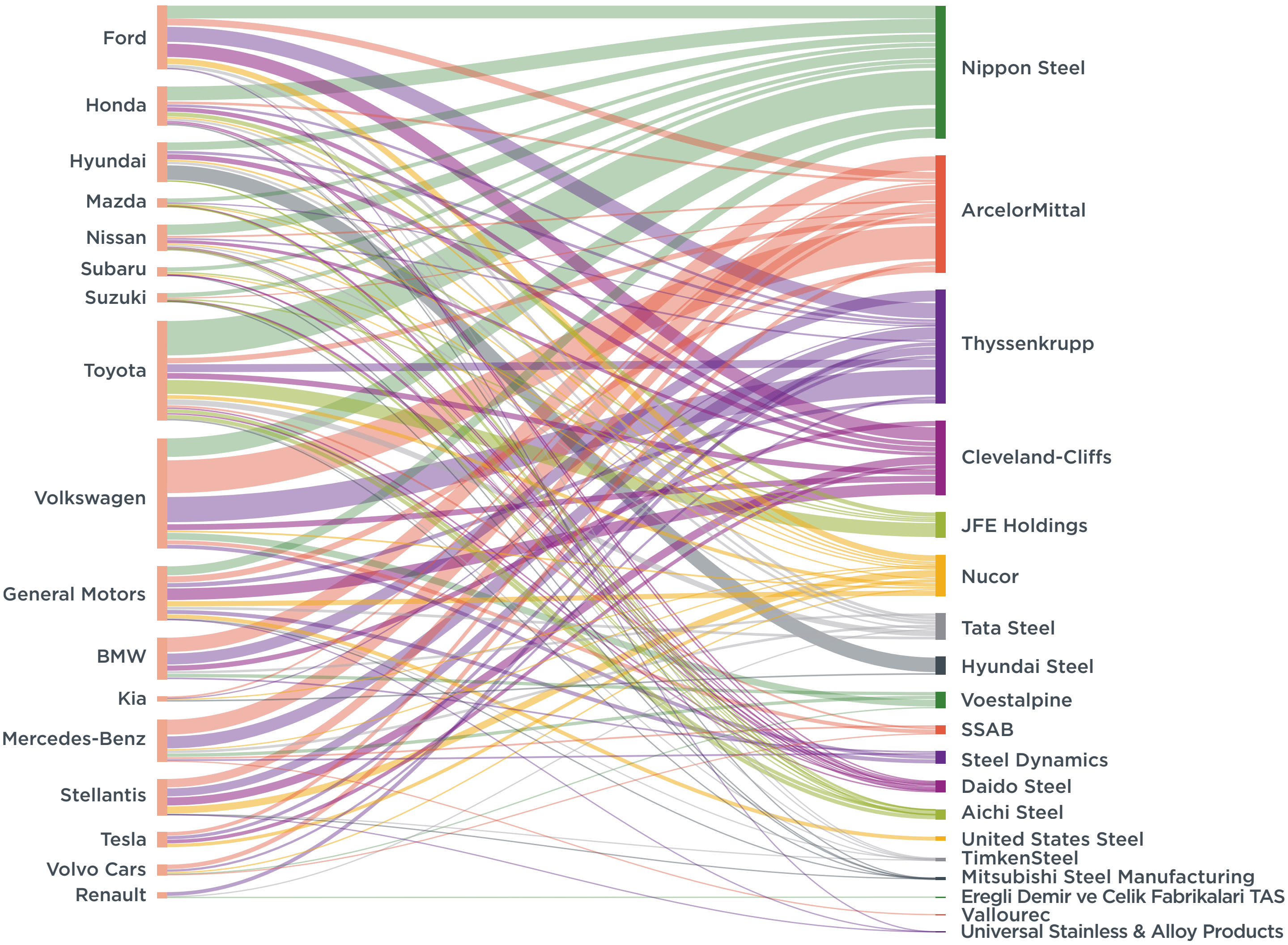
AUTOMAKERS' DIRECT STEEL SUPPLIERS

Figure 5 shows the quantified relationships between steel producers and the 17 selected automakers. The thickness of each line is proportional to the amount of money exchanged between an automaker and a specific steelmaker. The steel producers generating the greatest revenue from the 17 automakers are Nippon Steel, with 22% of revenue of all quantified automaker-steelmaker connections combined; ArcelorMittal with 19%; Thyssenkrupp with 18%; and Cleveland-Cliffs with 12%. However, some very large steel suppliers—including those in China—are likely missing in the dataset and therefore are not shown here.

Figure 5 also shows that most steel producers supply numerous automakers. In this analysis, steel producers have a relationship with an average of 6 of the 17 automakers. The steel producers with the most links to automakers are Thyssenkrupp (16), Nucor (15), ArcelorMittal (12), Nippon Steel (11), Cleveland-Cliffs (10), and Tata Steel (9).

Figure 5

Revenue flowing to steel producers from the 17 selected automakers



Notes: Line thickness is proportional to the revenue received by steelmakers from specific automakers. These estimates are based on supply chain data from Bloomberg L.P. (2024).

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As discussed in the methodology section, there are several limitations to this data. For example, the Bloomberg dataset does not have monetary values for all economic relationships identified. In particular, monetary values for the economic relationships with Chinese steel producers are not reported, and this is where 22% of selected automakers' vehicles are manufactured. Also, the dataset does not indicate qualitative values for relationships with smaller steel companies.

REGIONAL STEEL SUPPLY ANALYSIS

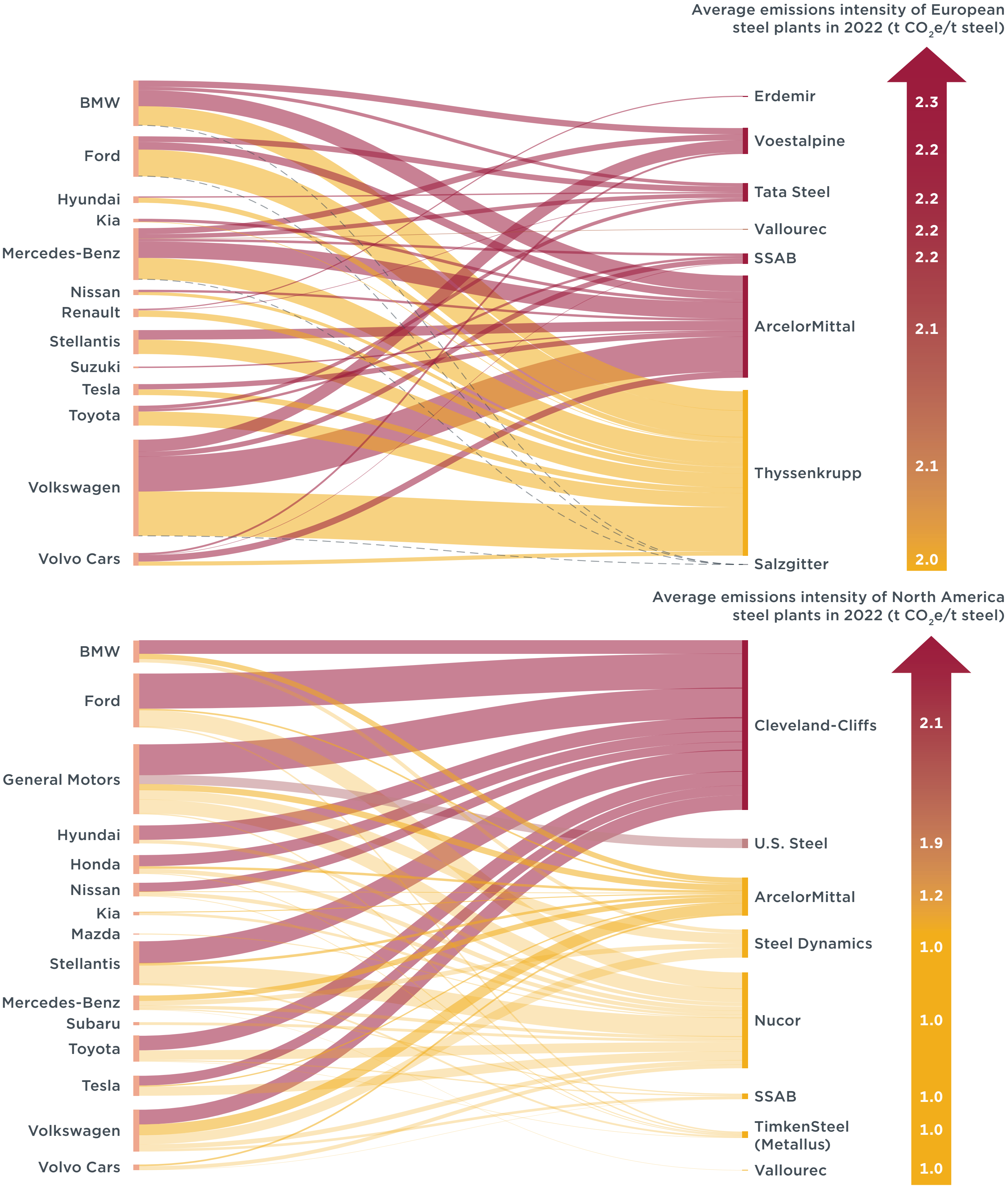
Table A3 in the appendix shows the automaker-steel producer relationships as derived from Bloomberg L.P. (2024). This study sorts these relationships by region, based on the location of automakers' PV production, the location of steel producers' plants, and the assumption that steel is produced and sold to automakers in the same region.

The table includes Bloomberg data for both quantified relationships—those where the monetary value of goods exchanged is known—and unquantified relationships. Using the data on quantified relationships, we assigned a percentage to indicate the share that a respective steel producer supplies to the global steel demand of an automaker. For steel producers with plants in multiple regions coinciding with an automaker's PV production facilities, the percentage is allocated among these regions based on installed steelmaking capacity. For example, ArcelorMittal supplies 38% of BMW's steel in this analysis. That percentage is split among BMW's plants in Europe (24%), South America (7%), North America (5%), and Sub-Saharan Africa (3%). Each row makes up the total value exchanged by each automaker with one or more steel producers. This calculation only considers the quantified relationships retrieved from Bloomberg. As explained in the methodology, quantitative information for some regions, such as China, are not shown in the table despite being relevant for both PV production and steel production.

Based on this regional assignment, Figure 6 shows the economic relationships between steel producers and automakers for PV production and steel production plants in North America and Europe. Figures A2 through A5 in the appendix show the economic relationships for PV production in Japan, South Korea, India, and China. These figures also show the average GHG emission intensities of the steelmakers' plants in the respective regions. A discussion of these values follows.

Figure 6

Average GHG emissions intensity of steel producers for their plants in Europe and North America in 2022 and the automakers supplied by these steel producers



Notes: Line thickness is proportional to the money spent by automakers with specific steel producers. Dotted lines indicate a relationship for which the economic data is not quantified. These estimates are based on supply chain data from Bloomberg L.P. (2024).

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GREENHOUSE GAS EMISSIONS INTENSITY

The GHG emission intensities of steel production in this paper are based on the country-specific average CO_2 emission intensities of the BF-BOF and EAF pathways, as provided by Hasanbeigi (2022a). The methodology section explains how these values are adjusted in two ways: to reflect the maximum recycled steel share currently used in automotive steel, and to include additional sources of emissions from steelmaking and other greenhouse gases. Figure A1 in the appendix displays the GHG emission intensities of the BF-BOF pathway and the EAF pathway for steel production in the European Union, United States, China, India, Japan, and South Korea.

We estimated the regional average GHG emissions intensity of steel producers based on their regional share of BF-BOF and EAF production capacity. Figure 6 shows the regional average emissions intensity of the analyzed steel producers for their plants in Europe and the United States, as well as their connections to major automakers in the corresponding regions.

As shown, all steel producers with plants in Europe have an average GHG emissions intensity of 2.0–2.3 t CO_2e/t steel. In North America, steel producers show a wider range of emissions, with some having an emissions intensity of 1.0 t CO_2e/t steel. Almost all automakers in the two markets procure a large share of their steel from steel producers with average GHG emission intensities of 2.1 t CO_2e/t steel or higher. For comparison, we report the emission intensities publicly disclosed by selected steel producers in the appendix (Table A5). These may differ from this analysis in the scope of emissions considered.

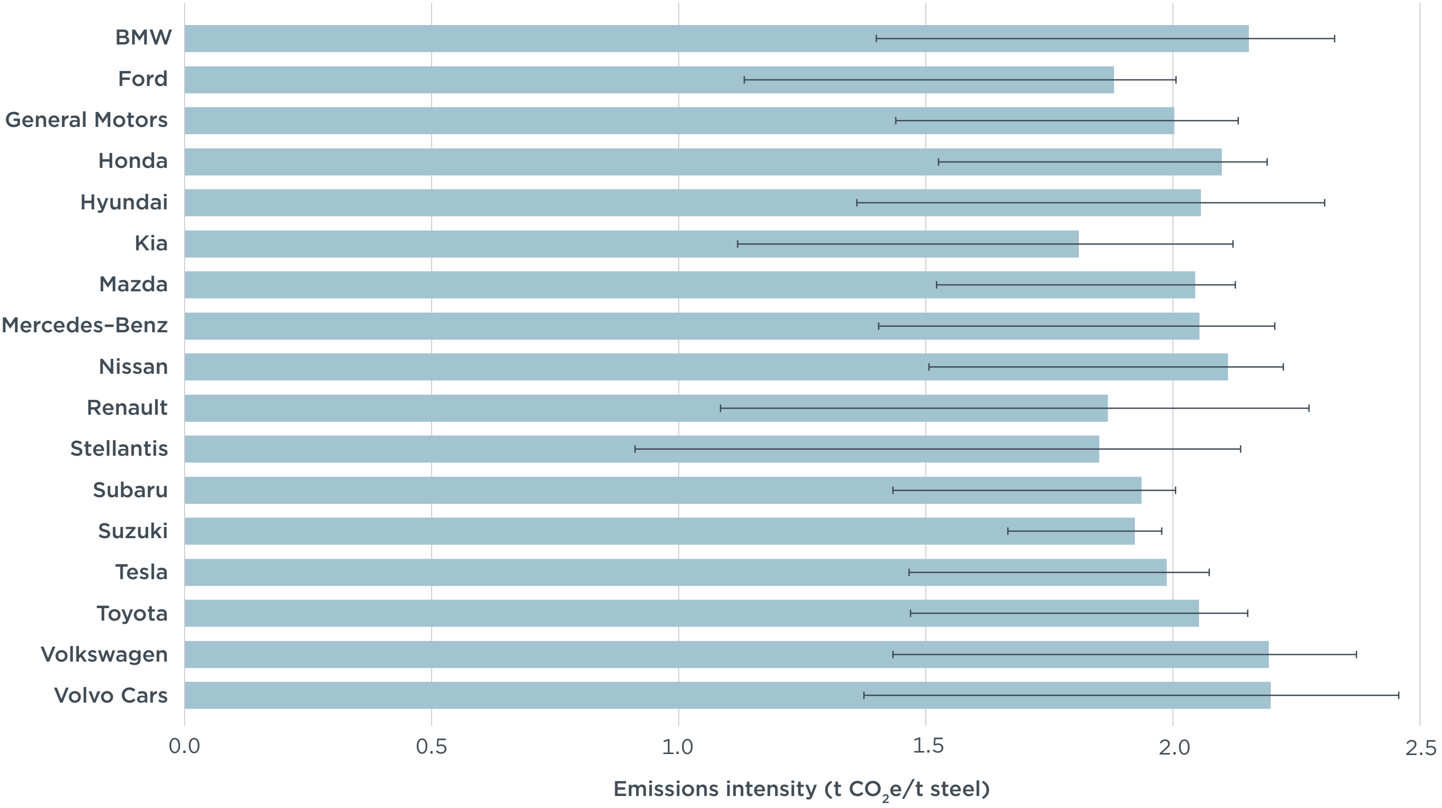
In a central estimate, we assume that automakers procure steel that corresponds with the regional average GHG emissions intensity of each supplier. Table A4 in the appendix presents—by automaker and by region of PV production—the calculated average GHG emissions intensity of steel used by automakers. In general, the regions with the highest GHG emission intensities are those where steel producers have a larger share of BF-BOF plants. Regions with lower emission intensities are those where steel producers have a higher share of EAFs. The emission intensities of the pathways can vary significantly among regions. For example, a BF-BOF plant in Europe has an average emissions intensity of 2.1 t CO_2e/t steel, while the values for this type of plant in India are as high as 3.3 t CO_2e/t steel, as shown in Figure A1.

Automakers might be supplied by individual steel plants with emission intensities that deviate from the regional average of the steelmaker. Therefore, Table A4 also indicates sensitivities based on plants of the steel suppliers with the lowest and highest GHG emission intensities in the respective regions. The lowest numbers imply selecting an EAF-based plant in a country with low average emissions intensity for this pathway. Conversely, the highest numbers imply selecting a BF-BOF-based plant in a country with high average emissions intensity for this pathway.

To compare these numbers, Table A4 also presents an estimated steel industry-average GHG emissions intensity for individual regions. This metric reflects the countries' average emissions intensity as based on Hasanbeigi (2022a) and expanded in the scope of emissions considered, without adjusting for the average recycled steel content to the requirements of automotive steel, as in the calculation for automotive steel (as detailed in the methodology section above). It can be seen that the steel purchased by automakers tends to have a higher emissions intensity than the industry average. Across all of the regions considered, most automakers have a higher GHG emissions intensity than the steel industry average, and in some regions, namely South America, Europe, North Africa, Middle East, Central Asia, and China, this is true even for all of the automakers.

The global average GHG emission intensities of the steel procured by the automakers are presented in Figure 7. These are derived from weighting the automakers' regional average GHG emissions intensity as displayed in Table A4—including their upper and lower sensitivities—with the automaker's PV production volumes in the respective regions.

Figure 7
Global average GHG emissions intensity of steel used by automakers



Note: Gray lines indicate the lowest and highest emissions intensity scenarios.

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All automakers show a relatively similar average emissions intensity at a global level. Moreover, the automakers' average emissions intensity is high when compared to the steel industry average for the regions where they have active PV production. In the methodology of this analysis, this mainly results from purchasing steel from producers with a high share of BF-BOFs in countries with higher emission intensities.

The emissions intensity of automotive steel can also vary significantly depending on the assumptions of which plants the steel comes from. When it is assumed that automakers source steel from plants with the lowest emission intensities in a region, which usually are those based on EAF, this reduces the emission intensities of the purchased steel by an average of 32%. For Renault, the reduction is 42% and for Stellantis, the reduction is 51%. When it is assumed that automakers source steel from plants with the highest emission intensities in a region, this increases the emission intensities of the purchased steel by an average of 8%. For Renault, the increase is 22% and for Kia, the increase is 17%. Better transparency regarding information on steel supply, GHG emissions intensity, and the use of recycled steel would allow more precise estimates of the current performance of automakers.

In Stellantis' case, the significant variation in emission intensities across different scenarios stems from its production base in Europe, where nearly half of its global PV production occurs. This region exhibits considerable variability in emissions intensity. Similarly, Kia faces a comparable situation, with a substantial portion of its PV production located in Japan and South Korea. The emissions intensity in these regions is subject to significant variability because of the diverse range of steel producers.

AUTOMAKERS' STEEL COMMITMENTS

This section discusses the selected automakers' commitments to reducing the GHG emissions intensity of the steel in their vehicles, both today and in the future. The evaluation focuses on the same 17 automakers selling PVs in Europe and the North America. We collected and analyzed data available through June 2024.

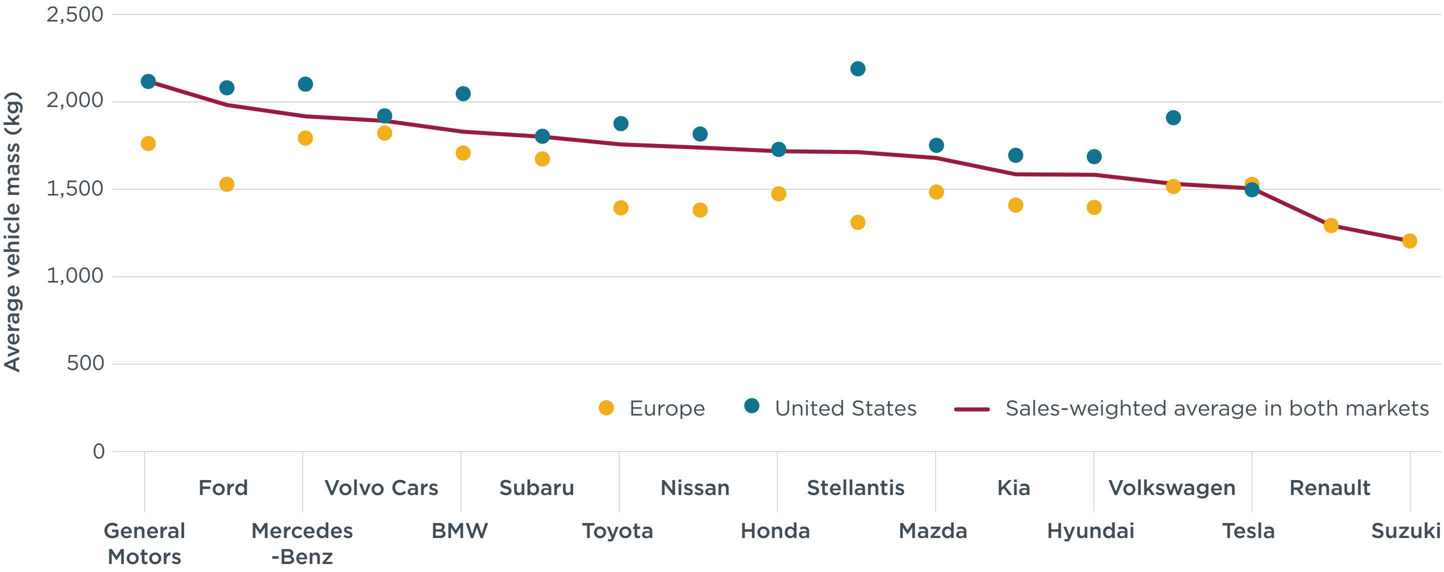
Voluntary actions automakers can take to reduce their steel-related emissions include reducing the amount of steel used in each vehicle, increasing the share of recycled steel in their vehicles, and procuring steel with lower GHG emission intensities. These actions are discussed in more detail below.

VEHICLE MASS

Using less steel in each vehicle is one way to reduce steel-related emissions. Figure 8 shows the average mass, not including batteries, of passenger vehicles sold in Europe and the United States in 2022.[7] Average vehicle mass tends to be higher in the United States compared with Europe. In both markets, the average vehicle mass has been increasing, with average vehicle mass being 19% higher in the European Union in 2022 compared with 2001 (International Council on Clean Transportation, 2024).

Figure 8

Average mass of passenger vehicles sold in Europe and the United States



Note: Europe includes the European Union plus Iceland, Liechtenstein, Norway, and Switzerland; average vehicle mass does not include the weight of batteries.

Sources: U.S. EPA (2024); International Council on Clean Transportation (2024)

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RECYCLED STEEL CONTENT

Using recycled steel in vehicle production is important for two reasons. First, steel produced from scrap has a lower GHG emissions intensity than primary steel. Second, creating a demand for automotive-grade recycled steel may help foster improvement in the sorting of metal parts during product dismantling and shredding towards more high-quality steel scrap, which might in turn lead to a higher use of recycled steel overall.

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[7] The numbers for Europe include the European Union plus Iceland, Liechtenstein, Norway, and Switzerland.

Few automakers disclose the amount of recycled steel they use; the information that is publicly available from five manufacturers shows high variability among automakers. BMW, which reports that the recycled steel content in its vehicles averages 25%, has announced plans to increase this percentage to 50% by 2030 (BMW Group, 2022b, 2022a; Shen et al., 2023). Volvo Cars reports using 15% recycled steel on a per-vehicle basis (Volvo Car Group, 2022). Mercedes-Benz states that the sheet steel procured from Steel Dynamics has a recycled steel content of at least 70%; this steel is used in all Mercedes-Benz models produced in Tuscaloosa, Alabama (Mercedes-Benz Group, 2023b). Renault Group estimates that the recycled steel content in its vehicles in 2022 ranges from 17% for flat steel to more than 90% for steel bars and cast iron (Renault Group, 2023). Stellantis states that it uses up to 30% recycled steel, according to their supplier average, which includes both pre- and post-consumption scrap (Shen et al., 2024).

STEEL-SPECIFIC GHG EMISSIONS INTENSITY TARGETS

The overall GHG emissions reduction targets established by automakers at the corporate level are important for setting a direction and a benchmark for companies' alignment with global efforts to mitigate climate change. However, more specific targets for steel are needed to understand the actual ambition and accountability of these efforts. Therefore, we focused on steel-specific targets rather than company-wide targets. We analyzed automakers' financial and sustainability reports, press releases, and news articles. Some automakers may have steel-specific internal goals which are not publicly available, and therefore are not included here.

Several automakers have joined industry initiatives that set steel-specific targets. Although a global standardized definition of “green” or “low-carbon” steel has not been established, automakers joining these initiatives provide an important market signal to steel producers.

Membership in SteelZero and the First Movers Coalition (FMC) requires a commitment to procure a certain share of steel in the future corresponding to a GHG emissions intensity threshold. The ResponsibleSteel initiative, whose members include both steel producers and steel users, has established steel production standards and categorizes steel plants on their GHG emissions intensity levels. Details on these three initiatives are shown in Table 2. The initiatives vary in their definitions of emissions intensity thresholds and the types of GHG emissions considered. Figure 9 offers a comparison of the thresholds for steel used by ResponsibleSteel, SteelZero, and the First Movers Coalition.

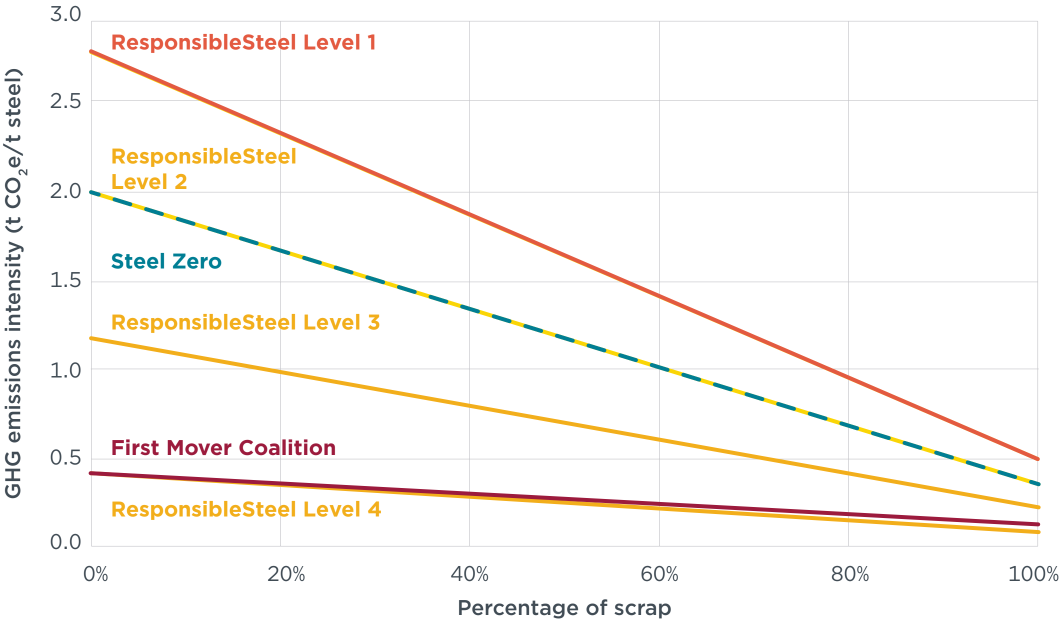
Table 2

Criteria for a membership in ResponsibleSteel, SteelZero, and First Movers Coalition

Initiative	Commitment
ResponsibleSteel	Organization recognizes and scores steelmaking sites according to environmental and social responsibility standards. For GHG emissions intensity, ResponsibleSteel considers four performance levels on a sliding scale. This approach implies lower threshold values for emissions intensity when using higher levels of recycled steel content. The standard specifies types of GHGs under consideration, including CO_2, CH_4, NF_3, N_2O, HFCs, PFCs, and SF_6. The scope of emissions include Scope 1, 2, and 3 from input materials and fuels, ironmaking, and steelmaking up to crude steel production (ResponsibleSteel, 2022, 2024).
SteelZero	Commitment that at least 50% of the steel purchased in 2030 is either acquired from steelmakers with "science-based emissions targets" or is "lower emission steel" aligned with ResponsibleSteel's Level 2 (Climate Group, 2024a). In addition to the 2030 target, the member companies commit to procure 100% "Net Zero Steel" by 2050. "Net Zero Steel" is defined as steel with a GHG emissions intensity "as close as operationally possible" to 0 t CO_2e/t crude steel, including the option to offset emissions (Climate Group, 2024b).
First Movers Coalition	Requirement that at least 10% of crude steel purchased annually be "near-zero emissions" by 2030 (First Movers Coalition, 2024). The scope of emissions is aligned with the International Energy Agency (International Energy Agency, 2022) , which include raw material supply (iron ore and limestone); fossil fuel supply; imported electricity, heat and hydrogen production; producing lime fluxes; producing reduction agents; iron ore agglomeration; ironmaking; and steelmaking. It excludes upstream production of other materials and downstream manufacturing of steel products.

Figure 9

Comparison of the GHG emissions intensity levels considered by SteelZero, ResponsibleSteel, and First Movers Coalition



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The German Steel Association, supported by the Federal Ministry of Economic Affairs and Climate Action (BMWK), recently issued the Low Emission Steel Standard (LESS) (Wirtschaftsvereinigung Stahl, 2024). The standard—the first example of a labeling scheme issued by a large steel-producing country—is scheduled to be introduced to companies during 2024. This standard adopts a similar approach to the initiatives reported in Figure 9, by detailing the threshold for emissions intensity based on the share of scrap used. Because LESS considers a broader scope of emissions, especially from downstream sources, it is presented separately from the other standards in Figure A6 in the appendix.

The Science Based Targets Initiative, another relevant industry effort, more generally defines and promotes best practices to help companies develop targets oriented to the Paris Agreement goals (Science Based Target Initative, 2023).

Volvo Cars is a member of SteelZero and has also committed to using 25% recycled steel in its manufacturing processes by 2025 (Volvo Car Group, 2022). Both Ford and General Motors are First Movers Coalition members. General Motors specifies that at least 10% of the crude steel purchased for the United States, Canada, and Mexico will be “near zero emissions” by 2030, provided that the prices for this material do not exceed the current commercial process by 20%, or as approved by General Motors leadership (General Motors, 2022).

Mercedes-Benz has announced a goal of procuring more than 200,000 tonnes of “CO_2-reduced steel” annually for their European facilities from European suppliers before the end of this decade. This is an estimated 10% of the company’s global steel demand. The automaker aims at using “almost CO_2-free” steel produced with “green hydrogen and renewable energies” when the technologies are available (Mercedes-Benz Group, 2023a, 2024).

BMW aims to use “low-carbon” steel to meet over 40% of demand at its European plants by 2030 (BMW Group, 2022a). The steel “will be produced using natural gas or hydrogen and green power,” although the company does not further specify whether natural gas-based of renewable electricity-based hydrogen will be used. BMW has 48% of its production in Europe, so this can be translated into about 19% of the company’s steel procurement globally.

For other automakers, we found public declarations concerning steel without specifying how much or when it will be purchased. For instance, Kia has announced its intention to procure “green steel” that will have one third as much carbon emissions by 2030 (Kia, 2024).

For further reference, Table A6 in the appendix summarizes decarbonization announcements of main steel producers.

AUTOMAKERS’ AGREEMENTS WITH STEEL SUPPLIERS

We collected publicly announced agreements between automakers and individual steel suppliers as another indicator of their commitment to reducing steel-related GHG emissions. A broad variety of terms and definitions are used in these announcements, which are often lacking in specifics about GHG emissions intensity and the scope of emissions considered. We found relevant announcements for the following automakers:

- **BMW** announced its procurement of “CO_2-reduced” steel from EAF plants operated by H2 Green Steel (BMW Group, 2021). H2 Green Steel is building a DRI-EAF plant in northern Sweden that uses renewable electricity and hydrogen produced from renewable electricity (known as green hydrogen), with large-scale production set to start in 2025 (H2 Green Steel, 2022). Starting in 2025, H2 Green Steel will deliver steel produced with hydrogen and renewable energy to BMW’s European factories (BMW Group, 2022a). In addition, BMW partnered with Salzgitter to receive “low-carbon steel” in European plants starting in 2026 (BMW Group, 2022a). Salzgitter AG has announced it will gradually switch to using green hydrogen and renewable electricity for their plants by the end of 2033 (Salzgitter AG, 2024), but it is unclear what emissions intensity the steel purchased by BMW from Salzgitter AG will have. BMW has also invested in Boston Metal, a company developing a molten oxide electrolysis technology that can be fossil-free if run on renewable electricity (BMW Group, 2022a). This is a pilot project and will require several years of research and development before it can be used commercially.

- **Ford Europe** came to an agreement with Tata Steel to receive “low-CO_2 steel” for its European plants after 2030 (Tata Steel, 2022b). This “low-CO_2 steel” would have an “allocated carbon footprint reduction up to 100%… based on CO_2 savings realized within Tata Steel Nederland since 2018” (Tata Steel, 2022b). This seems to involve mass balancing of emissions, which is when the reduced emissions realized by improvements at a plant are entirely allocated to a portion of the plant’s production.[8] This portion of production is then sold as low-emissions or emissions-free, while the remainder of the plant’s production is assigned the emissions intensity of the plant before the improvements. Ford Europe also signed a memorandum of understanding with Salzgitter AG and Thyssenkrupp to secure a supply of “low-carbon” steel (Ford, 2022; Tata Steel, 2022b).
- **General Motors** announced a supply agreement with U.S. Steel for “advanced and sustainable steel” called verdeX. This steel can contain up to 90% recycled steel and would have “70%–90% lower CO_2 emissions” compared with traditional steelmaking, although the production process has not been disclosed (U.S. Steel, 2024b). General Motors also announced an agreement with ArcelorMittal for steel made via the EAF production pathway and containing 70%–90% recycled steel (ArcelorMittal, 2023b). Shipments from ArcelorMittal were expected to start in Q2 of 2023. In addition, starting in 2022, General Motors was announced to be the first customer to receive Nucor’s steel produced with 100% renewable energy plus offsets to neutralize residual emissions (Lopez, 2021).
- **Mercedes-Benz** is also investing in H2 Green Steel, signing a supply agreement for over 50,000 tonnes of “almost CO_2-free” steel annually for its European factories. Production of steel with a targeted emissions intensity of 0.4 t CO_2/t steel is to start in 2025 (Mercedes-Benz Group, 2021). Mercedes-Benz also signed a contract with Steel Dynamics to supply more than 50,000 tonnes of reduced-emissions steel per year for its Alabama auto plant, starting in September 2023. The steel supplied by Steel Dynamics is produced in an EAF that runs on renewable electricity and has a recycled steel content of 70% or greater (Mercedes-Benz Group, 2023b). The agreements with H2 Green Steel and Steel Dynamics combined are estimated to be about 5% of the company’s global steel demand. Further, Mercedes-Benz announced it received prototype steel in 2022 from SSAB’s hydrogen-based DRI pilot plant in Sweden, and intended to receive “almost CO_2-free” steel from SSAB from 2026 onwards (Mercedes-Benz Group, 2023a). The company also currently sources “CO_2-reduced” flat steel from Salzgitter AG’s scrap-only EAF and from Arvedi, which has switched parts of its production to renewable electricity. The automaker has also signed a letter of intent for “CO_2-reduced steel” from Thyssenkrupp’s first DRI plant in 2026. The “CO_2-reduced steel” is to be produced through a pathway that would be “almost CO_2-free” in the future if green hydrogen is available.
- **Volkswagen** has signed an MOU with Salzgitter AG to procure “low-CO_2” steel starting at the end of 2025 (Salzgitter AG, 2022). Salzgitter AG plans is to produce this steel in Germany via the green hydrogen DRI route, which would “reduce CO_2 emissions by more than 95 per cent by 2033.” Volkswagen, however, has not disclosed the quantities it intends to purchase. Additionally, Volkswagen has announced a memorandum of understanding for up to 300,000 tonnes of “low-carbon steel” from Vulcan Green Steel starting in 2027 (Volkswagen Group, 2024). Vulcan Green Steel is building a DRI plant in Oman that will initially use natural gas, with plans to gradually shift to using green hydrogen because of the renewable energy projects underway in that country. Porsche, a Volkswagen subsidiary that accounted for 3.7% of Volkswagen’s sales in 2023, also signed an agreement for 35,000 tonnes of steel annually with H2 Green Steel starting from 2025 (MarkLines, 2023; Porsche, 2023)

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[8] For a complete definition of mass balancing, see Bui et al. (forthcoming).

- **Volvo Cars** has announced “fossil-free” steel procurement from SSAB by 2026 (Volvo Car Group, 2021). SSAB’s fossil-free steel product uses hydrogen produced with fossil-free electricity.
- **Nissan** announced that it will use Kobe’s “low CO_2 steel” for its production starting in 2023 (Nissan Motor Corporation, 2022). This steel will be produced by the traditional BF-BOF route, however, and it is unclear how much emissions will be reduced.

EVALUATION OF THE AUTOMAKERS’ PUBLIC TARGETS AND AGREEMENTS WITH STEEL SUPPLIERS

In this section, the level of ambition of the automakers’ commitments are evaluated, based on the public steel-related emission targets and agreements with steel companies.

We considered only commitments with quantitative targets, such as volumes or shares of steel procured by 2030 at the latest. While having an ambitious target for 2050 is valuable, it may not send a strong market demand signal to steel producers to start expanding fossil-free steel production now.

The analysis distinguishes between commitments to procure fossil-free steel and commitments to procure steel with reduced GHG emissions intensity. For the fossil-free steel commitments, we considered only those specifying steel production pathways that can contribute to deep decarbonization of the steel sector. This would include the green hydrogen-based DRI-EAF pathway and steel produced with GHG emission intensities compatible with the First Movers Coalition or ResponsibleSteel Level 4 thresholds. For commitments to procure steel with reduced GHG emissions intensity, we considered announcements with other production pathways and GHG emission intensities.

Among all automakers considered in this study, only General Motors, Ford, Mercedes-Benz, and Porsche (part of Volkswagen) have quantitative near-term commitments that we categorize as fossil-free. For General Motors and Ford, we consider their membership in the First Movers Coalition, which includes the commitment to purchase at least 10% of their crude steel demand as “near-zero emissions” by 2030.

For Mercedes-Benz, we consider the agreements with H2 Green Steel and Steel Dynamics. According to our estimates, both agreements combined correspond to about 100,000 tonnes of steel, or 5% of Mercedes-Benz current annual steel consumption for PV production globally.[9] Porsche’s commitment to procure 35,000 tonnes annually from H2 Green Steel accounts for roughly 0.55% of the steel consumed by Volkswagen annually.

For the less stringent commitment category of reduced emissions steel, membership in the SteelZero initiative, such as by Volvo Cars, is considered. Automakers can select several options for meeting 2030 targets, with varying levels of ambition. The first option is to procure at least 50% of steel from plants certified by ResponsibleSteel as Level 2, a level that allows emissions that are considerably higher than for fossil-free steel, as shown in Figure 9. The second option, to procure steel from a producer with science-based targets in place, may not result in additional demand for fossil-free steel by 2030. While these initiatives help scale up purchases of lower emissions intensity steel, they do not commit automakers to fossil-free steel uptake.

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[9] In this and subsequent calculations, an average of 900 kg of steel per vehicle are considered.

BMW announced that it aims to procure "low-carbon steel" for 40% of its European production by 2030, using either natural gas or hydrogen (BMW Group, 2022a). BMW produces about 48% of its PVs in Europe, so we considered this announcement to cover 19% of the company's global steel demand.

Mercedes-Benz has announced a target of procuring 200,000 tonnes annually of "CO_2-reduced steel" before 2030. As noted above, 100,000 tonnes from H2 Green Steel and Steel Dynamics are considered fossil-free. The remaining 100,000 tonnes, or another 5% of the company's estimated steel demand, are categorized as having reduced GHG emissions intensity. Finally, Volkswagen's agreement with Vulcan Green Steel to procure 300,000 tonnes of "low-carbon steel" is included here as a commitment to purchase reduced emissions intensity steel because this supply will be produced initially with natural gas. The agreement accounts for an estimated 4% of Volkswagen's total steel need.

Other agreements are not included in either category if they do not indicate the amount of steel to be procured—or a way to calculate that amount—or information about the technological pathway for producing the steel. General Motor's agreement with U.S. Steel is not included because it does not disclose quantities and the production pathway. BMW's agreement with H2 Green Steel does not disclose quantities. Volkswagen agreement with Salzgitter AG does not disclose which pathway will be used to produce "low CO_2" steel. Finally, Ford's agreement with Tata Steel is not included because it is based on mass balancing, which does not contribute to scaling up the production of low GHG emission steel (Bui et al., 2024).

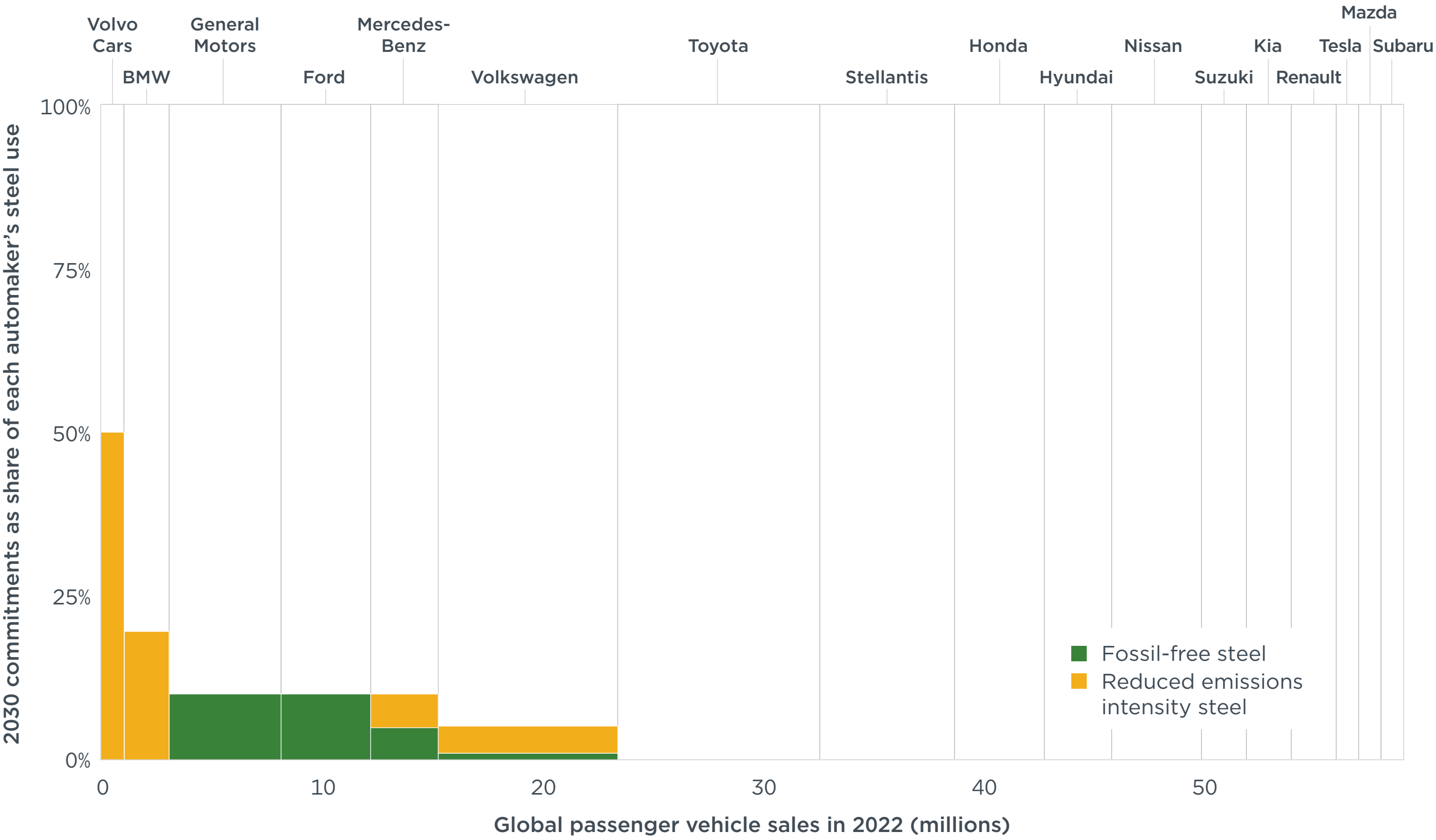
As shown in Figure 10, some of the largest automakers by global PV sales have not made any public commitments to purchase fossil-free or reduced emissions steel.

The fossil-free steel commitments made by four of the automakers correspond to only 2% of the global steel used by all 17 automakers considered in this study. Adding the commitments to buy steel with a reduced GHG emissions intensity raises that share to just 4% of all steel purchased.

According to the International Energy Agency's Net Zero scenario (International Energy Agency, 2021), the global steel sector needs to reduce CO_2 emissions by 25% by 2030. At this stage, none of the automakers appear to have sufficiently ambitious targets in 2030 to support the decarbonization of steel production.

Figure 10

Share of the automakers' global steel demand to be fossil-free or reduced GHG emissions intensity in 2030, based on automakers' public commitments



Note: Commitments up until 2030 are calculated as a share of total steel demand for each automaker without considering material utilization losses; only public commitments are included. The width of each section corresponds with global passenger vehicle sales.

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SUMMARY AND CONCLUSIONS

The automotive industry is the second-largest consumer of steel globally and a consumer of high-quality, primary steel products, generally produced through the coal-based BF-BOF pathway. The automotive sector is thus uniquely positioned to act as a lead market for primary fossil-free steel uptake. The steel industry must reduce its global emissions by 25% by 2030 to be on a pathway to become climate neutral by 2050, as outlined in the International Energy Agency's Net Zero scenario (International Energy Agency, 2021). Given the long lifetime of steel plants, investment decisions in this decade are critical to scaling up fossil-free steel production and meeting climate targets in the long term.

In this study, we analyzed the steel supply chains of 17 major automakers selling and manufacturing vehicles in Europe and North America. We then determined the global average GHG emissions intensity of steel used by these automakers. Lastly, we looked at the public commitments made by automakers to use fossil-fuel steel or reduced-emissions steel in 2030.

AUTOMAKERS' STEEL SUPPLY CHAINS

All major automakers selling PVs in Europe and North America procure steel that isproduced largely through the BF-BOF pathway and therefore has a GHG emissions intensity higher than the steel industry average. The steel plants supplying PV manufacturing facilities in Europe have a GHG emissions intensity of 2.0 t CO_2e/t steel or higher. For the steelmakers supplying automakers in Europe, 97% of the installed steelmaking capacity is based on the coal-reliant BF-BOF route and the remaining 3% is based on EAF routes. For comparison, the share of BF-BOF in the total European steel industry is only 56%, with 44% EAF. The fact that the automotive industry tends to purchase a high share of steel produced with the BF-BOF route may be explained by the requirement for high-quality steel.

In North America, steelmakers show a wider range of emissions. The highest-emitting steel producers are Cleveland-Cliffs (2.1 t CO_2e/t steel) and U.S. Steel (1.9 t CO_2e/t steel), while the lowest-emitting are Steel Dynamics, Nucor, SSAB, TimkenSteel, and Vallourec (1.0 t CO_2e/t steel). In North America, the steel producers supplying the automakers, on average, have a BF-BOF share that is in line with the regional average (31%). However, automakers tend to procure a disproportionally high share of primary steel produced with the BF-BOF pathways.

AUTOMAKERS' STEEL-RELATED GHG EMISSIONS INTENSITY

The study next estimated the average steel-related GHG emissions intensity for each of the 17 automakers on a regional level. Due to the lack of detailed data, a central estimate is based on the assumption that the steel procured by an automaker corresponds to the average emissions intensity of the steel producers' plants in the same region where the vehicles are manufactured. In a highest and lowest GHG emissions intensity sensitivity, the study explores how the emissions intensity varies when assuming that the automakers are supplied only from the lowest and highest emissions intensity steel plants of the steelmakers in the respective regions.

We found that across all of the regions considered, most automakers have a higher GHG emissions intensity than the steel industry average, and in some regions, namely South America, Europe, North Africa, Middle East, Central Asia, and China, this is true for all automakers. When comparing the emission intensities by region, we found that the regions with the highest GHG emissions intensity are those where steel producers have a larger share of BF-BOF plants, while the regions with a lower emissions intensity are those where the steel producers have a higher share of EAFs. Further, the emissions intensity of the individual pathways can vary significantly between regions. For example, a BF-BOF plant in Europe has an average emissions intensity of 2.2 t CO_2e/t steel, while the value for plants in India is as high as 3.4 t CO_2e/t steel.

To determine a global average for each automaker, these regional values were weighted in accordance with the automakers' PV production by region and by their spending on individual steel companies. In the central estimate, automakers use steel with global average values of 1.8–2.2 t CO_2e/t steel. In the lowest emissions intensity sensitivity, automakers use steel with a GHG emissions intensity of 0.9–1.7 t CO_2e/t steel, and 2.0–2.5 t CO_2e/t steel in the highest emissions intensity sensitivity.

Part of the uncertainty is due to the lack of disclosure from companies on their GHG emissions intensity and use of recycled steel. Better transparency would allow for a more precise assessment of the automakers' current performance.

AUTOMAKERS' COMMITMENTS TO DECARBONIZING STEEL

This study also analyzed the 17 automakers' publicly announced commitments to procure fossil-free and reduced GHG emissions intensity steel in the future, considering only quantified near-term commitments as impactful market signals. The results indicate that only General Motors, Ford, Mercedes-Benz, and Volkswagen have public commitments to procure fossil-free steel in 2030. Ford and General Motors are part of the First Movers Coalition, members of which commit to making at least 10% of their annual crude steel purchases be "near-zero emissions" by 2030. Mercedes-Benz has commitments with H2 Green Steel and Steel Dynamics, with a combined volume of 100,000 tonnes of fossil-free steel per year, which we estimate to correspond to about 5% of the automaker's global steel demand. Porsche, a subsidiary of Volkswagen, has a commitment to procure 35,000 tonnes of steel from H2 Green Steel, corresponding to about 0.55% of Volkswagen's global steel demand.

Other automakers have agreements or targets for steel procurements categorized as steel with a reduced GHG emissions intensity. As part of the SteelZero initiative, Volvo Cars has committed to making 50% of its steel purchases in 2030 be of reduced GHG emissions intensity compared to current levels. Similarly, BMW has a 2030 target of procuring 40% of the steel used in European manufacturing as reduced GHG emissions intensity steel, which corresponds to a 19% of the company's steel demand on a global level. Mercedes-Benz has a target of procuring 200,000 tonnes per year of steel with a lower GHG emissions intensity before 2030, which is estimated to correspond to about 10% of the company's global demand; 100,000 tonnes will come from fossil-free steel purchase agreements with H2 Green Steel and Steel Dynamics, while the other 100,000 tonnes will be reduced GHG emissions intensity steel. Additionally, Volkswagen has announced an MOU for up to 300,000 tonnes of "low-carbon steel" with Vulcan Green Steel starting from 2027.

In summary, this study finds similarly high levels of GHG emission intensities of the steel procured by automakers today. To decarbonize steel procurements in future, some individual automakers are taking important first steps to encourage scaling up fossil-free steel production. When compared to the total steel demand of all the selected automakers, however, the volumes of these commitments are still at a very low level. The commitments to purchase fossil-free steel correspond to 2% of all the steel used by the 17 selected automakers. Including the commitments to buy steel with a reduced GHG emissions intensity raises that share to just 4%.

RECOMMENDATIONS

This study finds that the GHG emissions intensity of steel used in vehicle production today is usually higher than industry average across the regions considered. For decarbonizing their steel procurements in future, some automakers are taking first steps by announcing commitments to procure fossil-free steel. However, there is ample room for improvement when it comes to reducing GHG emissions intensity, along with disclosing information about emissions and the percentage of recycled steel used in auto manufacturing. If the automotive steel demand is to be aligned to the International Energy Agency's Net Zero pathway for decarbonization of the steel sector, at least 25% of steel procured by automakers should be fossil-free by 2030. Based on the results of our study, we suggest the following recommendations for both automakers and policymakers.

ACTIONS FOR AUTOMAKERS TO CONSIDER

Demonstrate demand for fossil-free steel. Providing clear market signals could reduce the steelmakers' risk of investing in new technologies and facilities, as investments in fossil-free primary steel production are substantial and require planning over a long timeline. Such investments can be supported best by signing pre-purchase agreements with steel producers. Further, public commitments from automakers that specify timelines, the quantities of steel to be purchased, and the emissions reduction to be achieved help to provide more investment security. Automakers can also sign up for initiatives such as SteelZero or the First Movers Coalition at the maximum level of ambition (Climate Group, 2024; First Movers Coalition, 2024). An alternative initiative is the Sustainable Steel Buyer Platform managed by RMI, which aggregates demand for low-emission steel in North America (Rocky Mountain Institute, 2024).

Discourage steel suppliers from using blast furnaces. Alignment with the International Energy Agency's Net Zero pathway for decarbonizing the steel sector will require moving away from the coal-based steel production pathways and investing in fossil-free alternatives. Automakers are uniquely positioned to promote the availability of fossil-free steel, as the steel they purchase is usually high-quality and high-cost.

Invest in companies developing fossil-free steel. For example, BMW has invested $60 million in Boston Metal for the production of fossil-free steel through an innovative production method that uses electrolysis (BMW Group, 2021). Similarly, Mercedes-Benz has invested in the fossil-free steel startup H2 Green Steel (Mercedes-Benz Group, 2021)

Make vehicles easier to recycle. Vehicles can be designed and assembled with the aim of minimizing pollution with elements that can affect the quality of steel recovered during vehicle recycling at their end of life. This helps to increase the availability of high-quality scrap steel that can then be used in making new vehicles.

Increase the disclosure of steel emissions intensity and recycled content. This can be achieved by requiring environmental product declarations from steel producers by tracking and disclosing the emissions intensity and quantities of pre- and post-consumer scrap in the purchased steel. This can allow automakers to set future targets for steel emissions intensity and the share of post-consumer scrap.

Make vehicles lighter. Reducing the quantity of steel in a vehicle is one way to lower steel-related emissions. This is an emissions-reduction opportunity particularly for automakers with product lines that have a higher average vehicle mass than other manufacturers.

ACTIONS FOR POLICYMAKERS TO CONSIDER

Policies aimed at decarbonizing the steel sector as a whole can also result in lower emissions for the steel used in vehicles. A comprehensive overview of the policy developments in the European Union and in the United States is available in Bui et al. (2024).

Provide subsidies to scale up fossil-free steel production. Subsidies can encourage further private investments to accelerate the adoption of clean technologies that currently entail higher costs. Subsidies that aim for deep decarbonization of the steel industry can help to avoid investments that lock in use of fossil fuels for years to come. The U.S. government announced funding of $6 billion for commercial-scale industrial decarbonization projects in Mach 2024, including $1 billion for six steel decarbonization projects (U.S. Department of Energy, 2024). Similar subsidies have been granted to steel plants by EU Member States, including Germany and Spain (European Commission, 2024b; European Commission, 2023b). Part of the Japanese government's nearly ¥450 billion ($2.9 billion USD) in subsidies for steel decarbonization has been assigned to research and development of hydrogen based DRI-EAF (Japanese Ministry of Economy, Trade and Industry, 2015; Nagao, 2023). The South Korean government has allocated part of the KRW 268.5 billion (USD 196.3 million) in funding to support hydrogen technology development for steel (Solutions for Our Climate, 2021; South Korean Ministry of Trade, Industry and Energy, 2023).

Introduce an emissions trading system covering the steel sector. Auctioning a capped amount of emission certificates introduces a market-driven approach to reduce GHG emissions and incentivizes companies to invest in decarbonization and innovation. Furthermore, the revenue stream generated by such a system could be reinvested into fossil-free steel production technologies. The extension of the EU's Emissions Trading System to the steel sector could serve as a best practice example for such a policy (European Commission, 2024b).

Incentivize the use of fossil-free steel in vehicles. Automakers' current commitments to procure fossil-free steel are voluntary. Requiring a fossil-free steel quota or an average GHG emissions intensity threshold for steel used in new vehicles could boost demand and promote decarbonization investments by steel producers. As an example, in 2024 France introduced a manufacturing emissions intensity threshold to be eligible for a purchase bonus, which applies country-average rather than company-specific emission intensities (Décret N° 2024-102). In addition, the European Commission's proposal to revise the Ecodesign for Sustainable Products Regulation, which aims to establish a broad framework for producing products sustainably, including iron and steel products, could set a maximum GHG emissions threshold for steel products (European Commission, 2022).

Require vehicles to be designed for recycling and increase the supply of automotive-quality secondary steel. Measures to increase the supply of high-quality secondary steel for automotive applications include ensuring vehicle end-of-life collection and management, improving the sorting of metal parts during vehicle dismantling and shredding, and requiring a recycled steel quota in newly built vehicles. This is particularly relevant for automotive-quality steel, where contamination of scrap steel with copper, tin, antimony, and lead currently limit the use of recycled steel. The European Union's battery regulation, which will require an increasing share of materials to come from recycling, could serve as a best practice example for recycled content mandates (Regulation (EU) 2023/1542). Similarly, the European Commission's proposal for a new Regulation on Circularity Requirements for Vehicle Design and on Management of End-of-Life Vehicles considers binding targets for recycled content of the plastics used in vehicle production (Directorate-General for Environment, 2023). As discussed in the Commission's proposal, such recycled-content requirements could also be considered for the steel used in vehicle production.

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APPENDIX

Table A1

Regions considered in the analysis

Region	Countries included
North America	Canada, Mexico, Puerto Rico, United States
South America	Argentina, Brazil, Chile, Colombia, Peru, Venezuela, Uruguay
Europe	Albania, Austria, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Luxembourg, Moldova, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Türkiye, Ukraine, United Kingdom
North Africa	Algeria, Egypt, Libya, Morocco
Sub-Saharan Africa	Angola, Mozambique, Namibia, Nigeria, South Africa
Middle East	Bahrain, Iran, Iraq, Israel, Kuwait, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates
Central Asia	Azerbaijan, Georgia, Kazakhstan, Uzbekistan
India and Pakistan	India, Pakistan
ASEAN	Cambodia, Indonesia, Malaysia, Myanmar, Philippines, Singapore, Thailand, Vietnam
China	China
Japan and South Korea	Japan, South Korea
Pacific	Australia, New Zealand
Other	Guatemala, Kenya, Russia, Trinidad and Tobago

Table A2

Estimates of emissions intensity (t CO_2e/t steel) by process and country

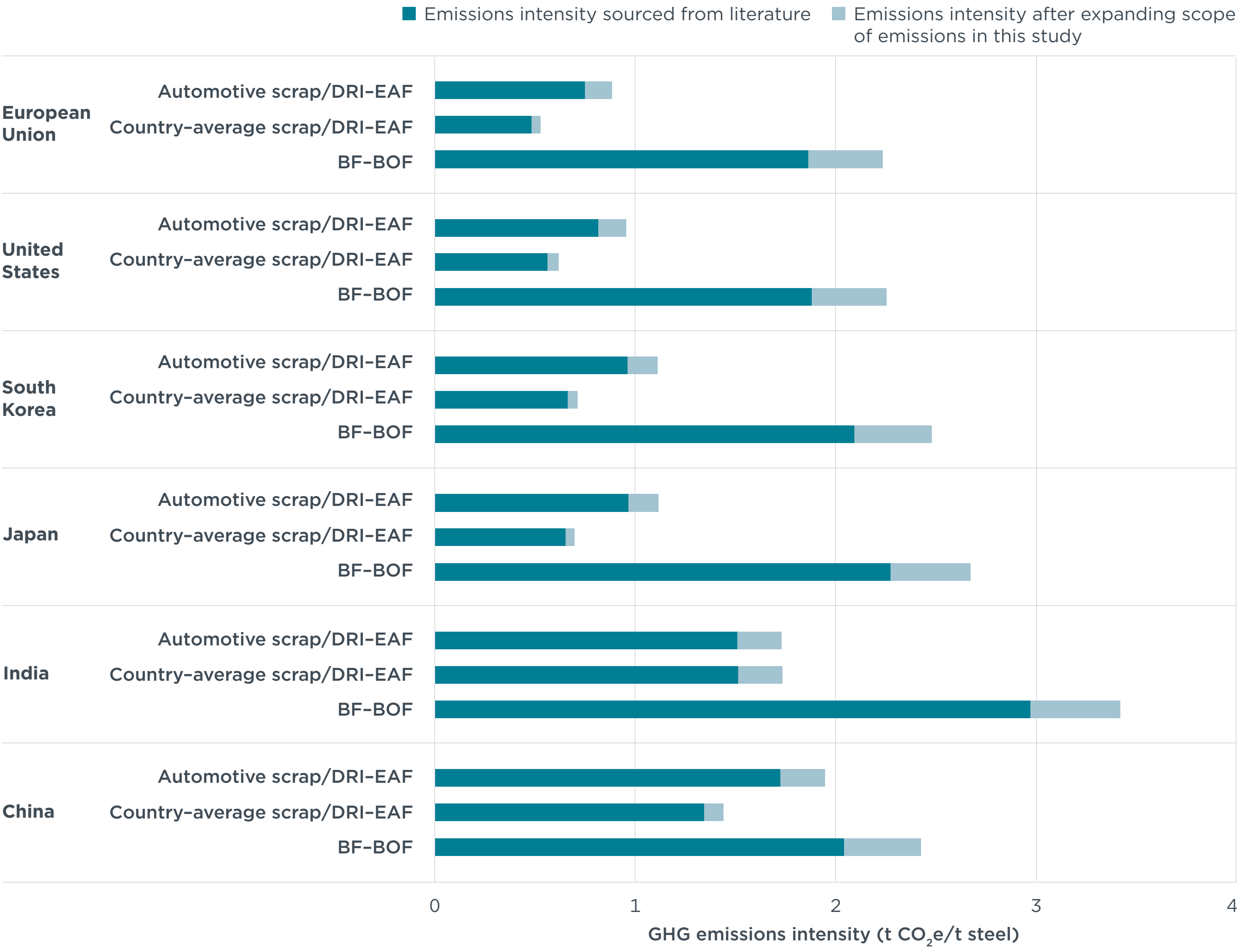
Countries	(Hasanbeigi, 2022a)[a]		(Koolen & Vidovic, 2022)[b]	
	BF-BOF	EAF	BF-BOF	EAF
Brazil	2.08	0.31	2.21	0.12
Canada	1.61	0.44		
China	2.04	1.34	1.84	0.52
France	1.88	0.34		
Germany	1.80	0.52		
India	2.97	1.51	3.83	0.45
Italy	1.99	0.52		
Japan	2.27	0.65	2.12	0.40
Mexico	1.88	0.79		
Russia	1.96	0.61	3.00	0.46
Serbia			2.26	0.82
South Africa			3.94	2.74
South Korea	2.09	0.66	2.05	0.41
Switzerland				0.10
Türkiye	1.89	0.57	2.2	0.29
Ukraine	2.43	0.62	2.49	0.39
United Kingdom			2.08	0.16
United States	1.88	0.56	2.09	0.27
Vietnam	2.34	0.90		
European Union	1.86	0.48	1.81	0.24

[a] System boundaries include coke making, pelletizing, sintering, ironmaking, steelmaking, steel casting, hot rolling, cold rolling, and processing such as galvanizing or coating. Mining and scrap are excluded. Fuel and electricity CO_2 emission factors are included. Embodied energy in net imported pig iron and DRI are included.

[b] System boundaries include coke plant, sinter plant, pellet plant, blast furnace, basic oxygen furnace, DRI-EAF, EAF, and upstream emissions of intermediate products.

Figure A1

GHG emissions intensity by process in major steel-producing countries and regions



Note: The GHG emissions intensity is displayed for the country-average percentage of scrap steel used in the EAF pathway and is adjusted for the lower percentage of scrap used in automotive steel.

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Table A3

Steel suppliers to automakers by region

Gray cells indicate the automaker does not produce passenger vehicles in that region. The automaker may have identifiable relationships with steel suppliers in the region, but these relationships are not considered in the regional emissions analysis.

Orange cells indicate the automaker produces passenger vehicles in the region, but the monetary values of any identifiable relationships with steel suppliers are not known.

Percentages indicate the share of an automaker's global spending on steel with that producer. Automakers may have identifiable relationships with other steel producers, but the monetary value is not available.

	North America	South America	Europe	Northern Africa	Sub-Saharan Africa	Middle East	Central Asia	India and Pakistan	ASEAN	China	Japan and South Korea	Other
BMW	ArcelorMittal (5%) Cleveland-Cliffs (14%) Steel Dynamics (4%)	ArcelorMittal (7%)	Thyssenkrupp (29%) ArcelorMittal (24%) Voestalpine (9%) Tata Steel (5%) ***Spending share unknown:*** Salzgitter AG H2 Green Steel		ArcelorMittal (3%)			***Spending share unknown:*** Goodluck India	Tata Steel (1%)	***Spending share unknown:*** CITIC Pacific Special Steel Group Hesteel Group Bengang Steel Plates Beijing Shougang Nanjing Iron & Steel		
Ford	Cleveland-Cliffs (24%) Nucor (11%) TimkenSteel[a] (1%) ArcelorMittal (2%) ***Spending share unknown:*** Universal Stainless & Alloy Products Inc. Cleveland-Cliffs Steel Holding Aleris	ArcelorMittal (2%) ***Spending share unknown:*** Grupo Simec SAB de CV	Thyssenkrupp (27%) ArcelorMittal (8%) Tata Steel (5%) ***Spending share unknown:*** Salzgitter AG		ArcelorMittal (1%)				Nippon Steel (19%), Tata Steel (1%)	***Spending share unknown:*** China Steel Corp. China Metal Products CITIC Pacific Special Steel Group Hesteel Group Xining Special Steel Hunan Valin Steel Nanjing Iron & Steel	***Spending share unknown:*** Topy Industries	
General Motors	Cleveland-Cliffs (24%) Nucor (11%) TimkenSteel[a] (1%), Steel Dynamics (8%) U.S. Steel (8%) ArcelorMittal (4%) ***Spending share unknown:*** Universal Stainless & Alloy Products Inc Universal Stainless Shiloh Industries Grupo Simec SAB de CV Aleris	ArcelorMittal (6%) ***Spending share unknown:*** Companhia Siderúrgica Nacional	Thyssenkrupp (9%)				ArcelorMittal (2%)	***Spending share unknown:*** Goodluck India Tube Investments of India	Tata Steel (6%) Nippon Steel (1%)	***Spending share unknown:*** China Steel Corp. China Metal Products CITIC Pacific Special Steel Group Hesteel Group Beijing Shougang Baoshan Iron & Steel Nanjing Iron & Steel	Nippon Steel (18%) ***Spending share unknown:*** Mitsubishi Steel Universal Stainless POSCO Holdings Kyeong Nam Steel SeAH Holdings Keum Kang Steel	
Honda	ArcelorMittal (3%) Cleveland-Cliffs (13%) Nucor (5%) TimkenSteel[a] (1%) ***Spending share unknown:*** Grupo Simec SAB de CV Industrias CH SAB de CV	ArcelorMittal (4%)	Thyssenkrupp (7%)					Nippon Steel (4%), ArcelorMittal (1%), Tata Steel (6%) ***Spending share unknown:*** JSW Steel Pennar Industries Tube Investments of India	Nippon Steel (2%) JFE (0.1%) Tata Steel (0.3%) ***Spending share unknown:*** Steel Pipe Industry of Indonesia PT	***Spending share unknown:*** Beijing Shougang Jiangsu Shagang	Nippon Steel (36%), JFE Steel (13%) Daido Steel (4%) ***Spending share unknown:*** Mitsubishi Steel Manufacturing Topy Industries Gohsyu Steel Center	
Hyundai	Cleveland-Cliffs (15%) Nucor (5%) ***Spending share unknown:*** Aleris	***Spending share unknown:*** Industrias CH SAB de CV	Thyssenkrupp (8%), Tata Steel (2%)					Nippon Steel (2%), Tata Steel (4%) ***Spending share unknown:*** Pennar Industries Tube Investments of India	Nippon Steel (1%) Tata Steel (0.3%)	***Spending share unknown:*** Xining Special Steel Hunan Valin Stee	Nippon Steel (19%) Hyundai Steel (42%) Aichi Steel (1%) ***Spending share unknown:*** Dongkuk Holdings POSCO Holdings Youngwire SeAH Holdings	
Kia	Nucor (21%) ArcelorMittal (6%)		Thyssenkrupp (9%), ArcelorMittal (31%)					***Spending share unknown:*** Pennar Industries Tube Investments of India			Hyundai Steel (33%) ***Spending share unknown:*** POSCO Holdings Pennar Industries Youngwire Bookook Steel SeAH Holdings Keum Kang Steel	
Mazda	Nucor (6%)		Thyssenkrupp (10%)						Nippon Steel (4%) JFE Steel (0.2%)		Nippon Steel (51%) JFE Steel (22%) Daido Steel (5%) Aichi Steel (2%) ***Spending share unknown:*** Kobe Steel Maruichi Steel Tube	
Mercedes-Benz	ArcelorMittal (5%) Nucor (3%) SSAB (1%) Steel Dynamics (5%) ***Spending share unknown:*** Aleris Corp	ArcelorMittal (7%) ***Spending share unknown:*** Grupo Simec SAB de CV Industrias CH SAB de CV	ArcelorMittal (25%) Thyssenkrupp (32%) Tata Steel (6%) Voestalpine (9%) SSAB (4%) Vallourec (1%) ***Spending share unknown:*** Salzgitter AG H2 Green Steel		ArcelorMittal (3%)			***Spending share unknown:*** Goodluck India	Tata Steel (1%)	***Spending share unknown:*** CITIC Pacific Special Steel Group Hesteel Group Bengang Steel Plates Nanjing Iron & Steel		***Spending share unknown:*** United Metallurgical

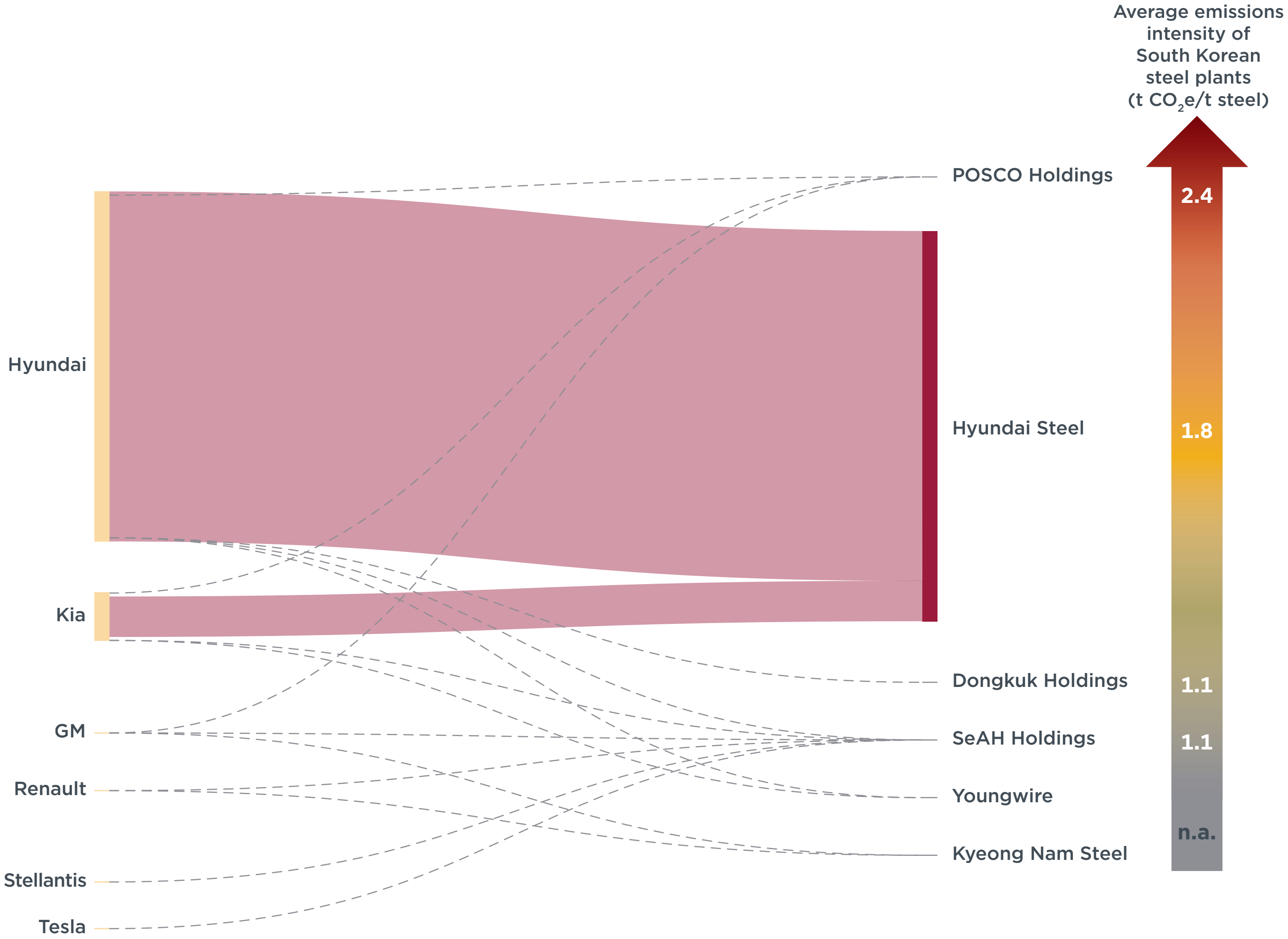
	North America	South America	Europe	Northern Africa	Sub-Saharan Africa	Middle East	Central Asia	India and Pakistan	ASEAN	China	Japan and South Korea	Other
Nissan	Nucor (6%), ArcelorMittal (1%), Timken Steel[a] (1%) Cleveland-Cliffs (15%) ***Spending share unknown:*** Grupo Simec SAB de CV	ArcelorMittal (1%)	Thyssenkrupp (8%), ArcelorMittal (5%), Tata Steel (2%)		ArcelorMittal (1%)			Nippon Steel (4%), ArcelorMittal (0.4%), Tata Steel (4%) ***Spending share unknown:*** Pennar Industries Tube Investments of India	Nippon Steel (3%), Tata Steel (0.3%)	***Spending share unknown:*** China Steel Corp. CITIC Pacific Special Steel Group Guangdong Zhongnan Iron & Steel Beijing Shougang	Nippon Steel (41%), Daido Steel (5%), Aichi Steel (1%) ***Spending share unknown:*** Kobe Steel Topy Industries	***Spending share unknown:*** Beloretsk Metallurgical Plant
Renault SA	***Spending share unknown:*** Aleris		Thyssenkrupp (70%) Erdemir (10%) Tata Steel (7%)				Beloretsk Metallurgical Plant United Metallurgical	Tata Steel (13%) ***Spending share unknown:*** Goodluck India Pennar Industries Tube Investments of India		***Spending share unknown:*** Bengang Steel Plates Xining Special Steel	***Spending share unknown:*** Kyeong Nam Steel SeAH Holdings	
Stellantis	ArcelorMittal (4%) Cleveland-Cliffs (25%) Nucor (22%) Timken Steel[a] (2%) ***Spending share unknown:*** Universal Stainless & Alloy Products Shiloh Industries. Cleveland-Cliffs Steel Holding Grupo Simec SAB de CV Industrias CH SAB de CV	ArcelorMittal (5%)	ArcelorMittal (17%), Thyssenkrupp (25%)	ArcelorMittal (0.2%)				***Spending share unknown:*** Pennar Industries			***Spending share unknown:*** Mitsubishi Steel Manufacturing SeAH Holdings	
Subaru	Nucor (15%)								Nippon Steel (4%) JFE Steel (0.2%)		Nippon Steel (51%) Daido Steel (6%) JFE Steel (21%) ***Spending share unknown:*** Mitsubishi Steel Manufacturing Nippon Steel Trading Topy Industries	
Suzuki		ArcelorMittal (2%)	ArcelorMittal (7%)					Nippon Steel (5%), ArcelorMittal (1%) ***Spending share unknown:*** Goodluck India Tube Investments of India	Nippon Steel (3%) JFE Steel (0.2%)		Nippon Steel (51%) JFE Steel (20%) Daido Steel (6%) Aichi Steel (3%) ***Spending share unknown:*** Mitsubishi Steel Manufacturing Sanyo Special Steel Topy Industries	
Tesla	Cleveland-Cliffs (26%) Nucor (24%) ArcelorMittal (4%) ***Spending share unknown:*** Aleris		Thyssenkrupp (23%), ArcelorMittal (22%)							***Spending share unknown:*** China Steel Corp CITIC Pacific Special Steel Group Hesteel Group Zhejiang Kingland Pipeline & Technologies	***Spending share unknown:*** SeAH Holdings	
Toyota	Cleveland-Cliffs (7%) Nucord (5%) SSAB (1%) Timken Steel[a] (100%) ***Spending share unknown:*** U.S. Steel		Thyssenkrupp (10%), Tata Steel (2%), SSAB (2%)					Nippon Steel (4%), Tata Steel (4%) ***Spending share unknown:*** Goodluck India Ltd Pennar Industries Jindal Stainless Hisar Tube Investments of India	Nippon Steel (3%) JFE Steel (0.2%) Tata Steel (0.3%)	***Spending share unknown:*** China Steel Chun Yuan Steel Industry Hesteel Group Guangdong Zhongnan Iron & Steel Beijing Shougang Nanjing Iron & Steel	Nippon Steel (37%) JFE Steel (17%) Daido Steel (2%) Aichi Steel (5%) ***Spending share unknown:*** Mitsubishi Steel Manufacturing Kobe Steel Nippon Steel Trading Topy Industries	
Volkswagen	Cleveland-Cliffs (6%) Nucor (2%) Steel Dynamics (4%) ArcelorMittal (4%) SSAB (1%) ***Spending share unknown:*** Aleris	ArcelorMittal (6%)	Thyssenkrupp (26%), ArcelorMittal (20%), Voesalpine (7%), SSAB (3%) ***Spending share unknown:*** Salzgitter AG		ArcelorMittal (2%)			ArcelorMittal (2%), Nippon Steel (11%) ***Spending share unknown:*** Goodluck India Tube Investments of India	Nippon Steel (8%)	***Spending share unknown:*** China Steel CITIC Pacific Special Steel Group Beijing Shougang Nanjing Iron & Steel		
Volvo Cars	ArcelorMittal (8%) Nucor (15%) SSAB (1%)		Thyssenkrupp (24%) ArcelorMittal (39%) Voestalpine (12%) SSAB (2%)							***Spending share unknown:*** Beijing Shougang		

Note: The monetary value of spending by automakers with individual steel companies is based on supply chain data from Bloomberg L.P. (2024).

[a] TimkenSteel changed its name to Metallus in February 2024.

Figure A2

Average emissions intensity of steel plants in South Korea by manufacturer in 2022 and the automakers supplied by these steel producers



Notes: Line thickness is proportional to the revenue received by steel companies from specific automakers. Dotted lines are used when revenue data is not available. These estimates are based on supply chain data from Bloomberg L.P. (2024).

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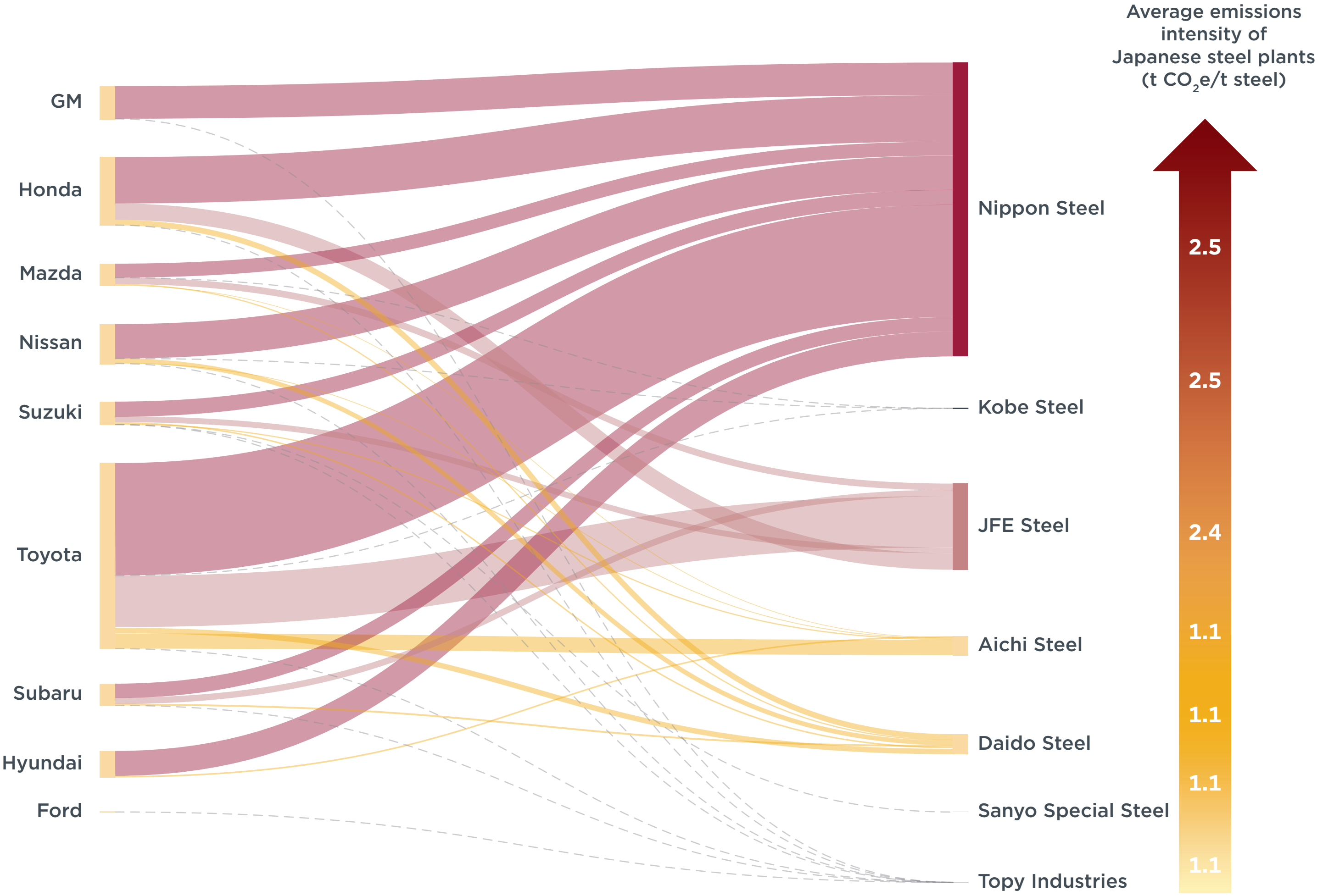
Figure A3

Average emissions intensities of steel plants in Japan by manufacturer in 2022 and the automakers supplied by these steel producers



Notes: Line thickness is proportional to the revenue received by steel companies from specific automakers. Dotted lines are used when revenue data is not available. These estimates are based on supply chain data from Bloomberg L.P. (2024).

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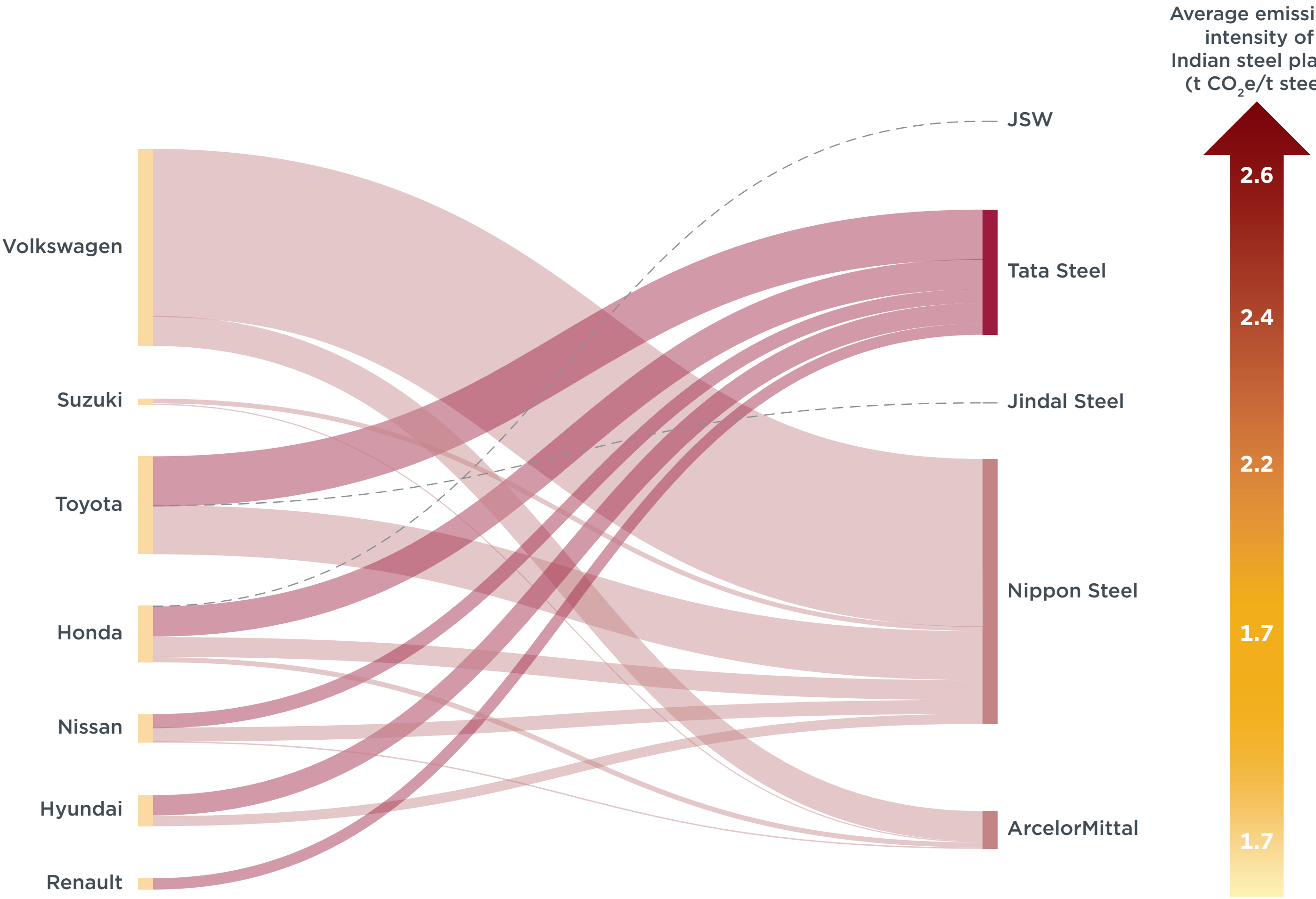
Figure A4

Average emissions intensities of steel plants in India in 2022 and the automakers supplied by these steel producers



Notes: Line thickness is proportional to the revenue received by steel companies from specific automakers. Dotted lines are used when revenue data is not available. These estimates are based on supply chain data from Bloomberg L.P. (2024).

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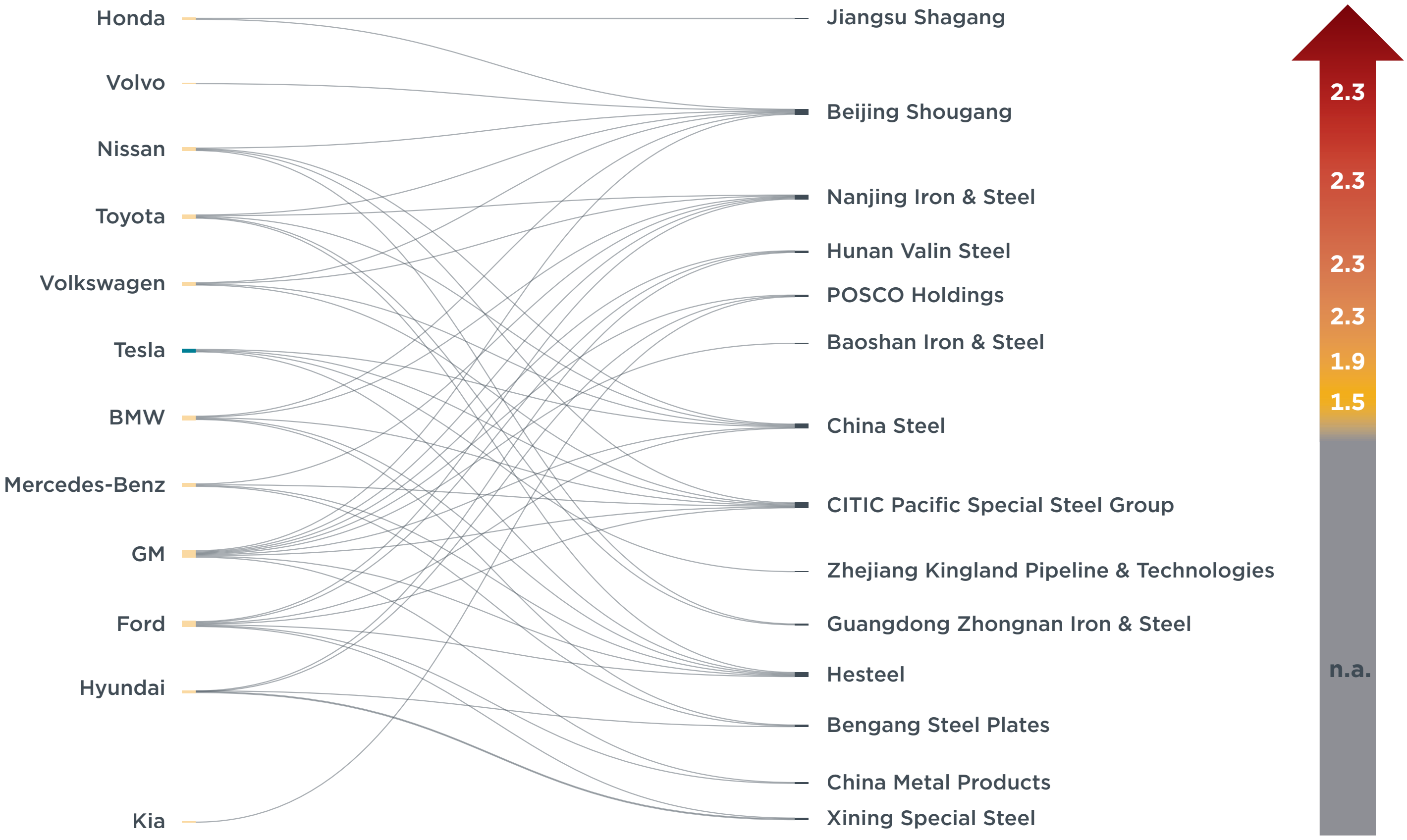
Figure A5

Average emissions intensities of steel plants in China in 2022 and the automakers supplied by these steel producers



Notes: Information on revenue is not available for steel producers in China. The gray area of the arrow indicates companies for which estimates of emissions intensity are not available. Automaker and steel supplier relationships come from supply chain data gathered by Bloomberg L.P. (2024).

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Table A4

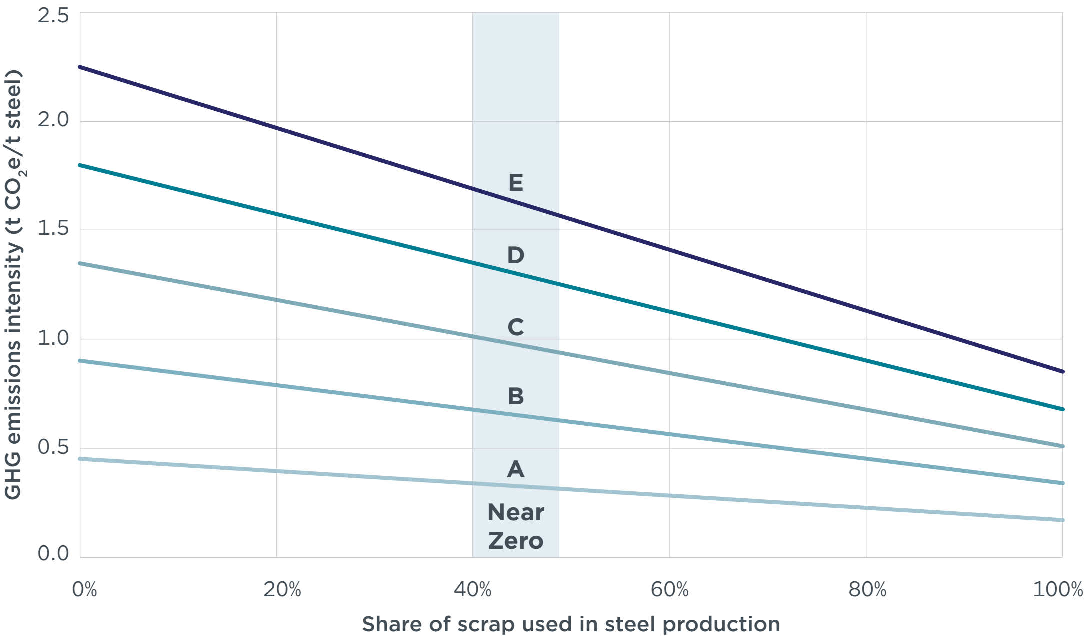
GHG emission intensities of steel (t CO_2e/t steel) for each automaker by region and global average

Automaker	North America	South America	Europe	North Africa	Sub-Saharan Africa	Middle East	Central Asia	India and Pakistan	ASEAN	China	Japan and South Korea	Global average
Steel industry average GHG emissions intensity (t CO_2e/t steel)	**1.1**	**1.8**	**1.4**	**0.5**	**2.6**	**0.7**	**2.1**	**2.5**	**1.9**	**2.3**	**2.0**	–
BMW	**1.7** (0.9–1.9)	**1.9** (0.7–2.5)	**2.2** (1.2–2.4)		**3.4** (3.4–3.4)				**1.4** (1.4–1.4)	**2.4** (1.9–2.4)		**2.2** (1.4–2.3)
Ford	**1.7** (0.9–1.8)	**1.9** (0.7–2.5)	**2.2** (1.1–2.3)		**3.4** (3.4–3.4)				**1.4** (1.4–.4)			**1.9** (1.1–2.0)
General Motors	**1.6** (0.9–1.7)	**1.9** (0.7–2.5)					**2.3** (2.3–2.3)		**1.4** (1.4–1.4)		**2.6** (2.0–2.7)	**2.0** (1.4–2.1)
Honda	**1.7** (0.9–1.8)	**1.9** (0.7–2.5)						**3.0** (2.1–3.1)	**1.4** (1.4–1.4)		**2.5** (1.7–2.6)	**2.1** (1.5–2.2)
Hyundai	**1.8** (1.0–1.9)	**2.0** (2.5–0.7)	**2.2** (1.2–2.2)		**2.5** (1.5–3.4)	**1.1** (0.8–1.7)		**2.2** (1.7–2.9)	**1.4** (1.4–1.4)		**2.0** (1.4–2.3)	**2.1** (1.4–2.3)
Kia	**1.0** (0.9–1.1)		**2.1** (0.9–2.7)								**1.8** (1.1–2.1)	**1.8** (1.1–2.1)
Mazda	**1.0** (1.0–1.0)					**1.1** (0.8–1.7)			**1.5** (1.5–1.5)		**2.4** (1.7–2.5)	**2.0** (1.5–2.1)
Mercedes-Benz	**1.1** (0.8–1.2)	**1.9** (0.7–2.4)	**2.2** (1.2–2.4)		**3.4** (3.4–3.4)				**1.4** (1.4–1.4)			**2.1** (1.4–2.2)
Nissan	**1.7** (0.9–1.8)	**1.9** (0.7–2.5)	**2.2** (1.1–2.4)		**3.4** (3.4–3.4)			**2.1** (1.7–2.6)	**1.4** (1.4–1.4)		**2.4** (1.9–2.5)	**2.1** (1.5–2.2)
Renault		**2.0** (0.7–2.5)	**2.2** (1.2–2.2)	**0.9** (0.9–2.2)				**2.4** (1.7–3.4)			**2.2** (1.1–2.6)	**1.9** (1.1–2.3)
Stellantis	**1.5** (0.9–1.6)	**1.9** (0.7–2.5)	**2.1** (0.9–2.4)	**0.9** (0.9–0.9)		**1.1** (0.8–1.7)			**2.1** (1.4–2.7)			**1.8** (0.9–2.1)
Subaru	**1.0** (1.0–1.0)								**1.5** (1.5–1.5)		**2.4** (1.7–2.6)	**1.9** (1.4–2.0)
Suzuki		**1.9** (0.7–2.5)	**2.1** (0.9–2.8)					**1.7** (1.7–1.7)	**1.5** (1.5–1.5)	**2.4** (1.9–2.4)	**2.4** (1.7–2.5)	**1.9** (1.7–2.0)
Tesla	**1.5** (0.9–1.6)		**2.1** (0.9–2.5)									**2.0** (1.5–2.1)
Toyota	**1.6** (1.0–1.7)	**2.0** (0.7–2.5)	**2.2** (1.1–2.2)		**2.5** (1.5–3.4)			**2.1** (1.7–2.6)	**1.5** (1.5–1.5)		**2.4** (1.6–2.5)	**2.0** (1.5–2.1)
Volkswagen	**1.4** (0.9–1.6)	**1.9** (0.7–2.5)	**2.2** (1.1–2.4)		**3.4** (3.4–3.4)			**1.7** (1.7–1.7)	**1.4** (1.4–1.4)			**2.2** (1.4–2.4)
Volvo Cars	**1.0** (0.8–1.1)		**2.2** (1.1–2.5)						**2.1** (1.4–2.7)			**2.2** (1.4–2.5)

Notes: Darker colors indicate higher emission intensities. The potential ranges for GHG emission intensities, based on the sensitivity analysis, are in parentheses. The same regional GHG emissions intensity is used for all automakers producing vehicles in China because of the lack of data on steel suppliers.

Figure A6

Labeling system under the Low Emission Steel Standard



Note: The Low Emission Steel Standard was initiated by the German Steel Association and is supported by the Federal Ministry for Economic Affairs and Climate Action (Wirtschaftsvereinigung Stahl, 2024).

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Table A5

GHG emissions publicly disclosed by selected steel producers

Company	Steel pathway	Year	Scope[a]	GHG emissions	Source
ArcelorMittal	—	2022	1, 2, and limited 3	1.98 t CO_2e/ t of crude steel	ArcelorMittal (2023a)
Cleveland-Cliffs	BF-BOF	2022	1 and 2	1.6 t CO_2e/t crude steel	Cleveland-Cliffs (2023)
	EAF		1 and 2	1.04 t CO_2e/t crude steel	
Nippon Steel	—	2023	1 and 2	1.92 t CO_2/ t crude steel	Nippon Steel (2023)
Nucor	EAF	2022	1 and 2	0.44 t CO_2e/t of steel produced (0.76, including Scope 3)	Nucor (2023a)
Tata Steel	—	2022	1, 2, and 3	2.21 tCO_2/ t crude steel	Tata Steel (2022a)
Thyssenkrupp	—	FY 2022–2023	1 and 2	23.9 Mt CO_2e	Thyssenkrupp (2024)
U.S. Steel	BF-BOF	2022	1 and 2	2.05 t CO_2e/t crude steel	U.S. Steel (2023)
	EAF		1 and 2	0.41 t CO_2e/t crude steel	
Voestalpine	—	2022	1, 2, and 3	24.5 Mt CO_2e	Voestalpine (2023)

Note: Information on steel production pathways were not available for ArcelorMittal, Thyssenkrupp, Voestalpine, Nippon Steel, and Tata Steel.

[a] Scope 1 refers to direct emissions by a company. Scope 2 refers to indirect emissions resulting from energy used a company that is generated offsite. Scope 3 refers to all other indirect emissions in the value chain of a company.

Table A6

Targets and planned actions disclosed by selected steel producers to reduce GHG emissions

Company	2030 targets	2050 targets	Considered levers (as stated by companies)	Source
ArcelorMittal	35% reduction in CO_2 emissions in Europe by 2030 (2018 baseline)	Carbon neutral in 2050	In a first phase, transition from coal (in the blast furnace) to natural gas (in a DRI plant) as a precursor to green hydrogen DRI; zero-carbon emission energy (green hydrogen, circular forms of carbon and CCUS technologies); increase use of scrap; source clean electricity; offset residual emissions	ArcelorMittal (2021)
Cleveland-Cliffs	25% reduction in Scope 1 and 2 emissions by 2030 (2017 baseline)		Using lower carbon fuels such as natural gas; consuming higher amounts of recycled materials; purchasing renewable energy; utilizing HBI (hot briquetted iron) in blast furnaces to help lower fuel rates; supporting commercial development of hydrogen as a decarbonization strategy (completed hydrogen injection trial in BFs and investments in hydrogen hub)	Cleveland-Cliffs (2023)
Nippon Steel	30% reduction in CO_2 emissions by 2030 (2013 baseline)	Carbon neutral in 2050	Hydrogen direct reduction of iron; direct injection of hydrogen into BFs; increase use of scrap; green electricity; CCUS; carbon offset	Nippon Steel (2024)
Nucor	35% reduction in Scope 1 and 2 GHG emissions intensity in 2030 (2015 baseline)	Carbon neutral in 2050	Clean electricity; CCS; near zero GHG ironmaking; reduce consumption of injection and charge carbon and reduce use of natural gas in production processes; innovative solutions including the use of renewable biocarbon, carbon encapsulation within concrete, sequestration, more efficient lance injection, nuclear power, and green hydrogen	Nucor (2023b; 2024)
Tata Steel	5 Mt lower emissions in the Netherlands by 2030	Carbon neutral in 2045	Increase EAF and scrap utilization; increase energy and process efficiency; increase renewable electricity use; shift from metallurgical coal to fuels with lower CO_2 emissions intensities such as natural gas/coal bed methane; CCUS; new technologies at low technology readiness level; DRI with natural gas but hydrogen ready	Tata Steel (2022c)
Thyssenkrupp	30% reduction in Scope 1 and 2 emissions by 2030 (2018 baseline)	Carbon neutral in 2045	Energy efficiency; renewable and climate neutral energy; direct hydrogen injection in current plants; eventually shift to green hydrogen DRI plants	Thyssenkrupp (2023; 2024)
U.S. Steel		Carbon neutral in 2050	Process optimization; EAF capacity; future mini mills development; DRI with natural gas; CCS/CCUS (carbon capture and storage); DRI with hydrogen; electric grid improvement; electrification and hydrogen use; offsets/credits	U.S. Steel (2024a)
Voestalpine			Hybrid technologies as a first step; gradually convert from coal-based blast furnace route to electric steel route powered by green electricity; produce input materials, liquid pig iron and hot briquetted iron, in a direct reduction plant using natural gas instead of coal; increase use of green electricity; pilot use of green hydrogen	Voestalpine (2023b)

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