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THE HETEROGENEITY OF STEEL DECARBONISATION PATHWAYS

REPORT PREPARED FOR THE 2023 JAPANESE PRESIDENCY OF THE G7

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Executive Summary

Taking the heterogeneity of steel industries into account is a key factor for a successful and ambitious low-carbon transition within the global steel sector. It is instrumental for reaching climate goals, and helps to ensure inclusiveness and a just transition.

This report, prepared for the 2023 Japanese G7 Presidency to contribute to the work under the Industrial Decarbonisation Agenda, maps the heterogeneity of global steel industries. It shows how steel industries differ in key aspects of relevance to decarbonisation, and explores how these differences should be taken into account in developing definitions of near zero and low-emissions steel production, emissions measurement methodologies and data collection frameworks.

The report focuses on four main aspects of heterogeneity: assets, inputs for production, the market and business environment as well as innovation, and discusses a detailed set of indicators to map these, which allow for the distinction of different steel decarbonisation pathways across countries. On the basis of this analysis, the report identifies six key factors related to heterogeneity that should be taken into account in developing definitions of near zero and low-emissions steel production, emissions measurement methodologies and data collection frameworks: heterogeneity in reduction requirements, fairness, abilities, incentives, time horizons and product quality. Taking these factors into account in no way should be seen as the scaling down of realising much needed climate ambitions, but could in fact help accelerate these. The factors are also relevant for designing complementary policies to foster agreement and adherence to such definitions, methodologies, and data frameworks.

The analysis leads to the following recommendations:

1. In developing definitions of near zero and low-emissions steel production, emissions measurement methodologies and data collection frameworks **it is important to take the heterogeneity of steel industry structures and decarbonisation pathways well into account**.
2. This requires that differences across countries in **abilities, incentive structures, innovativeness, time horizons, product quality and other factors** discussed in this report inform decision making on definitions, emissions measurement methodologies and data collection frameworks. This is of particular importance for ensuring that such methodologies, definitions, and data collection frameworks are **fit for circumstances across industrialised economies as well as in developing and emerging economies** and for ensuring a **level playing field**.
3. The development of definitions, emissions measurement methodologies, and data collection frameworks is a key component for an effective and efficient global steel decarbonisation agenda that regards the creation of lead markets, procurement, technology scaling-up, financing and trade, which necessitates an **inclusive and comprehensive approach**.
4. Given the multifaceted nature of the steel decarbonisation agenda and the need for an inclusive and comprehensive approach, the development and implementation of such definitions, emissions measurement methodologies and data collection frameworks would benefit from a **sectoral approach** ensuring the involvement and expertise of steel industry organisations and other stakeholders as well as policy makers in relevant policy domains, including climate and energy,

industry, and trade. This would also help foster policy support for steel decarbonisation and encourage that all countries and industries participate in the process.

1 Introduction

Advancing the decarbonisation of the global steel industry is a key topic on the international agenda. Given the multifaceted character of the steel decarbonisation challenge, this requires an integral approach, addressing the various aspects of relevance in this fundamental restructuring of the industry.

Decarbonising steel is a long-standing issue, the urgency of which is only increasing with the important objectives for net zero towards 2030 and 2050 rapidly approaching. A key element of the steel decarbonisation agenda is to reach further consensus on what we mean by steel decarbonisation: what do we measure? What type of data do we need to do that? And how do we then define what constitutes low-carbon emissions steel?

There are strong advantages of moving towards a globally accepted perspective on these matters, metrics for which have been proposed already for quite some time. The wider the consensus and application, the greater the potential markets for low-carbon emissions steel and the better the possibilities to incentivise and monitor its progress. It can also contribute to more open and competitive markets. However, this need for further common ground takes place against a background that is very much differentiated. Countries differ widely in the structure of their steel industries, in technologies used, the market environment in which they operate and the innovations they seek. To work towards commonly accepted emissions measurement methodologies, definitions and data frameworks that work for all, it is essential that this differentiated global steel industry landscape is better understood.

This report, prepared for the Japan 2023 G7 Presidency aims to provide a bridge between the need for commonality and the relevance of heterogeneity, and aims to inform policy makers, industry, and other stakeholders of what this could entail for the setting of definitions, emissions measurement methodologies and data collection frameworks.

Chapter 2 of this report sets the stage for the analysis, focusing on the global steel decarbonisation challenge and the importance of booking progress in definitions of near zero/low-carbon emission steel, emissions measurement methodologies and data collection frameworks to address these. Chapter 3 reflects on the heterogeneity of steel industry structures world-wide, and the importance of better understanding this. Chapter 4 maps this heterogeneity, discussing a set of indicators related to four core aspects of the heterogeneity of steel industry structures. Chapter 5 assesses the relevance of this mapping exercise for understanding steel decarbonisation pathways, whereas Chapter 6 discusses the relevance for the setting of definitions emissions measurement methodologies and data frameworks. Finally, in conclusion this report includes a number of recommendations on how a better understanding of heterogeneity of steel industry structures and decarbonisation pathways can help inform the setting of definitions, emissions measurement methodologies and data frameworks.

This report was produced by the OECD for the 2023 Japanese G7 Presidency and the G7 Working Group on the Industrial Decarbonisation Agenda, to inform discussions during the G7 Ministers' Meeting on Climate, Energy and Environment. The report complements a report prepared by the IEA in parallel on emissions measurement methodologies and data collection frameworks.

2 Decarbonisation: a key imperative for the global steel industry

This chapter discusses the key challenges for steel decarbonisation, including the importance of reaching agreement on definitions for near zero/low emission steel production, emissions measurement methodologies, and data collection frameworks.

From decarbonisation objectives to implementation

The steel sector and decarbonisation: an intertwined imperative

The iron and steel sector accounts for nearly 8% of global emissions from the energy sector and ranks as one of the highest emitting industry sectors (around 30% of industrial carbon emissions) (OECD, 2022[1]). With such a large carbon footprint, decarbonising the steel sector is key to achieve climate goals.

The steel industry is increasingly rising up to this challenge, with the number of net-zero pledges growing. Indeed, more than 90% of global steelmaking capacity and crude steel production are in countries that have announced a net-zero target (OECD, 2022[1]). While these net-zero pledges are not directed to the steel sector alone (but to the whole economy), it is clear that such targets imply a fundamental shift in steel production modes (and industrial production in general) to bring it on a net-zero pathway. In fact, as of end-2021, companies with net-zero targets accounted for 30% of global steel production (OECD, 2022[1]).

Deep transformation of the sector

To meet the Paris Agreement objective of limiting global warming to 1.5 °C, global CO_2 emissions must decline on an unprecedented scale, reaching net-zero in 2050 (IPCC, 2022[2]). To comply with this overall goal, direct emissions from the steel sector and related carbon intensity must decline by 90% from 2020 levels by 2050 (IEA, 2021[3]). This shows that the steel industry has a long way to go to reach near-zero emissions, and how the carbon neutrality target is a game changer – both in terms of challenges and opportunities - for the steel industry.

Reaching this level of emission reductions calls for a deep transformation of the sector and requires the combination of various approaches. It necessitates improved performance (through energy efficiency or processes optimisation), fuel switching and breakthrough technologies (including hydrogen and carbon capture, utilisation, and storage (CCUS)) for production. On the demand side, material efficiency and circular economy trends are other key drivers contributing to emission reductions.

Equally, this transformation brings new challenges that are likely to reshape the steel industry. These include scaling-up innovative technologies, investments, competitiveness, ensuring a global playing field, markets for near-zero emission steel, strategic inputs, as well as social aspects. The transformation may also raise opportunities, for instance related to choices about the location of new production facilities.

Despite progress, action towards implementation is critically needed

Echoing the COP 27 Presidency's call for implementation, the stake now lies in turning ambition into action ((COP27, 2022[4]), (Breakthrough Agenda, 2022[5])). The steel industry is making progress in several areas towards decarbonisation (projects to develop breakthrough technologies, scrap recycling, energy efficiency, among others). However, assessing progress highlights that further action is required for the steel sector to be on a trajectory compatible with climate goals (OECD, 2022[1]).

For instance, steelmaking countries' net-zero pledges are not systematically mirrored by those of steel producers. As of end-2021, companies with net-zero targets accounted for 30% of global steel production (OECD, 2022[1]). This share has doubled compared to 2020, though further commitments are necessary to reduce the mismatch with the net-zero pledges made at the country level in steel-producing economies.

Equally, the lack of diversified near-zero emission steel production routes currently available at commercial scale (i.e. enabling mass production) hinders the ability to significantly decrease carbon intensity in the short-term. Large investments for new innovative production routes suggest that the transformation is underway, however scaling-up such technologies remains an issue. Indeed, less than 1 million metric tonnes (mmt) of primary near-zero emission steel is produced per annum (Breakthrough Agenda, 2022[5]).This is further reinforced by the prevalence of carbon-intensive assets in new capacity projects underway or planned over the next three years. In fact, these carbon-intensive assets account for more than half of the total capacity planned (GFSEC, 2022[6]).

Moreover, while projects focussing on innovative near-zero emission production routes have more than doubled in the last two years, they still need to reach higher levels of industrial maturity and to ensure production at commercial scale (GFSEC, 2022[6]).

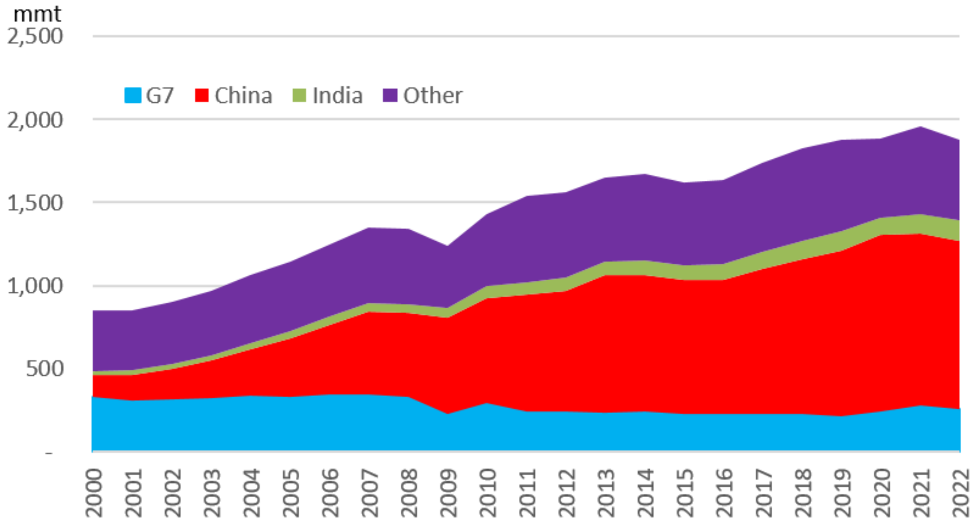
The scale of the challenge is such that closing the gap between the level of ambition and implementation will require all regions to embrace decarbonisation of steel production.

Steel: a global industry with global challenges

Steel is an essential material for infrastructure such as bridges and railways and contributes to people's lives and well-being by providing an essential material for the production of machines, medical equipment, household and metal goods, automobiles, ships and countless other products needed to support society and its well-being. Steel is also necessary to build the renewable power infrastructure, thus enabling significant emission reductions in other sectors and applications.

The G7 economies, the People's Republic of China (hereafter China) and India account for a combined 70% of the world's total steel production, equivalent to 1878.5 mmt in 2022. Steel production developments across these economies vary based on differences in demographics, economic development and structures, government policies towards the steel sector, and levels of steel demand. The G7 share of global production has been declining in past years, while emerging economies have experienced growing shares of production. OECD data show that more than 100 countries have steelmaking capacity in place, indicating that steel decarbonisation is a global challenge affecting many countries.

Figure 1. Evolution of crude steel production



Source: worldsteel

Definitions, emissions measurement methodologies and data collection frameworks

Part of the steel decarbonisation agenda focuses on defining what constitutes near-zero and low-emission steel production. This is a complex and sometimes contested endeavour, which requires conceptual clarity (WTO, 2022[7]).

A first prerequisite regards clarity (and agreement) on what should be measured. Setting-up emissions measurement methodologies is a prerequisite to develop and apply definitions. Emissions measurement methodologies form the methodology to calculate emissions and emission intensity of production. These methodologies set the scope, boundaries, and granularity for emissions accounting (and by extension for defining the thresholds for definitions). Consequently, this raises for instance questions on the type of Greenhouse Gases to be considered (CO_2 or wider), on the system boundary for production process (crude steel or finished products), or for inputs (raw materials, fossil fuels supply or other materials). In addition, implementing emissions measurement methodologies relies on data collection frameworks, providing input data to apply the methodology.

Second, there is a need for definitions on what constitutes low or near-zero carbon emissions steel. These definitions, including their emission intensity performance thresholds, are paramount to foster steel decarbonisation. By enabling market differentiation, they contribute to support first movers in adopting innovative routes, as well as the design of targeted policies for implementing steel decarbonisation. For instance, such definitions may help building financing frameworks and taxonomies that support low-carbon emission steel projects. On the procurement side, such definitions can help incentivising both the public and private sector to purchase 'green' steel products. In the domain of international trade, they contribute to enhance the global level playing field and operationalise agreements or measures based on emission content criteria. Although views vary if one single definition is possible or feasible across these domains, it is clear that having a common yardstick of some sorts is critical to advance the steel decarbonisation agenda.

In response to these challenges, various definitions for low-carbon and near-zero emissions steel have been proposed in recent years (Hasanbeigi, 2023[8]). In the context of the G7 Industrial Decarbonisation Agenda 2022, the IEA developed definitions covering both near-zero' and low-emission steel, including emission intensity thresholds (IEA, 2022[9]). Other definitions building on a similar approach include those from the First Movers Coalition (First Movers Coalition, 2022[10]), and on-going work by the Clean Energy Ministerial Industrial Deep Decarbonisation Initiative (CEM IDDI) building on the IEA G7 Industrial Decarbonisation Agenda definition (Clean Energy Ministerial, 2021[11]). From the industry side, initiatives building on a similar approach have been developed by ResponsibleSteel (ResponsibleSteel, 2022[12]) and endorsed by SteelZero (SteelZero, 2022[13]), the German Steel Federation (German Steel Federation, 2021[14]), or ArcelorMittal (without thresholds, (ArcelorMittal, 2022[15])). Other private initiatives are also active on that front, including the Science Based Target Initiative (SBTi, (SBTi, 2022[16])), or financial related initiatives with the Climate Bond Initiative (Climate Bond Initiative, 2022[17]) and the Sustainable STEEL Principles (Sustainable Steel Principles, 2022[18]). The Global Steel Climate Council has also announced the development of such definitions (Global Steel Climate Council, 2022[19])

Similar to definitions, various emissions measurement methodologies related to iron and steel emissions and data collection frameworks have been proposed. The review of such emissions measurement methodologies, and data collection frameworks are detailed in (IEA, 2022[9]).

This multiplicity of definitions, emissions measurement methodologies and data collection frameworks raise comparability issues for measurement, reporting and verification. Ultimately, this may undermine an efficient implementation for steel decarbonisation. As part of the 2023 Industrial Decarbonisation Agenda, the challenge related to emissions measurement methodologies and data collection will be informed by a dedicated IEA report.

3 Understanding heterogeneity

This chapter discusses the importance of understanding the heterogeneity of steel industry structures and decarbonisation pathways.

The global steel industry: a heterogeneous environment

While the global steel industry faces key common challenges in decarbonisation, the steel industry in different countries and their decarbonisation pathway differ significantly. Heterogeneity in the steel industry has many different aspects.

First, heterogeneity may relate to the characteristics of assets of the steel industry across countries, for instance the type of technologies and production methods used, their age or energy use performance.

Second, heterogeneity relates to the inputs used for iron and steel production. This involves the availability of raw materials, including scrap, as well as energy sources.

Third, the market and business environment may differ widely across steel industries. Some industries focus on higher value-added products (differentiated and relatively more sophisticated steel products for niche markets, such as electrical sheets and coated plates), whereas others on more conventional products (such as hot-rolled coil). Some steel industries are strongly export oriented, whereas some economies may depend more on imports of steel products. Similarly, the size of companies, financial performance or access to capital may differ.

Fourth, steel industries may differ in their focus on innovation, with some industries focusing on available technologies whereas others invest heavily in decarbonisation-oriented Research and Development (R&D) to improve production processes and products.

Figure 2 summarises the key aspects of heterogeneity discussed in this report.[1]

[1] Various peer reviewers have suggested the institutional and regulatory framework and policy setting across countries can be seen as an additional heterogeneity aspect. Indeed, wide differences exist among countries in this respect. A possible follow-up to this study on heterogeneity in steel industry structures could be a deep-dive analysis that i) maps the heterogeneity in policy approaches for steel decarbonisation and ii) provides evidence-based policy guidance to support decarbonisation pathways in steel industries across countries in the most effective way.

Figure 2. Key Aspects of Heterogeneity

Chapter 4 maps steel industries across countries along these four aspects.

Heterogeneity as a key enabler of the steel decarbonisation agenda

While there is a common objective to decarbonise, the fact that steel industry structures differ across countries is important to take into account for a number of reasons:

- Achieve climate goals: Steel decarbonisation scenarios suggest that multiple options are needed to move towards near-zero emission steel (IPCC, 2022[2]) (IEA, 2021[3]). Focusing on one decarbonisation option thus runs counter to what is required to achieve near-zero emission steel, and thus climate goals.
- Strive for inclusiveness: By considering various steel industry structures and characteristics, more countries are likely to be involved in the steel decarbonisation agenda. This ultimately leads to enhanced collaboration and contributes to level the global playing field.
- Support a Just Transition[2]: By striving for inclusiveness, it enables more countries to benefit from spillover effects of the low-carbon transition on overall economic growth.
- Accelerate technology development and uptake for the low-carbon transition: With an increased number of regions involved in the steel decarbonisation agenda, it boosts progress towards the scaling-up and implementation of the needed technologies. By stimulating the development of various options, it also fosters innovation for breakthrough technologies, which is a key driver of the low-carbon transition.
- Recognise regional variety in access to resources: As regions across the world face uneven access to natural resources and other assets, the availability and affordability of strategic inputs for decarbonising steel production may differ widely (raw materials and energy sources). Recognising such differences across countries, as well as differences in the low-carbon infrastructure, is important for supporting effective steel decarbonisation strategies.

[2] See also ILO (2015), Guidelines for a just transition towards environmentally sustainable economies and societies for all.

- Leverage progress made by the steel industry: Steel producers are involved in various projects to reduce emissions, which are based on multiple decarbonisation options (GFSEC, 2022[6]). Focusing only on one means or one specific pathway would prevent taking advantage of the progress made by steel producers on innovation, thus undermining decarbonisation advancements.

In short, recognising and understanding the heterogeneity of the global steel decarbonisation landscape is crucial for an efficient steel decarbonisation. Various dimensions of heterogeneity in the steel industry are likely to drive decarbonisation strategies and pathways, preferred mitigation options and their pace of implementation (see Chapter 5).

Relevance of heterogeneity for definitions, emissions measurement methodologies, and data collection frameworks

A better understanding of the heterogeneity of the steel industry is also important for reaching progress on common definitions, emissions measurement methodologies and data collection frameworks.

The detailed implications of heterogeneities on definitions, emissions measurement methodologies, and data collection frameworks are discussed in chapter 6. However, some insights are provided below to stress that heterogeneity also has implications on these aspects.

For definitions, the heterogeneity of the steel industry indicates that there are different starting points in terms of emission intensity, especially depending on the type of asset, its age, type of raw material and energy sources used, or type of product produced. Consequently, the magnitude of decarbonisation actions to be undertaken will differ among countries, companies, and site facilities. Likewise, the ability to move towards low-carbon emission steel may be uneven (depending on companies' profitability or innovation characteristics for instance), thus leading to differences in the pace of transformation. Pathways towards near-zero emission steel may require a different technology mix too. In short, heterogeneity in the steel industry implies that, whereas the importance of finding common ground on definitions is clear, the implications for steel producing economies can be very different. Economies may not reach the same level of emission reduction and emission intensity of steel production at the same time.

For emissions measurement methodologies, heterogeneity in the steel industry implies that there are multiple configurations of steel production routes, products and inputs (e.g. raw materials and energy sources) to be covered in emission accounting methodologies. As a consequence, related data collection frameworks should reflect these aspects. Indeed, this means that data to be collected or measured to feed into these methodologies needs to be comprehensive and granular enough to cover these different configurations. In addition, heterogeneity across regions means that there may be different levels of capabilities in data collection, reporting, measurement and verification that have to be acknowledged.

Overall, it is particularly important to take heterogeneity into account in developing emissions measurement methodologies, definitions, and data collections frameworks, in order to:

- Rally countries to adopt them: From the perspective of inclusiveness, more countries are likely to adopt these definitions and methodologies if their own steel industry characteristics would be reflected. A wide adoption of common methodologies and definitions would contribute to accelerate the low-carbon transition, foster global cooperation, increase the level playing field, but also facilitate the implementation of such methodologies and definitions for trade related aspects.
- Trigger further policy support for steel decarbonisation: As a consequence of rallying more countries to adopt common methodologies and definitions, the global ambition to decarbonise steel production could grow. This would bring further impetus to steel decarbonisation, not only for countries to reach their domestic emission targets, but also to remain relevant on global trade

markets for low-carbon emission steel products. This race for low-carbon emission steel could trigger the development of further enabling policy frameworks towards steel decarbonisation, eventually beneficial for implementation.

- Avoid duplication: Considering one specific pathway (related to a specific industry structure) could push countries to develop their own definitions and methodologies in line with their own steel industry characteristics. This could lead to duplication of non-comparable definitions and methodologies, likely to undermine the implementation of the low-carbon transition. By rallying more countries to adopt similar definition and methodologies, considering heterogeneity thus limits the risk of duplication.
- Support technological neutrality: Considering one specific pathway (related to a specific industry structure) could push the development of only certain low carbon emission steel production routes. This would exclude the use of other technologies and reduce the range of possible solutions to decarbonise. Considering heterogeneity in definition setting would thus support technological neutrality, offering a wider range of decarbonisation choices to fit regional circumstances. This would also support the diversification of the use of production inputs (raw materials and energy sources), contributing to alleviate market pressure on some of them (such as scrap).
- Acknowledge uneven access to strategic inputs: As previously mentioned, access to natural resources, availability and affordability of strategic inputs for decarbonising steel production may differ across countries (for instance raw materials and energy sources). Considering one specific pathway would drive the use of specific production inputs. However, these strategic inputs may not be necessarily available in all regions or may face a lack of suitable infrastructure (e.g., transport and storage of hydrogen or CO_2 and low carbon electricity capacity). Taking into account heterogeneity in definition setting would contribute to recognising such differences across regions. In addition, this would alleviate potential market or trade tensions that would result from the exclusive use of one specific input (e.g., export restrictions on scrap).
- Mitigate the risk of carbon leakage: By rallying more countries to adopt definitions and emissions measurement methodologies, considering heterogeneity increases the global level playing field. Therefore, it contributes to reduce the risk of carbon leakage, as decarbonisation ambitions would expand worldwide.
- Mitigate the risk of stranded assets: By enabling various industry structures to be recognised in methodologies and definitions, considering heterogeneity avoids excluding certain types of assets, and encourages their transition to low emission steel. Consequently, this reduces the risk of stranded assets.
- Recognise different capabilities to transform and implement: Heterogeneity in the steel industry is reflected in different capabilities to move towards low-carbon emission routes. In particular, as decarbonisation requires large investments, differences in terms of companies' profitability or access to capital across regions may result in different abilities and paces of transformation. Likewise, differences in levels of innovation may reinforce these aspects. Uneven capabilities to implement steel decarbonisation also relates to data collection, measurement, reporting and verification. Indeed, some countries or firms may lack capacity or infrastructure to provide the data pertaining to the application of definitions and emissions measurement methodologies. Taking into account heterogeneity in the setting of definitions and methodologies would foster recognition of such differences.
- Support for the viability of export-oriented countries: Countries whose steel industry is highly export-oriented and characterised by higher emission intensive assets (compared to other regions) are likely to be hardest impacted by the application of definitions for trade. Taking into account heterogeneities in the ability to transform and in access to resources would also support the

viability and transformation of the steel industry in such countries, boosting global competition, if accompanied by well-designed transition measures.

4 Mapping Heterogeneity in the Steel Industry

This chapter maps heterogeneity in the steel industry structures and decarbonisation pathways across countries, following the four aspects of heterogeneity proposed in Figure 2 in Chapter 3. The chapter discusses indicators that illustrate these aspects, focusing on G7 countries, but – where possible – also including other major steel producing economies.

Table 1 show the list of indicators that illustrate the difference of each steel industry.

Table 1. List of the indicators for heterogeneity

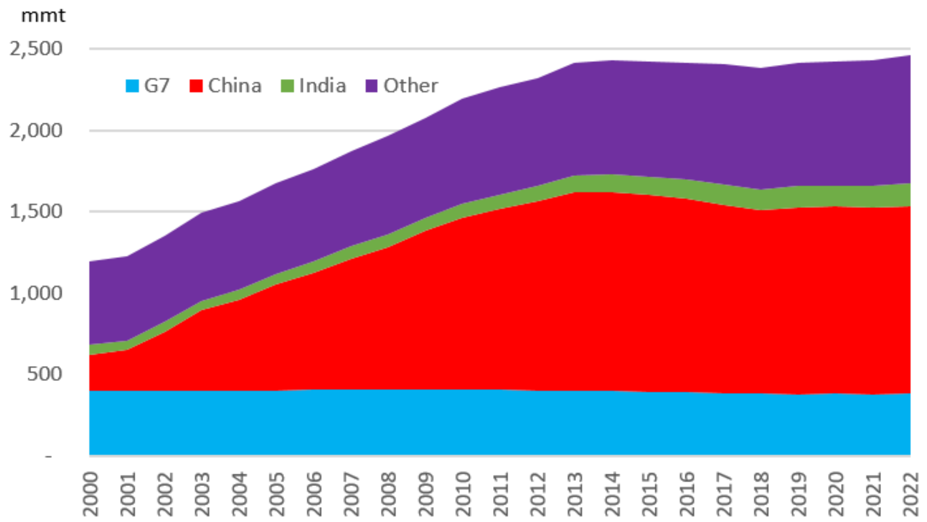
Heterogeneity aspect	Indicator
Assets Characteristics	Capacity development
	Crude steel production process
	Direct Reduced Iron (DRI) production
	Age of assets
Inputs for Production	Scrap availability
	Electricity price
	Low carbon power generation
	Import dependencies on raw material for steelmaking
Market & Business Environment	Fragmentation
	Export orientation
	Direction of export/imports
	Export specialization
	Profitability
Innovation	Patents
	Hydrogen
	CCU/S

Heterogeneity in Assets Characteristics

Capacity development

Similar to crude steel production trends shown in Figure 1, steelmaking capacity expanded rapidly after 2000, led by China. Figure 3 shows that the combined capacity of G7 economies has remained almost constant over the past 20 years, while China and India have expanded their steelmaking capacity rapidly. Given the long life-span of steelmaking plants, as shown in Figure 6, new capacity investments in high-carbon emitting plants constitute a challenge for the realisation of steel decarbonisation objectives.

Figure 3. Evolution of crude steelmaking capacity



Source: OECD

Crude steel production process

Manufacturing processes for crude steel production differ widely depending on the quantity and quality of the required steel products, the availability and cost of energy and raw materials, including steel scrap, and to meet the evolving needs of downstream steel-consuming industries. As Figure 4 shows, the share of BF/BOF in crude steel production is highest in China, the UK and Japan and lowest in Italy and the U.S.

According to worldsteel, the CO_2 emission intensity for BF-BOF, Scrap-EAF and DRI-EAF[3] are 2.32, 0.67 and 1.65 tonnes CO_2/tonne of crude steel, respectively (worldsteel, 2023[20]).

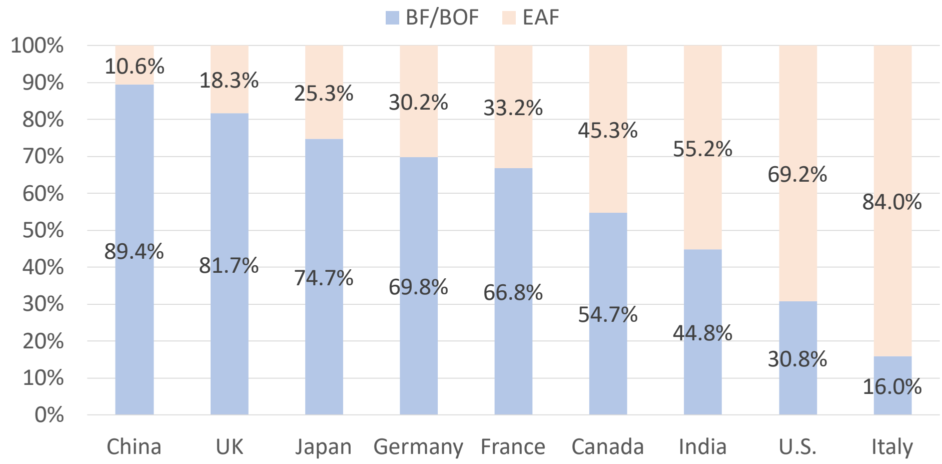
About 89% of a BF-BOF's energy input comes from coal while coal and electricity account for 11% and 50% respectively for the EAF route (worldsteel, 2021[21]). To reduce emission intensities and ensure the decarbonisation of steelmaking processes, the efforts to reduce the use of coal for BF and to foster low carbon electricity for EAF will be crucial.

Steel scrap is highly recyclable and provides excellent opportunities to reduce carbon emissions from steelmaking processes. Scrap is used in high proportions in EAFs, but is also used extensively in BOFs along with hot metal from the blast furnace to produce steel. However, there are two main challenges with steel scrap. The steelmaking process can remove most impurities that may be present in scrap steel.

[3] The data are calculated based on a sub-set of steel firms that participate in the exercise. Thus, they may not be fully representative of the whole industry.

However, some elements, especially copper, can be difficult to remove, which in turn can affect the quality of steel products. Ensuring scrap availability is a key challenge. The World Steel Association estimates that end-of-life scrap availability will increase from 400 mmt in 2019 to 600 mmt by 2030 and 900 mmt by 2050 (worldsteel, 2021[22]). For EAFs to increase their share in global crude steel production, it will be important that all scrap is recycled and that scrap collection activities are made as efficient as possible, particularly in economies where there is still room for improvement in this regard. Nevertheless, primary steel production, involving pig iron or direct reduced iron from BF and DRI plants, respectively, may still be needed for some time while encouraging those processes to decarbonise.

Figure 4. Share by process of crude steel production (2021)



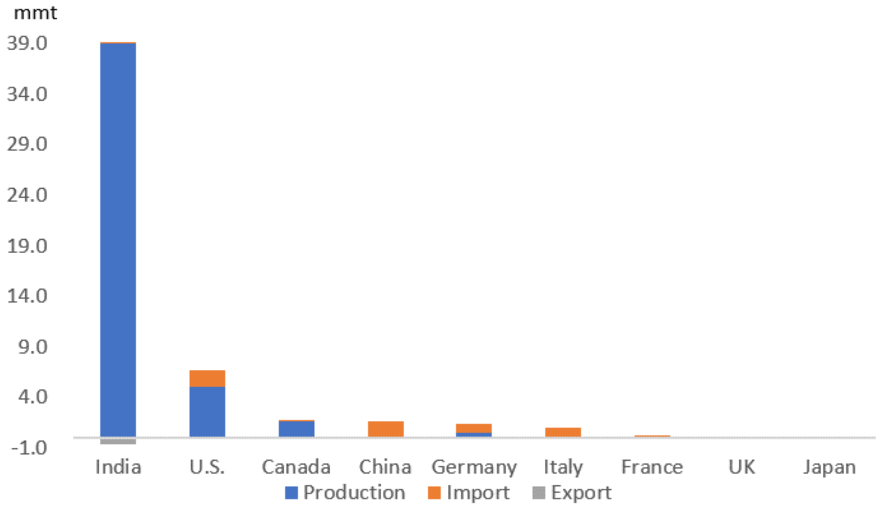
Source: worldsteel

DRI Production

Direct Reduction Iron (DRI) production is an iron-making process that utilises reducing gases such as natural gas, coal gas and product gases generated in BF-BOF facilities to reduce iron ore to produce DRI. The emissions intensity of DRI production varies depending on the gas used as a reductant. Key drivers for DRI production include gas access and its cost as well as access to high-grade iron ore. DRI technology requires a higher grade of iron ore than BFs, with such ores making up less than 5% of global iron ore supply (S&P Global, 2022[23]). As shown in Figure 5, DRI is most prevalent in India and much less in other countries.

Some steel firms, which have no access to natural gas, are working on providing low-carbon steel by replacing some of the iron ore with Hot Briquetted Iron (HBI) in order to reduce the use of coke. HBI is a form of DRI, but more beneficial because it can be transported over long distances and stored outside for long periods of time. However, the cost of maritime transportation and the volumes needed to meet demand pose challenges for the use of HBI.

Figure 5. DRI apparent consumption (2021)



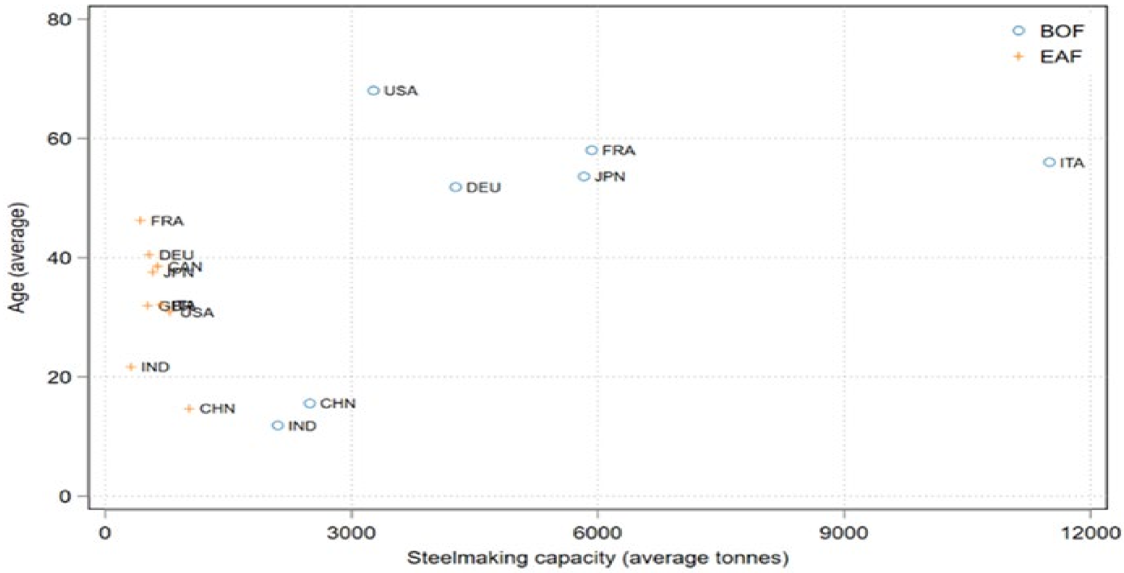
Note: It should be noted that in some instances DRI is produced with coal instead of natural gas, for example in India, as well as through hydrogen and syngas (synthesis gas).
Source: worldsteel

Age of assets

In the steel industry, coke was first used in the smelting of iron ore in the 18th century, after which the production of pig iron began to expand. As shown in Figure 6, the average age of BOFs in France, Germany, Japan and the United States is between 50 and 70 years. On the other hand, the average age of BOFs and EAFs in China and India is relatively low at nearly 20 years, indicating that much of their production capacity was installed at the turn of this century. In terms of steelmaking capacity, newer plants and EAFs are smaller compared to BOF plants.

The structure of steel production and the pace of industry growth typically differ depending on the state of economic development across countries. Differences in the age of assets provide different opportunities for investing in strategic technologies for decarbonisation.

Figure 6. The average age of steelmaking capacity (years and thousands of tonnes)



Note: Age is calculated as the difference between the start year and 2020. The tonnages shown on the X-axis are in thousands.
Source: OECD

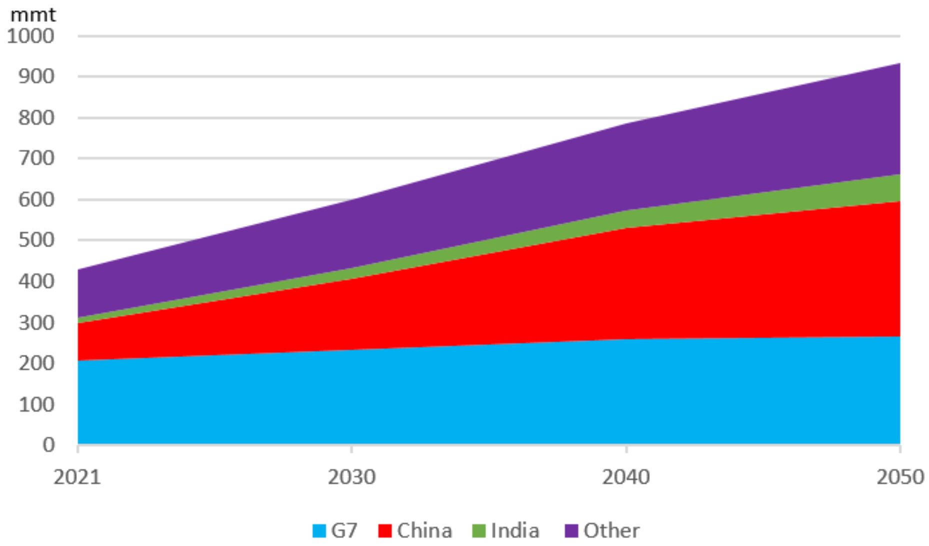
Heterogeneity in Inputs for Production

Scrap availability

Every steel plant uses scrap as part of its raw materials mix. According to worldsteel, around 650 mmt per year of scrap is consumed each year for steel production, with comparable amounts of scrap used in the primary and secondary routes (worldsteel, 2021[22]).

As the economy develops, the amount of steel consumed increases. As steel products reach their end of lives, they can be recycled and used to produce new steel. For example, China has maintained high economic growth for nearly 30 years since the late 1970s. The construction sector accounts for half of Chinese steel demand. Buildings, highways, railways and airports typically have average lifespans of around 50 years, meaning that a large amount of steel scrap could be made available towards 2040. While there may be some physical limitations to the estimated end-of-life scrap supplies available in the future, the quantity of scrap supplied in the market often reacts closely to its price. Moreover, improving efficiency of scrap collection and distribution systems can also be enhanced in some economies to support higher supply and use of scrap in the future, and steel products continue to be designed for easier recycling of the steel they contain. As Figure 7 shows, end-of-life scrap availability is expected to grow in particular in China over the next 30 years.

Figure 7. End-of-life scrap availability forecast



Source: worldsteel

Electricity price

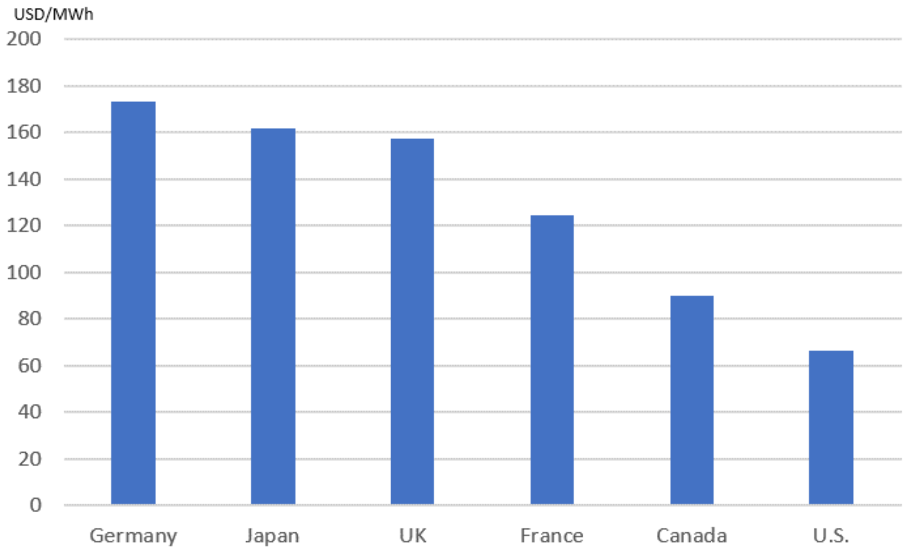
The steel industry consumes significant amounts of energy, such as coal and electricity, in addition to raw materials to make products. Energy constitutes a significant portion of the cost of steel production, from 20% to 40% (worldsteel, 2021[21]), which makes the industry vulnerable to rises in energy costs as currently taking place in Europe and other regions. As steel is a highly tradable good, exposed to high competition in international markets, energy prices and improvements in energy efficiency have important effects on steel production costs.

Figure 8 show that electricity prices for total industry[4] in 2020 were higher in Germany, Japan, and the UK than in the US or Canada.

Reducing emissions from power generation will be crucial for the decarbonisation of the steel industry. Furthermore, it will be equally important to provide a stable, sufficient, and affordable supply of low-carbon electricity to support the decarbonisation of the steel industry.

[4] Policy measures such as Feed-In-Tariff exemptions are not reflected.

Figure 8. Electricity prices for total industry (2020)

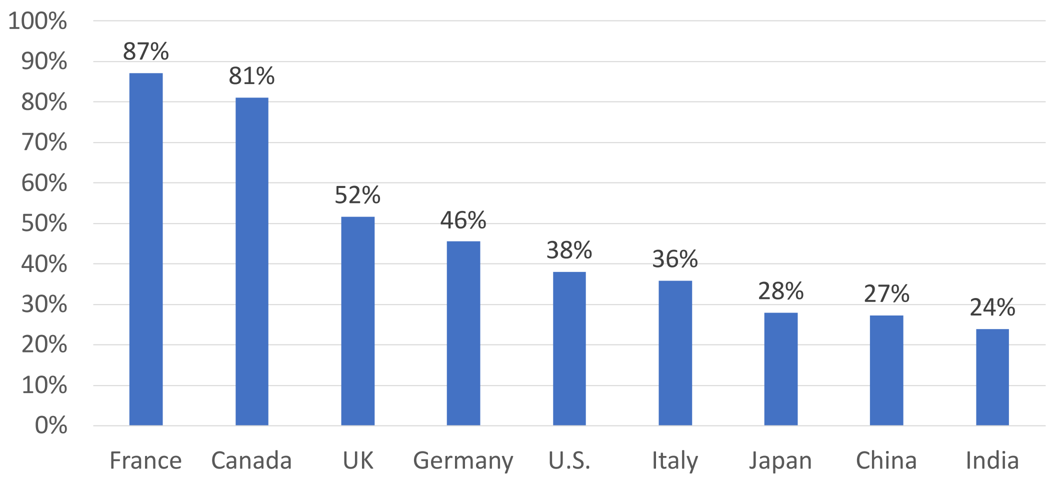


Note: Data for Italy, China and India are not available. Policy measures such as Feed-In-Tariff exemptions are not reflected. Dedicated exemptions granted may result in this figure overstating electricity costs for heavy industry.
Source: IEA World Energy Statistics 2021

Low carbon power generation

Access to low carbon power generation differs widely depending on a variety of factors, including access to natural resources, renewable energy availability, costs, and energy policy. Industries that consume large amounts of electricity, including the steel industry, will require low/zero-carbon electricity in order to reduce CO_2 emissions in the steelmaking process. Access to low-carbon energy sources is relatively high in France and Canada, and less in Japan, China, and India.

Figure 9. Low-carbon sources as a share of total power generation (2021)



Note: Low carbon sources include nuclear, renewable energy and hydro power.
Source: IEA

Import dependencies on raw material for steelmaking

Making progress on steel decarbonisation will require access and open markets for the necessary raw materials. This is because no economy is fully self-sufficient in all steelmaking raw materials.

Figure 10 shows import dependencies for three key steelmaking raw materials. Import dependency for a given raw material is calculated as imports as a share of apparent consumption of that raw material. As production of iron ore and coking coal is geographically relatively concentrated, many steel-producing economies need to rely on imports, highlighting the importance of open trade. On the other hand, since scrap is not a natural resource but is generated from final steel products that have already been consumed, import dependencies are relatively low since many of these countries have had relatively high levels of steel consumption in the past. In fact, most of these economies are net exporters of scrap.

Procurement of natural resources and scrap will be essential raw materials for decarbonisation of the steel industry, requiring stable and secure supplies. The pace of steel industry decarbonisation in the future in different economies will therefore require policies that support open markets and access to the needed raw materials.[5]

Figure 10. Import dependencies on three key raw materials for steelmaking

Note: Import dependency shows the ratio of imports to apparent consumption (production plus imports minus exports).
Chinese iron ore production is converted, so that its iron content is about equal to that in the rest of the world on average.
Source: worldsteel, IEA and The Japan Ferrous Raw Materials Association.

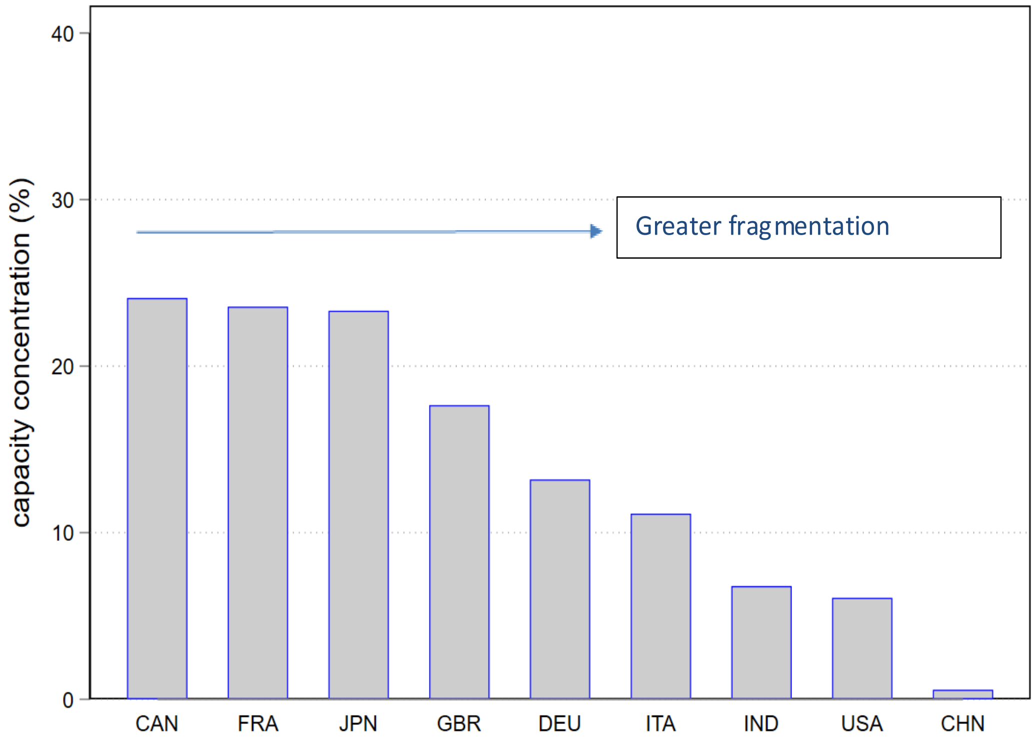
[5] As was indicated in the peer review, responsible sourcing of raw materials can also be seen as an integral part of steel decarbonisation and high imports also underpin the need to account for emissions arising out of sourcing and transportation of raw materials.

Heterogeneity in Market & Business Environment

Fragmentation

The steel industry differs significantly across countries in its degree of concentration, including in relation to certain upstream raw materials and some downstream consuming industries. This reflects factors such as the number and size distribution of firms, the size of the market, the types of steel plants, and past restructuring efforts. Figure 11 presents the Herfindahl index as an indicator of industry fragmentation and shows that the degree of fragmentation is lower in countries like Canada, France and Japan compared to China and the US. How fragmented the industry is may affect the number of decarbonisation pathways for a given economy, the number of plants that will need to decarbonise, and the overall cost of the transformation.

Figure 11. Extent of steel industry fragmentation



Note: This figure displays the Herfindahl index, calculated as the sum of the squares of capacity shares of steel companies in the steel sector. The Herfindahl index increases as the number of firms falls and as the variance of capacity shares increases. Therefore, the index combines information about both the number and the size distribution of firms.
Source: OECD

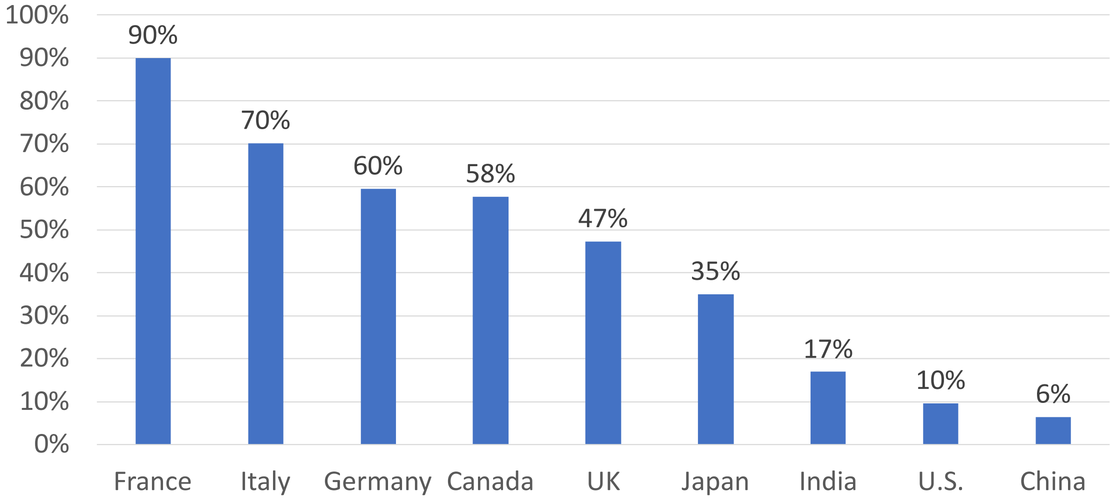
A further aspect of fragmentation relates to the prevalence of small- and medium sized enterprises (SMEs), although no comparable data for all countries on the size distribution of firms in the steel sector are available. Since SMEs make up for the vast majority of firms across sectors, also in the steel industry they make up for the vast majority of total steel firms. However, the importance of SMEs differs across countries. For instance, the share of SMEs in steel value-added in Italy (58%) is almost three times as high as in

Germany (21%).[6] Since SMEs may face different challenges in decarbonisation than larger firms, this could be a relevant factor to take into account (OECD, 2021[24]).

Export orientation

With approximately 25% of steel products traded internationally, the steel industry is highly exposed to fluctuations in international markets, changes in global demand for steel and trade policies. The share of exports differs and can reflect factors such as competitiveness and steel quality, but can also be affected by national approaches and policies directed to the steel industry. The export orientation of steel production in France, Italy and Germany is considerably higher than in the US or China.

Figure 12. Export orientation (exports of semifinished and finished steel products as a share of crude steel production, 2021)



Note: Semi-finished and finished steel products. Data for European Union economies include intra-European trade. Data do not include indirect steel exports such as steel embedded in automobiles.
Source: worldsteel

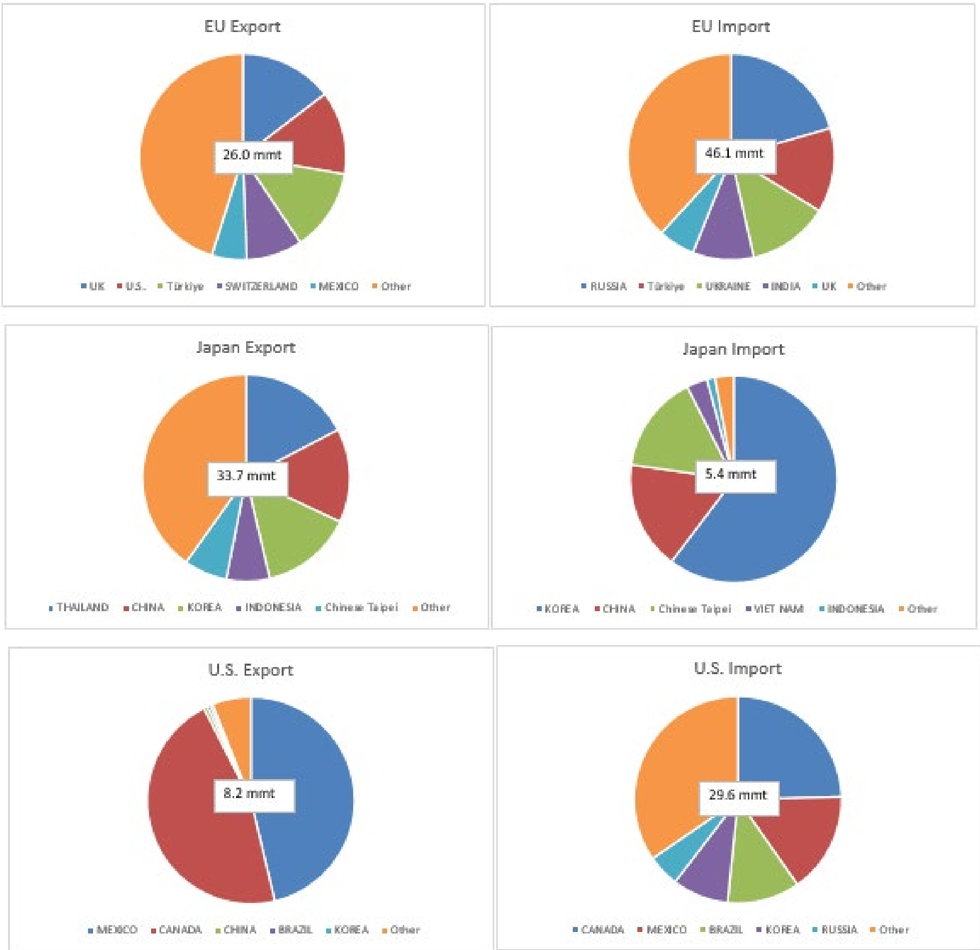
Direction of export/imports

Figure 13 shows the five largest trading partners for the EU, Japan, and the United States. Trade in steel often takes place at the regional level or with trading partners relatively close in proximity. For example, 92% of US exports are directed to Canada and Mexico.

Furthermore (though not shown in the figure), some countries such as Japan are net exporters of steel, while the U.S. and EU are significant net importers of steel.

[6] OECD Structural and Demographic Business Statistics.

Figure 13. Exports and imports of steel by key trading partner (2021)



Note: All steel products including semi-finished products. For EU trade, EU intra-trade is not included.
Source: ISSB

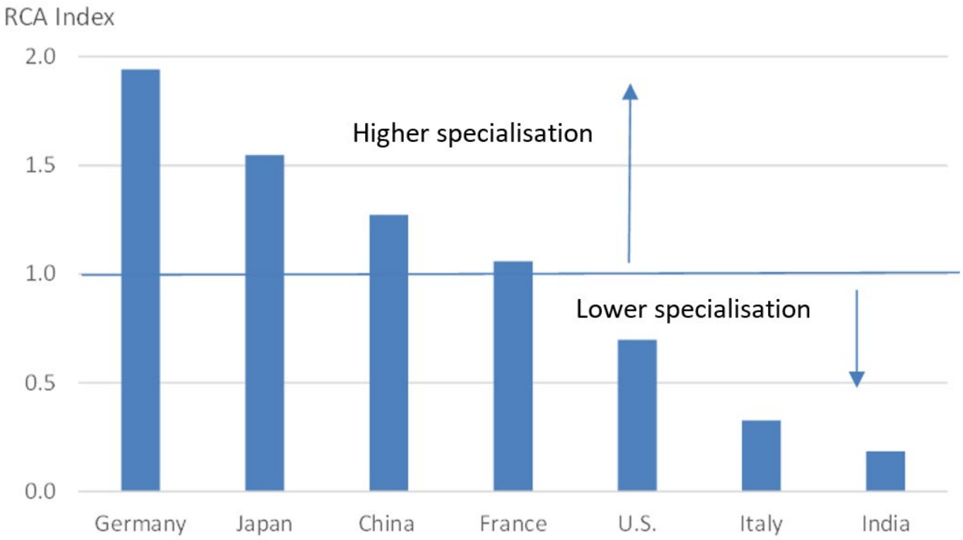
Export specialisation

Steel companies around the world specialise very differently in the steel products that they export to international markets. An indicator of export specialisation is how much a country exports of a specific steel product as a share of its total steel exports, compared with the world export share of that same steel product. Figure 14 shows such an indicator, denoted as the "revealed comparative advantage" (RCA) index, using electrical sheets as an illustrative example. RCA index values greater than one for a given product indicate high export specialisation, whereas values less than one suggest lower specialisation in those exports.

Figure 14 shows the high export shares of Germany and Japan. Electrical sheets require many more steps in the production process compared to, for example, conventional hot-rolled coils (HRC). Electrical sheets are a variety of cold-rolled sheets that contain silicon and other additives to enhance their magnetic properties. Theoretically, it means that the steel firm that produces the electrical sheets using its own HRC as an input would generate higher CO_2 compared to those steel firms that mainly produce HRC.

This is only one anecdotal example of heterogeneity that can be important for decarbonisation considerations; while electrical sheets may be associated with more carbon in the production process, they also contribute to significantly lowering the emissions in the applications for which they are used (in particular electric vehicles) (NIPPON STEEL, 2022[25]).

Figure 14. Export specialisation: example of electrical sheets used in electric vehicles (2021)



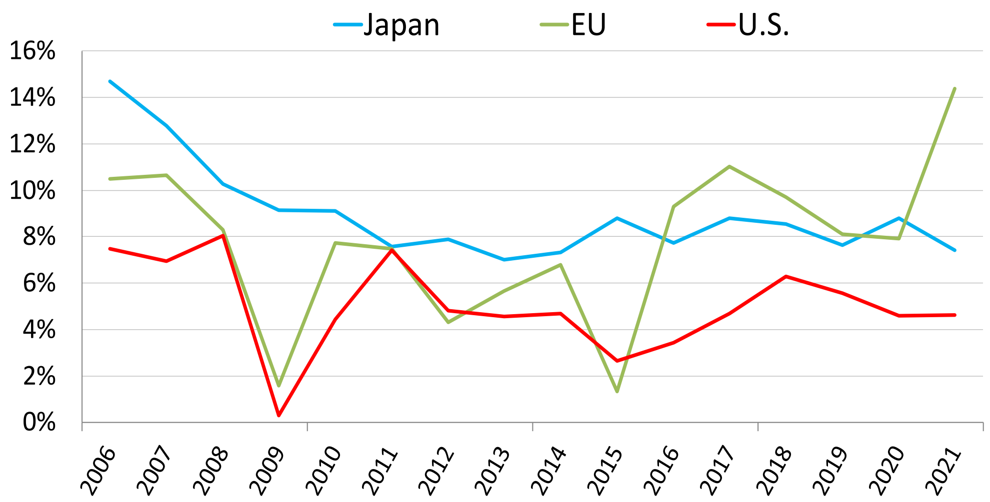
Note: The indices are calculated as the ratio of the share of electrical sheet exports in an economy's total steel exports to the share of that product in world steel exports.
Source: OECD calculations based on data from ISSB.

Profitability

Figure 15 shows the profitability (operating profits) in the EU, Japan and the US. Maintaining profitability is essential to the sustainable and healthy development of the steel industry. Steel firms are making efforts to remain profitable, however, they are also heavily negatively influenced by issues of global excess capacity, supply chain disruptions, and high energy costs. While profitability margins can fluctuate year to year based on the general economic situation, since 2010 they have generally remained low as a result of global excess capacity. Excess capacity affects profitability through different channels. Two main channels are costs and prices. In periods of low-capacity utilisation, economies of scale are not fully exploited and thus costs are higher and profits lower. Prices also tend to be lower during periods of low-capacity utilisation, thereby directly impacting profits. At the global level, the effects of excess capacity are transmitted through trade; excess capacity can lead to export surges, leading to price declines and market share losses for import-competing domestic producers (OECD, 2015[26]).

For some steel companies, profitability levels are unsustainable considering the investments needed for the sector's transformation such as huge investments in R&D, retrofitting and installing new production processes for decarbonisation objectives.

Figure 15. Operating profits in the steel industry in Japan, EU and US (between 2006-2021)



Note: Operating profitability is defined as EBITDA (earnings before interest, taxes, depreciation and amortisation) to sales revenue in per cent. Each line provides information on median operating profitability across firms.
Source: OECD calculations based on data from Refinitiv

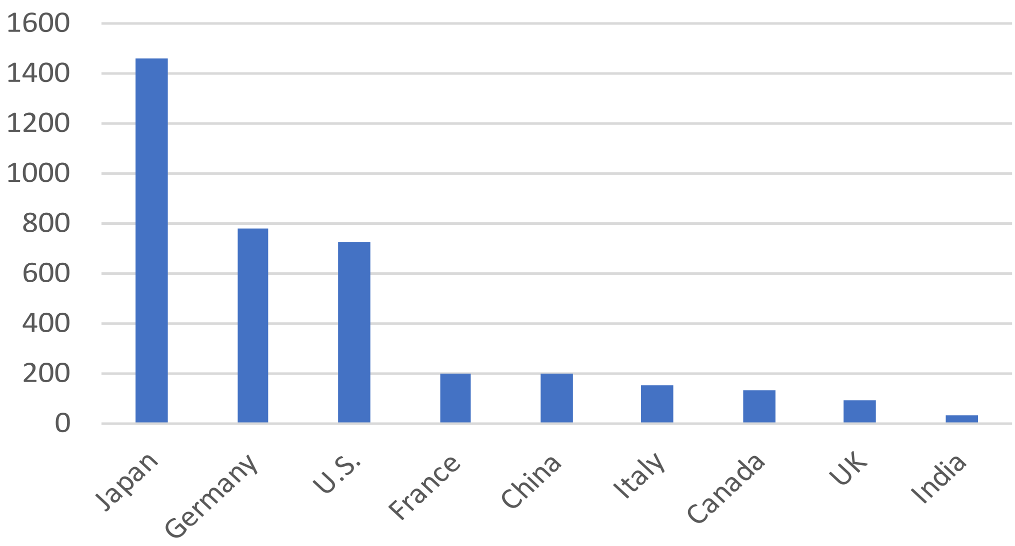
Heterogeneity in Innovation

Patents

Innovative technologies are key to ensuring the decarbonisation of steelmaking production. R&D by the steel industry itself constitutes an important part of that, but public R&D (through universities and governments) can play an important role as well. Therefore, it is important to encourage R&D and disseminate new innovative technologies to accelerate decarbonisation of the steel industry.

Figure 16 shows that patents for low carbon technologies in steel are highest in Japan, Germany, and the U.S.

Figure 16. Patents related to low carbon technologies for the steelmaking (between 1985-2020)



Note: Number of IP5 patent families, by earliest filing date and applicant's location.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, February 2023.

Hydrogen

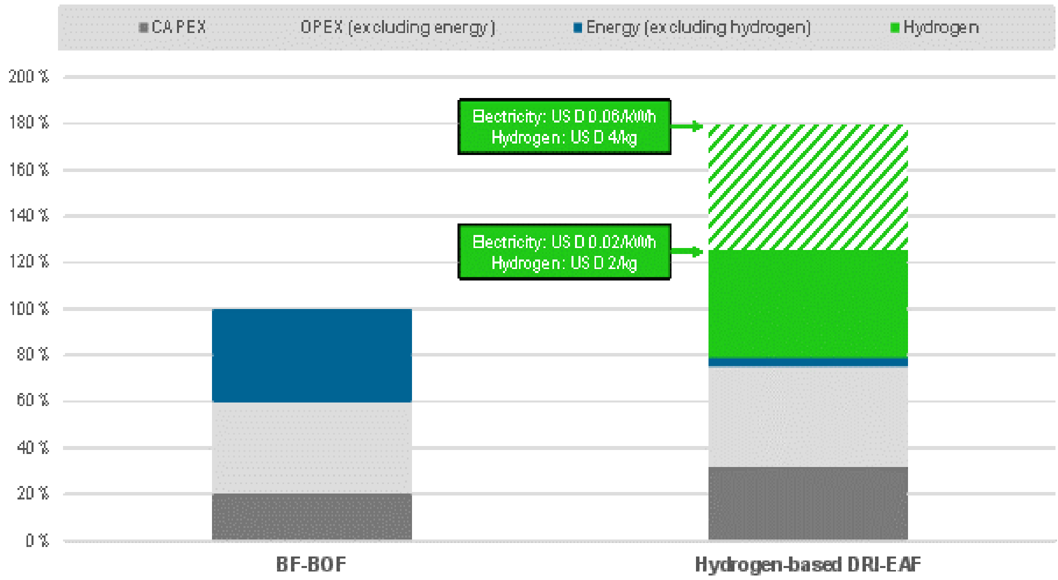
Coal is the main source of energy for iron and steel production. Hydrogen produced from low-carbon feedstocks can play an important role to substitute coal and other fossil fuel use, thereby helping the decarbonisation of the iron and steel sector.

Hydrogen can replace coal as a reducing agent. Several steelmakers have already injected hydrogen into blast furnaces via tuyeres to partly substitute coal injection. This can reduce CO_2 emissions of existing blast furnaces. Yet, as blast furnaces would still require coke to operate, most of their emissions would remain unabated.

Over the last year, several companies have announced hydrogen-based DRI production projects, for instance in Germany, Spain, Sweden or Canada. Current DRI plants typically use natural gas as a reducing agent. In new plants, hydrogen could supply all energy needs, leading to a virtually emission-free process. In existing plants up to 70% of natural gas can be substituted with pure hydrogen. Pure hydrogen reduction is still at an early phase of commercialisation, but is expected to scale up rapidly in the next decade as the first industrial plants are under construction.

It is critical that hydrogen production does not emit CO_2 to ensure that its use in blast furnaces or direct reduction plants leads to emissions reductions. For instance, using renewable electricity to produce hydrogen via electrolysis can lead up to 90% emissions reductions compared to fossil-fuel based processes such as steam methane reforming and coal gasification. In such cases, access to renewable electricity at low cost is critical for the competitiveness of the steel plant, as illustrated in Figure 17.

Figure 17. Illustrative steel production cost comparison between blast furnace production route and hydrogen-based DRI-EAF route costs through the H2-DRI-EAF route



Note: The BF-BOF stacked column shows a reference cost, based on current data. In both cases, the CAPEX and OPEX costs (except for electricity and hydrogen) refer to average values, based on the current situation.
Source: OECD

CCUS

Carbon Capture, Use and Storage (CCUS) can help to achieve deep CO_2 emission reductions in iron and steel plants. The technology is particularly attractive for large emission sources with a high CO_2 concentration. For that reason, current CCUS pilot projects target blast furnaces and direct reduction plants. There are also a number of research projects that analyse its use for other assets, such as sinter plants and coke plants.

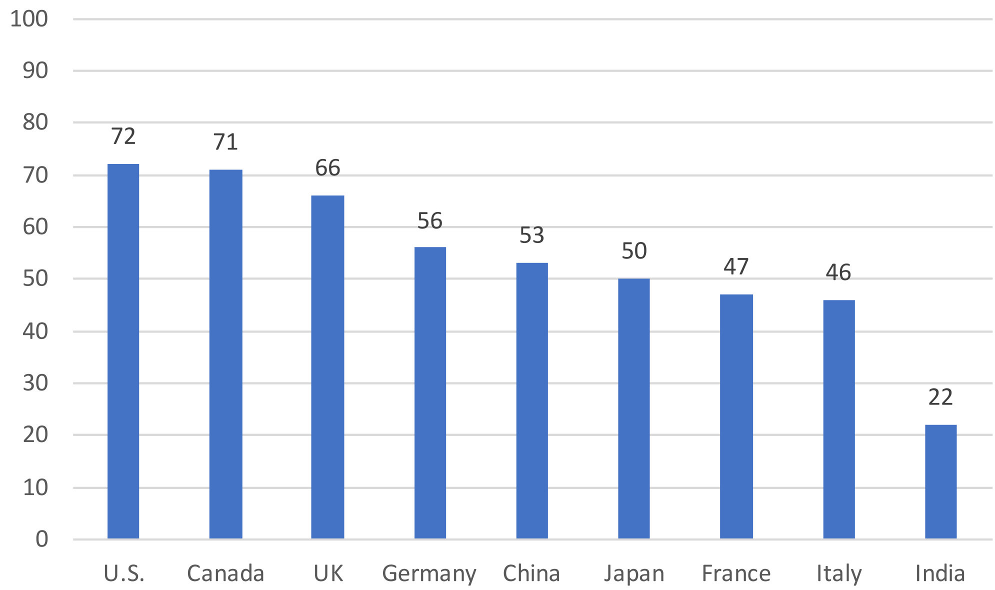
The main advantage of carbon capture is that it can technically be integrated with the existing conventional iron and steel plants. It can reduce up to 90% of the emissions of the conventional blast furnace process. Yet, the maximum emission reduction reported by theoretical studies amount to 77% (Perpiñán, 2023[27]), considering as well that the capture process requires additional heat and electricity to operate.

The business case for CCUS remains challenging. Technology is capital-intensive and it requires energy to operate. The cost of carbon capture in the iron and steel sector is estimated around USD 40-100 per tonne of CO_2 (IEA, 2021[28]), and not all countries have carbon prices or other policies in place to make it economically attractive. Another option to increase the profitability is to convert the captured CO_2 into marketable products such as ethanol or convert it into chemicals by combining with low-carbon hydrogen. But this requires markets and other enabling factors to be in place and there are other cost dynamics.

The ease to develop CCUS also depends on the availability of infrastructure to transport and store CO_2. After its capture, CO_2 needs to be compressed and transported, mainly via pipelines or ships, to geological formations for storage such as saline aquifers or depleted oil and gas reservoirs. Therefore, countries benefitting from such facilities will be better placed to develop CCUS projects in their steel industry.

Figure 18 shows the CCS readiness for a number of countries, with the U.S., Canada, and the UK showing high readiness.

Figure 18. Comparison of CCS Readiness Index for the G7 countries (2021)



Note: The CCS Readiness Index tracks a country's requirement for CCS, its policy, law and regulation and storage resource development. The index provides a score from 0 (lowest readiness) to 100 (highest readiness) at country-level.[7]
Source: The Global CCS Institute

Key insights from heterogeneity indicators

This chapter mapped the heterogeneous landscape of the global steel industry along four key aspects using a varied set of indicators. A relevant question is to what extent patterns are visible across the four aspects and underlying indicators.

To this end, Table 2 summarises the findings on heterogeneity discussed in this chapter. For each indicator for which sufficient comparable country information was available, the table indicates the relative position of each G7 country as well and China and India.[8]

A cluster analysis performed at the level of the aspects and indicators combined shows that there is no overall pattern visible across indicators to group countries (see Annex A).

In the next two chapters, the analysis in Chapter 4 summarised in Table 2 will be related to steel decarbonisation challenges and pathways (Chapter 5) and definitions, methodologies, and data collection frameworks (Chapter 6).

[7] CCS readiness overall is not necessarily reflective of CCS readiness in steelmaking, and regional differences within each country may affect the readiness index.

[8] The relative position of countries on each indicator was determined on the basis of a cluster analysis at indicator level.

Table 2. Summary of heterogeneity indicator analysis

Heterogeneity aspect	Indicator	Canada	France	Germany	Italy	Japan	UK	U.S.	China	India	Note
Assets Characteristics	Crude steelmaking capacity (2022)	Low	Low	Low	Low	Medium	Low	Medium	High	Medium	**Figure 3**
	Crude steelmaking capacity growth from 2000 to 2022	Low	Low	Low	Low	Low	Low	Low	High	Medium	**Figure 3**
	Share of BOF by process of crude steel production (2021)	Medium	Medium	Medium	Low	High	High	Low	High	Low	**Figure 4**
	DRI production	Low	Low	Low	Low	Low	Low	Medium	Low	High	**Figure 5**
	Average age of BOF	-	Medium	Medium	Medium	Medium	-	High	Low	Low	**Figure 6**
	Average age of EAF	High	High	High	Medium	High	Medium	Medium	Low	Low	**Figure 6**
Inputs for Production	Electricity price	Low	Medium	High	-	High	High	Low	-	-	**Figure 8**
	Low carbon power generation	High	High	Medium	Low	Low	Medium	Medium	Low	Low	**Figure 9**
	Import dependencies (Iron ore)	Medium	High	High	High	High	High	Low	Medium	Low	**Figure 10**
	Import dependencies (Coking coal)	Low	High	High	High	High	Medium	Low	Low	Medium	**Figure 10**
	Import dependencies (Scrap)	High	High	High	High	Low	Medium	Medium	Low	-	**Figure 10**
Market & Business Environment	Fragmentation	High	High	Medium	Medium	High	Medium	Low	Low	Low	**Figure 11**
	Export orientation	Medium	High	High	High	Medium	Medium	Low	Low	Low	**Figure 12**
Innovation	Patents	Low	Low	Medium	Low	High	Low	Medium	Low	Low	**Figure 16**
	CCS readiness	High	Medium	Medium	Medium	Medium	High	High	Medium	Low	**Figure 18**

5 Implications of Heterogeneity for Decarbonisation Pathways

This chapter interprets the heterogeneity analysis provided in Chapter 4 from the perspective of its implications for steel decarbonisation pathways. In this chapter, 'decarbonisation pathway' refers to the starting point and final objective in terms of emissions (magnitude and time dimension), as well as the set of decarbonisation options selected to meet this objective.

Heterogeneities shape multiple- but tailored- decarbonisation pathways

Heterogeneity within each indicator previously discussed results in various starting points and configurations for decarbonising steel production, as well as in different challenges. These unique characteristics lead to multiple decarbonisation strategies, options, as well as differences in paces of implementation. Such regional differences in decarbonisation pathways are reflected in various net-zero scenarios pertaining to the steel sector((IPCC, 2022[2]), (IEA, 2021[3]), (E3G, 2021[29]), (MPP, 2022[30]), (Net Zero Steel, 2021[31])).

Moreover, as heterogeneity is reflected beyond the country level, decarbonisation pathways may also differ at a more granular scale: regions (OECD, 2023[32]), companies, plants. Typically, within one country, steel companies may have different decarbonisation approaches given their own assets, financial or innovation characteristics. Likewise, within one company, decarbonisation projects may differ from steel plant to steel plant due to specific plant's characteristics or project business plan.

Table 3 illustrates this diversity of approaches through a number of decarbonisation projects announced by major steel producers in G7 countries. Equally, new EAF steel mills based on the latest and low-emitting technologies are underway (OECD, 2022[33]). Whereas Table 3 lists projects towards near-zero emission routes, it should be noted that the trend in terms of new projects at the global scale differs. Indeed, carbon intensive assets in new capacity projects planned over the next three years still prevail (GFSEC, 2022[6]).

In addition to the heterogeneities analysed in Chapter 4 (which relate to the steel industry), decarbonisation pathways are likely to be influenced by other cross-cutting decarbonisation factors, that are not specific to the steel industry. For instance, heterogeneity in the availability or deployment of infrastructure pertaining to near zero emission technologies for steel (e.g., transport and storage for hydrogen or CO_2, infrastructure, and capacity for low-carbon electricity...) may impact steel decarbonisation options, as well as location choices of supply. Equally, strong or lack of policy support towards one specific cross-cutting option (e.g., hydrogen, CCUS, circular economy) may indirectly drive decarbonisation preferred choices for the steel sector.

Given such heterogeneities, a tailored approach to steel decarbonisation that takes these into account is important.

Table 3. Examples of announced projects by major steel producers in G7 countries

Country	Steel producer	Project location	Project Type	Existing plant configuration (Type of plant)	Decarbonisation option
Canada	Algoma	Sault Ste Marie	Plant replacement	BF-BOF	EAF
Canada	ArcelorMittal	Hamilton	Plant replacement	BF-BOF	DRI EAF
EU (Belgium)	ArcelorMittal	Ghent	Plant adaptation	BF BOF	BF with CCU
France	ArcelorMittal	Dunkirk	Plant replacement	BF-BOF	DRI EAF
France	ArcelorMittal	Fos-sur-Mer	Plant replacement	BF-BOF	EAF
Germany	Thyssenkrupp	Duisburg	Plant adaptation	BF-BOF	BF with CCU
Germany	Thyssenkrupp	Duisburg	Plant replacement	BF-BOF	DRI BOF
Japan	Nippon Steel	Kimitsu	Plant adaptation	BF-BOF	BF with H2
Japan	JFE Steel	Chiba	Plant adaptation	BF-BOF	BF with CCU
UK	British Steel	Scunthorpe	Plant replacement	BF-BOF	EAF
US	Nucor	-	Power Purchase Agreements	EAF	Low-carbon electricity supply to reduce indirect emissions from EAF
US	USS	Arkansas	New plant	-	EAF

Note: This table does not intent to provide a comprehensive list of industrial projects, but to highlight differences in decarbonisation choices. In particular, the examples in the table illustrate projects that show differences within one country, or even within one steel company in a specific country.
Source: Steel companies' annual and sustainability reports, corporate websites.

Interpreting heterogeneity in decarbonisation pathways

Asset characteristics

Given its relatively low emission intensity (worldsteel, 2023[34])[9], the steel decarbonisation pathway from the EAF secondary route would require lower emission reductions compared to other routes. For such assets, emission reductions could be mainly related to low-carbon electricity supply.

For BF BOF assets, higher emission reductions would be required to achieve deep decarbonisation, given their relative high emission intensity (compared to other routes). In terms of options, this would imply deep plant transformations, including CCUS or switching to EAF/DRI EAF (e.g., projects in Table 3). The time horizon to reach such levels of emission reductions is also likely to be longer, given such deep transformations to be implemented. In addition, breakthrough technologies required for BF-BOF (such as CCUS) are not necessarily available at commercial scale yet. Interim solutions may thus be considered for such assets (energy efficiency improvements, hydrogen injection in BF) as part of a phased decarbonisation approach, but with a limited emission reduction potential in a net-zero context.

For DRI EAF plants, the magnitude of emission reductions needed would highly depend on the type of inputs used (e.g., natural gas or coal). On decarbonisation options, DRI EAF plants could be the ground for a switch to hydrogen-based steel production, or CCUS (depending on access to resources and infrastructure).

Beyond decarbonisation options and the type of plants, the age of asset may particularly influence the timeframe for decarbonising through investment considerations. Young high emission intensive assets which have not reached their first investment cycle may not be able to undertake deep plants transformations in the short term. For such assets, this may lead to a longer and costlier transition. For

[9] CO_2 emissions intensities provided in this reference are calculated using the worldsteel CO_2 Data Collection methodology, which includes all scopes (1, 2, and some scope 3)

older assets reaching the end of their lifetime, this may be an opportunity to replace or phase out highly emission intensive plants.

The implications of heterogeneity in capacity developments on decarbonisation pathways are closely linked to the previous considerations. Growing capacity while decarbonising may be especially challenging by the limited number of deep decarbonisation options currently available at commercial scale. In addition, regions with growing capacity are predominantly developing and emerging economies, mainly characterised by high reliance on fossil fuels, low scrap availability and limited access to capital. This primarily results in BF-BOF as the preferred choice for new plants (DRI EAF to a lesser extent, e.g., Middle East), as evidenced by steelmaking projects planned or underway (OECD, 2022[33]). From a decarbonisation perspective, it is thus likely to require higher emission reductions. It would also require a longer and costlier transition to reduce emissions, as deep retrofitting operations or early retirement would be needed to avoid emission lock in and stranded assets.

Inputs for production

In terms of decarbonisation pathways, regions with access to abundant and quality scrap may favour the scrap based EAF route (subject to low-carbon electricity supply). Likewise, the availability and affordability of low-carbon electricity may drive decarbonisation choices towards EAF (primary and secondary routes), including electrolytic hydrogen-based steelmaking. For regions with access to natural gas resources, the DRI route may be favoured too.

These considerations equally apply to infrastructure that related to these inputs. Regions lacking adequate infrastructure development (be it low-carbon electricity, hydrogen, or CO_2) could be impeded to develop hydrogen or CCUS based options.

Finally, it is important to note that policy support towards one specific cross-cutting option (e.g., hydrogen, CCUS) may equally drive decarbonisation choices for the steel sector. In such circumstances, decarbonisation choices may not be necessarily linked to access to domestic natural resources (e.g., hydrogen route in Europe).[10]

Market and business environment

Profitability may impact decarbonisation pathways from an investment perspective. Low profitability could for instance hamper deep plant transformations requiring large investments (whatever the type of technology) or investing in innovative routes. It may thus favour the adoption of interim solutions with lower emission reduction potential, ultimately leading to a slower transition. High profitability may facilitate the move towards emission reductions by investing in innovation and undertaking plant modifications.

For industry structures focusing on the production of high steel grades, the implications and challenges for decarbonisation pathways refer to the previous discussion on assets. As most of these products are currently produced through the BF-BOF route (worldsteel, 2021[22]), significant plant transformations (CCUS or switch to EAF) and a longer time horizon to reach deep decarbonisation would be required. These considerations can also be extended to industry structures favouring mass production volumes, as such production is driven by BF-BOF (higher nominal capacity, see planned projects in (OECD, 2022[33])).

For countries with high emission intensive assets, a high export orientation may result in accelerated or delayed decarbonisation efforts, thus impacting the time horizon of their decarbonisation pathways. Trade measures supporting low-emission steel products or demand for ‘green’ steel in importing countries partners may act as an incentive to decarbonise. On the contrary, a high share of exports directed to

[10] As indicated in Chapter 3, policies and the institutional framework (including for instance carbon pricing) are of relevance, but are not in the scope of this report.

countries where there is limited or no demand for 'green' steel may hinder decarbonisation efforts for reasons of competitiveness and market shares preservation.

Innovation

Innovative technologies are key to ensure deep decarbonisation of steel production. They mainly include CCUS and hydrogen-based technologies, but also technologies with a relatively lower technology readiness level (TRL) such as direct iron ore electrolysis (IOE). The implications of heterogeneity in innovation on decarbonisation pathways are twofold. On the one hand, countries highly investing in innovation and R&D on such technologies may choose one of the breakthrough technologies they are focusing on as the preferred option for steel decarbonisation. In this way, innovation may contribute to shape the decarbonisation pathway. On the other hand, there may be implications in terms of time horizon too. The implementation of such breakthrough technologies at scale has indeed to be considered on a longer time frame (especially compared to existing and commercially available options).

Illustrating decarbonisation challenges through common patterns

Heterogeneity in the steel industry leads to different decarbonisation challenges and pathways. Table 4 provides three examples of steel industry structures resulting in different decarbonisation challenges, based on the indicator analysis in Chapter 4.

Table 4. Examples of steel industry structures

	Example 1	Example 2	Example 3
Differentiating characteristics which drive specific decarbonisation challenges	Primary steelmaking route (BF-BOF or DRI EAF)		Secondary steelmaking route (scrap based EAF)
	High emission intensity		Low emission intensity
	Old assets	Young assets	
	Low-steelmaking capacity growth	High-steelmaking capacity growth	
	Innovation oriented	Low innovation	
	Export orientation		

Note: This table does not intent to provide a comprehensive list of configurations, but examples of industry structures leading to different decarbonisation challenges and pathways.

The characteristics mentioned form the main drivers of the decarbonisation challenges discussed below.

The two first types of industry structures depicted in Table 4 both relate to large scale primary steelmaking producers and a high emission intensity (Example 1 and Example 2). These common characteristics imply similar challenges across the two groups, namely

- deep plant transformations required,
- CCUS, hydrogen and low-carbon electricity as key options for deep decarbonisation,
- large investments needed to enable such a transformation,
- competitiveness challenges (given the high production cost related to the innovative routes compared to the conventional ones),
- access and affordability of strategic inputs for innovative production routes, as well as the related infrastructure (depending on the decarbonisation choice: hydrogen, low-carbon electricity, CO_2, high grades of iron ore),

Beyond the common characteristics of large scale and high emission intensive production, these two examples are further differentiated in terms of capacity growth, age of assets, innovation focus and export orientation. It results in specific challenges for these two types of industry structures.

Based on the country's characteristics presented in Table 2, G7 countries with a high share of BF-BOF production – namely Canada, France, Germany, Japan, and UK – may fit into the first group, while China and India may fit into the second one.

For the first group (Example 1), these include:

- importance of plant replacement strategies, given the age of assets,
- challenge of scaling up innovative technologies,
- steel products subject to emission-based measures for trade (export orientation).

For the second archetype (Example 2), specific challenges include:

- potential growth in emission intensive assets, given the capacity growth,
- risk of stranded assets, given the previous point and the young assets,
- challenge of access to innovative technologies.

The third group (Example 3) implies decarbonisation challenges of a quite different nature. Given the relatively low emission intensity, no structural transformation is required compared to the previous groups. In this way, stakes mainly relate to securing access and affordability of strategic inputs for production, namely low-carbon electricity and quality scrap. Based on the country's characteristics presented in Table 2, G7 countries with a high share of EAF production, namely Italy and the U.S, may fit into this group.

6 Implications for Definitions, Emissions Measurement Methodologies and Data Collection Frameworks

This chapter discusses the possible implications of the heterogeneity of the steel industry and decarbonisation pathways for the development of definitions of low-carbon and near zero emissions steel, emissions measurement methodologies, and data collection frameworks.

Implications for definitions for near zero and low emission steel production

There is an inherent tension between the heterogeneity of the steel industry and the need and way to develop common arrangements to achieve policy objectives. On the one hand, the development of common frameworks and definitions is necessary in providing clarity to markets on expectations, in the development of new technologies, in supporting implementation at scale, in enabling dialogue and cooperation. On the other hand, the variety of circumstances and actors can also make it challenging to find commonalities and can possibly advantage one group above others and hence cause level playing field challenges.

Heterogeneities in terms of assets characteristics, inputs for production, market and business environment or innovation have one impact in common, in the sense that they lead to different starting points and capabilities to transform towards near zero and low emission steel. These differences have as a consequence that the nature, the scale and the pace of decarbonisation efforts to be undertaken will vary across economies. For definitions, it means that every country, steel firm, or asset will position differently in terms of emission intensity, thus not likely to comply to the same emission threshold at the same time.

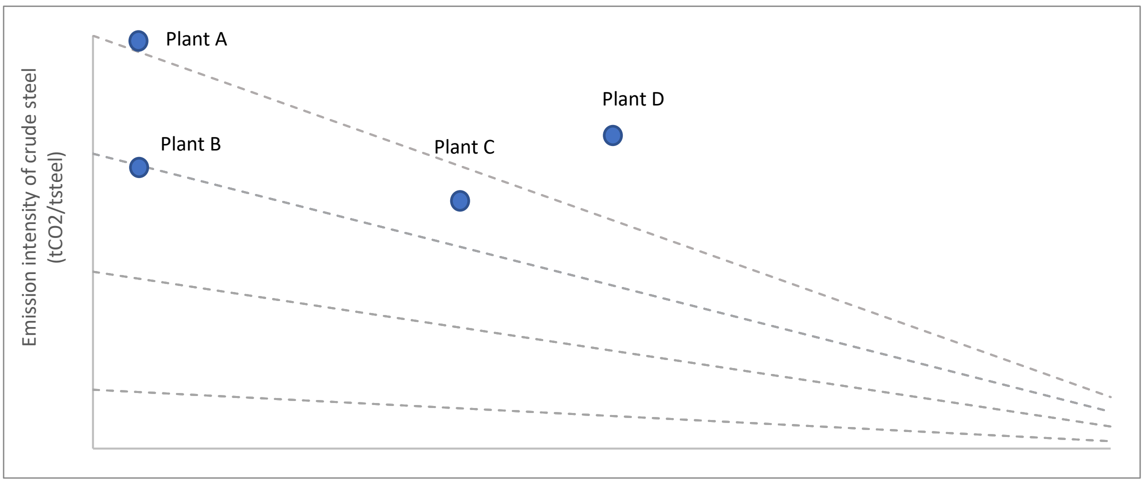
When interpreting the concept of heterogeneity from these generic considerations, six factors stand out as key (Figure 19). The implications of the various types of heterogeneities for definitions for near zero and low emission steel are further explored in the sections below following these six factors.

Figure 19. Key factors for interpreting heterogeneity

Heterogeneity and reduction requirements

Figure 20 highlights how heterogeneity (whatever its type) in the steel industry results in differences in emission intensities. Given these differences, a country, steel firm or plant is closer or further away from the threshold that qualifies its steel production as 'near zero or low-carbon emission steel'.

Figure 20. Heterogeneities shape differences in starting points



Note: This figure is for illustration purpose only, highlighting differences in emission intensity starting points across assets, companies or countries. It does not intend to state or compare any emission threshold value.

Given the differences in terms of starting points, emission reduction requirements to reach near zero emissions steel by 2050 are significantly larger for some industries and economies than for others.

Typically, depending on the type of asset, its age, process efficiency, type of raw material and energy sources, the current level of emission intensity will differ (Figure 20). For instance, while scrap based EAF plants may focus on the supply of low-carbon electricity and scrap availability to decarbonise, deep plant transformations may be required for existing BF-BOF plants to comply with definitions of near zero emission steel (e.g., retrofit with CCUS, shift towards EAF). As for production inputs, regions with greater access to quality scrap or low-carbon electricity may be initially better positioned to comply with definitions thresholds through the scrap-based EAF route, given its relative lower emission intensity compared to other routes (worldsteel, 2023[34]). Such differences in starting points towards emission reductions - and resulting both from regional steel industries' legacy and access to resources - should be acknowledged when applying definitions.

Heterogeneity and 'fairness'

The heterogeneity analysis also shows that there could be considerations related to 'fairness' in relation to complying with emission thresholds.[11]

The two examples previously mentioned equally translate into 'fairness' considerations: legacy in terms of assets, as well as access to resources and raw materials may be an advantage or a disadvantage for some countries to decarbonisation efforts. Again, requirements in terms of emission threshold compliance may differ across regions given such 'fairness' considerations. There is therefore a need for definitions to be technology neutral that allow for a level playing field across the varied landscape of current assets performances.

Heterogeneities in the business environment lead to 'fairness' considerations too. As decarbonisation options require large investments, capabilities to move towards low emission steel may differ depending on companies' profitability, access to capital or size. In practice, it may be more challenging for small firms or firms with poor financial performances to undertake deep plant transformations. These differences should be acknowledged when applying definitions for near zero and low emission steel. For instance, some adjustments mechanisms may be envisioned such as allowing a tailored application of such definitions to small firms.

Jobs and social considerations may also relate to such aspects. For regions where the steel sector strongly contributes to the economy, steel decarbonisation may involve large social transitions, including the need to upskill or reskill the workforce. Consequently, stakes related to jobs aspects may lead to consider a phased transformation and Just Transition mechanisms.

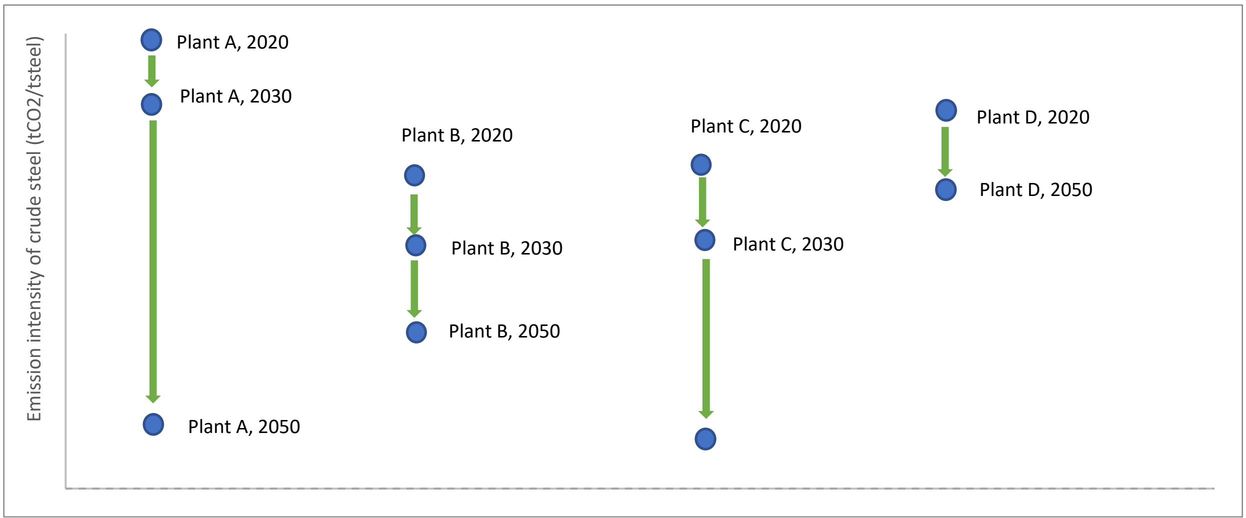
Regarding innovation, the implications in terms of 'fairness' are twofold. First, differences in the level of innovativeness of a country may result in differences in achieving a sufficiently high Technology Readiness Level (TRL) for breakthrough technologies to be deployed at scale. For some countries, this may thus complicate the ability to switch to near-zero technologies. These differences should be acknowledged when applying definitions. They also call for technology co-developments and transfers to be considered alongside the implementation of definitions. On the other hand, innovation efforts towards near zero emission routes imply riskier investments, and a longer timeframe for implementation compared to other available decarbonisation options. These innovation efforts should be valued when applying the definitions, despite the long-term emission reduction results involved.

[11] Comments in the peer review underlined that the use of the concept of 'fairness' in this analysis of heterogeneity should not be confused with the way the term fairness is more generally used in climate analysis and policy discussions.

Heterogeneity and abilities

Figure 21 shows through four examples how heterogeneity (whatever its type) translates in different abilities to transform towards decarbonisation, ultimately impacting the emission intensity (and thus the positioning with respect to the thresholds of near zero and low emission steel).

Figure 21. Heterogeneities shape differences in the ability to transform



Note: This figure is for illustration purpose only, highlighting differences across assets, companies or countries in the nature, scale and pace of transformation (2020, 2030, 2050) towards near zero or low emission steel production. It does not intend to state or compare any emission threshold value.

Some economies or (smaller) firms may be at a disadvantage in adhering to definitions than more established producers. In this way, the 'fairness' considerations related to the business environment, jobs, and innovation considerations, equally refer to differences in abilities to transform (investments, size of firms, business dynamism, jobs and social aspects, access to innovative technologies). Complementary policies, such as training or technology co-development, may be needed to address this.

Further examples of differences in the ability to transform may relate to asset characteristics. For instance, in the absence of breakthrough technologies available at commercial scale, it would be challenging for primary steelmaking routes-based plants to transform towards near zero emission steel in the short term. In addition to the type of asset, its age may also impact the ability to transform. As a component of the business case for transformation, it may impact the economic viability of decarbonisation investments. Typically, young assets that have not reached their first investment cycle may not be able to consider deep plants transformations requiring large investments, but rather interim solutions for emission reductions. Definitions should thus be applied in a way that acknowledge these differences in abilities to transform. This should be designed in a way that enables various types of assets to be part of global decarbonisation efforts, but without undermining the level of ambition to reach near-zero emission steel.

As for production inputs, uneven access to strategic inputs also impacts the ability to decarbonise steel production. For instance, access to quality scrap or low-carbon electricity may ease the move towards the scrap-based EAF route. Regions with access to such resources may have a greater ability to reach near zero emission steel in the short term, as scrap based EAF is a well-established and commercially available route and has a lower emission intensity compared to other routes (worldsteel, 2023[34]). Another example is the poor access to abundant and affordable low-carbon electricity, which may impede the ability to move towards electrolytic hydrogen-based routes. These considerations equally apply to infrastructure related to strategic inputs. Regions lacking adequate infrastructure development (be it low-carbon electricity, hydrogen, or CO_2) could be impeded to develop some decarbonisation options, thus limiting their potential to move towards near zero emission steel. In their application, definitions should reflect uneven access to resources, which combined with different asset types calls for technology neutrality. Considering uneven access to resources would also ensure that implementing the definitions would not generate supply, market or trade tensions on strategic inputs. Indeed, acknowledging only one type of resource through definitions could generate tensions supply, both in terms of availability and affordability.

Heterogeneity and incentives

Incentive structures to decarbonise may differ across economies. For instance, differences in incentive structure may pertain to government support or enabling policies towards decarbonisation. Countries benefitting from stronger support towards decarbonisation may thus be in a better position to move towards near zero or low-carbon emission steel (compared to others). This is therefore also linked to differences in abilities when it comes to definitions, as well as ‘fairness’ considerations.

In addition, steel producers with a strong export orientation (and/or steel producing economies with considerable openness to steel imports), operate on a different chess board than those producing primarily for domestic demand. They are indeed likely to be hardest impacted by the application of definitions for trade. This aspect reinforces the importance for definitions to consider heterogeneities in the ability to transform. Indeed, this would also support the viability of the steel industry in such countries by enabling them to be part of global decarbonisation efforts.

Heterogeneity in countries’ export orientation raises implications of a different nature, namely on the practical use of definitions into the trade sphere. For definitions to be applied for trade, it is crucial that they can be translated to the various types of steel products that are traded across regions. Moreover, interoperability between potential different definitions across regions should be ensured. Finally, a flexible approach that considers differences in the ability to transform could be adopted when implementing definitions between trading partners.

Heterogeneity and time horizons

Heterogeneities in terms of assets characteristics, inputs for production, market and business environment or innovation all lead to differences in the paces of decarbonisation efforts. For definitions, it means that at a specific time, every country, steel firm, or asset will position differently in terms of emission intensity, thus not likely to comply to the same emission threshold at the same time.

This aspect may be of particular relevance in the context of innovation and relates to the previous issue on incentives. Some industries invest heavily in (breakthrough) innovation of new products and processes. Such breakthrough innovations are key to achieve global climate goals. However, depending on the way definitions are set, there is a risk that those industries that focus on innovation, with a related longer time horizon to achieve reduction objectives, are put at a disadvantage compared to those that work towards lower emissions based on existing or nearer to market technologies. Again, definitions should enable a level playing field for those different decarbonisation trajectories and should not distort much needed long-term incentives to innovate. These innovation efforts should be valued and incentivised in definitions, despite the long-term emission reduction results involved.

Equally, deep plant transformations may be required for some types of plants (linked to the type of asset or quality product) to comply with definitions of near zero emission steel (e.g., retrofit with CCUS, shift towards EAF). These transformations may be also linked to investment cycles considerations. Interim solutions may be considered for such assets (energy efficiency improvements, hydrogen injection in BF etc.) as part of a phased decarbonisation approach. This would thus imply longer timeframe to be considered to comply to the same emission threshold compared to a plant that would require less transformation efforts.

Echoing to the 'fairness' considerations, it may take more time for some types of firms to transform towards net-zero (see previous), as well as for some regions were jobs and related social aspects are at stake. Such differences in pace of transformation should be acknowledged when applying definitions.

Heterogeneity and product quality

Finally, a key consideration is for definitions to take into account that steel products differ in quality.

As some steel grades are not currently easily produced through scrap-based EAF facilities in several steelmaking producing countries some firms may highly rely on primary steelmaking to produce high quality steel products (Nippon Steel, 2021[35])). As previously discussed, in the absence of breakthrough technologies available at commercial scale, it will be more challenging for primary steelmaking routes-based plants to reach near zero emission steel in the short term. This would result in a slower pace of transformation for such assets, thus not likely to comply to the same emission threshold, when compared to other assets producing lower grades. Conversely, for high quality steel produced through EAF, definitions should also recognise and value a higher level of performance when it comes to emission intensity.

Moreover, differences in quality and product types implies for definitions to consider the appropriate scope emission boundaries related to these products (beyond crude steel and including further process steps for finished products for instance), as well as specific inputs that would be required for this product (stainless steel or high alloys steel for instance). More generally, it raises the question to apply or translate definitions to products in order cover different product types, and which is particularly of relevance when considering trade aspects.

Implications for emissions measurement methodologies and data collection frameworks

Implications for emissions measurement methodologies

Setting-up emissions measurement methodologies is a prerequisite to apply definitions. Indeed, these emissions measurement methodologies form the basis to calculate emissions and related intensity of production. In particular, these methodologies set the scope, boundaries and granularity for emissions accounting (and by extension these for defining the thresholds for definitions). An overview of existing emissions measurement methodologies for iron and steel and related methodologies is provided in (IEA, 2022[9]).

For emissions measurement methodologies, heterogeneity in asset characteristics implies that there are diverse steel production routes to be covered in emission accounting methodologies (such as BF-BOF, EAF, DRI EAF, see for instance (worldsteel, 2022[36])).

Likewise, heterogeneity in terms of inputs for production means that various raw materials or energy sources have to be covered in these methodologies (such as coking coal, iron ore, natural gas, see for instance (worldsteel, 2022[36])).

Through the development of new production routes and their related inputs (such as hydrogen based DRI EAF or CCUS based routes), the innovation dimension involves extending the existing methodologies with these additional configurations. It is worth noting that including new routes indirectly implies developing emissions measurement methodologies for new production inputs that relate to these routes, and for which an agreed emissions measurement methodology is not established yet (typically the case for hydrogen).

Heterogeneity in product types or quality leads to the same considerations. Covering various types of products implies for emission accounting methodologies to reflect the appropriate scope boundaries related to these products (including industrial process steps such as hot rolling, cold rolling for instance), as well as specific inputs that would be required for this product (stainless steel or high alloys steel for instance).

Heterogeneity in countries' export orientation raises implications of a different nature. Contrary to the previous types of heterogeneities discussed, the implications are not linked to the methodologies content per se, but to their practical use in the trade sphere. For steel export-oriented countries - and for trade considerations of low emission steel products in general -, it will be crucial that the measurement methodologies applied for emission accounting are similar between trading partners (even if supervised by different bodies). This is a critical point to ensure that emission related data across traded products are comparable, and thus to facilitate interoperability between different definitions of 'near zero' or 'low emission steel' that may exist across regions.

Heterogeneity in the business environment translates into different abilities to implement emissions measurement methodologies. Across steel firms, there may be indeed uneven access or ability to build the required data infrastructure, or to ensure a suitable data collection, measurement, reporting and verification. Differences in abilities thus relate to 'fairness' considerations. These considerations equally apply to countries (not only to firms), as there may be different levels of capabilities to deal with these aspects too. This implies that technical assistance and capacity building may be needed to ensure an efficient implementation of measurement methodologies, while limiting the administrative burden. In addition, it may be required to define a methodology to be used by default to fill data gaps (while primary data should be prioritised, where possible). Given the differences in abilities previously mentioned, this could also lead to different timeframes to be able to implement emissions measurement methodology requirements.

Implications for data collection frameworks

Implementing emissions measurement methodologies relies on data collection frameworks, which provide input data to apply these methodologies. As a consequence, related data collection frameworks are impacted by heterogeneity in a very similar way to measurement methodologies, namely:

- Data to be collected or measured needs to be comprehensive and granular enough to cover multiple production process configurations: existing and new production routes, related inputs and associated to different product types.
- For trade aspects, a common data collection framework would be desirable. This would ensure that emission related data across traded products are comparable, and thus would facilitate interoperability between different definitions of 'near zero' or 'low emission steel' that may exist across regions.
- Different capabilities across countries and firms to managing or to comply with data collection frameworks suggest that technical assistance may be needed, as well as limiting administrative burden and establishing a methodology to be used by default to fill data gaps (while primary data should be prioritised, where possible).
- Given the differences in abilities previously mentioned, this would also lead to different time horizons to be able to comply with data collection framework requirements.

Final reflections and discussion

This report benefited from an extensive peer review and multiple contributions during the Workshop on 27 February 2023. In this last section, some of the issues that came up during the peer review are further reflected upon.

- **Acknowledging heterogeneity should and can go hand in hand with ambitious emission reduction objectives.**

  The considerations on heterogeneity in no way should be seen as a reason to lower climate ambitions. Differences in starting points and capabilities should not come at the price of pursuing a business-as-usual approach, nor of maintaining an unlevel playing field.

  Despite heterogeneities, countries should strive for the common objective of reaching near zero emission steel. It is therefore important that steel emission reduction targets are formulated in a robust and ambitious way for all production regions. Taking heterogeneity into account can in fact help in building common ground to realise and accelerate these ambitions.

- **Working towards common definitions, emissions measurement methodologies and data frameworks has strong advantages, but also needs some nuance.**

  Common definitions, emissions measurement methodologies and data frameworks would present multiple benefits for global steel decarbonisation efforts. They would especially support the alignment of steel decarbonisation objectives across countries, ensure a fair comparison across assets and a level playing field, or ease the reporting and verification of emissions. However, the heterogeneity analysis in this report and discussions during the peer review allow for further reflection on this.

  First, definitions and emissions measurement methodologies may be intended to serve different objectives. For instance, they may target domestic or international aspects, procurement, trade, financing, or innovation. As raised by stakeholders, it might be challenging to rely on one single definition, depending on whether the objective is to incentivise decarbonisation efforts or product labelling. Nevertheless, it will be essential that despite potential different definitions and methdologies, they enable like for like comparisons.

  For trade aspects, common and shared definitions are particularly at stake. It will be especially crucial that the emissions measurement methodologies applied for emission accounting are similar between trading partners (even if supervised by different bodies). This would ensure that emission related data across traded products are comparable, and thus to facilitate interoperability between different definitions of 'near zero' or 'low emission steel' that may exist across regions.

  Finally, discussions showed that common ground on advancing on emissions measurement methodologies and data collection frameworks might be easier to establish than on definitions, where views more widely diverge.

- **Different perspectives underpin the recognition of heterogeneity in definitions.**

  There are currently different views across the steel industry on how to consider heterogeneity in the design of definitions.

  A first approach takes heterogeneity into account through a sliding scale of the share of scrap used in production and accompanied by performance 'bands'. The rationale for this definition design is twofold. The sliding scale aims to acknowledge that quality scrap may not be available in sufficient quantities in every region of the world. It also seeks to recognise that primary steel production will continue to play an important role for global steel production in a net-zero context. In addition, the objective of the 'bands' is to value interim decarbonisation progress.

A second perspective lies in using a single definition based on the actual emissions, regardless of the production process or technology used. The rationale is that the key driver to reach net-zero targets should be the absolute emissions. Moreover, the argument is made that using a single and absolute emission threshold would avoid labelling in the same way products from scrap EAF and from BF-BOF process, even though the latter has higher absolute emissions.

A third approach that was advanced would be to acknowledge other types of heterogeneities, beyond the use of scrap. Such aspects could include differences in product quality, and how these relate to differences in emissions or innovation related factors and incentives that definitions should provide for these in the short and medium time. Such an approach could enable to cover some of the implications raised upon the six factors (Figure 19), and beyond the sole aspect of scrap availability.

- **Heterogeneity is not just relevant for the design, but also the implementation of definitions, emissions measurement methodologies and data collection frameworks.**

  Beyond the design aspects previously discussed, heterogeneity could be acknowledged when applying such methodologies and definitions. This could notably take shape through adjustment mechanisms to enable a tailored and flexible application. Such mechanisms would acknowledge circumstances of countries and thus taking adequate measures to allow for a practical implementation. As was put forward in the review, such adjustment mechanisms would only make sense if they do not overly reduce incentives to decarbonise and are only considered in situations when economies make credible process towards steel decarbonisation and do not continue to expand capacity primarily based on high polluting production methods

  This may include adjusted and temporary measures on how and when to apply these methodologies and definitions (for instance targeting small firms, on-going innovation efforts). This approach would support the urgency of implementing, beyond the differences in starting points and abilities.

- **Taking heterogeneity into account in definitions, methodologies and data collection frameworks requires a comprehensive approach to steel decarbonisation, including accompanying policies to help implement this.**

  Heterogeneity implies that when pursuing common definitions, methodologies, and data collection frameworks a wider and more comprehensive approach should be considered to design and implement these. This could include accompanying policies to ensure that the transition works in the different steel industry settings described in this paper.

  Further research could shed light on the accompanying policies required to ensure that the heterogeneity challenges listed are well taken into account.

7 Conclusion and Recommendations

This report, prepared for the 2023 Japanese G7 Presidency, has mapped the heterogeneity of global steel industries and decarbonisation pathways. It shows how steel industries differ in key aspects of relevance to decarbonisation, and explores if and how these differences are important to take into account in developing definitions of near zero and low-emissions steel production, emissions measurement methodologies and data collection frameworks.

The report shows that taking heterogeneity into account is important for a successful decarbonisation of the steel industry. It is instrumental for reaching climate goals, and helps to ensure inclusiveness and a just transition. Understanding heterogeneity should not be seen as a reason to water down ambitions. On the contrary, taking differences into account can in fact help accelerate an inclusive transition. Comments made in the peer review of this report underline the importance of finding common ground on data frameworks, emissions measurement methodologies and definitions for low carbon emissions steel, and how understanding heterogeneity can help achieve this.

The report focused on four key aspects of heterogeneity: assets, inputs for production, the market and business environment and innovation, and discussed a detailed set of indicators to map these, which allow for the distinction of different decarbonisation pathways across global steel industries. The report identifies six key factors related to heterogeneity that should be taken into account in developing definitions of near zero and low-emissions steel production, emissions measurement methodologies and data collection frameworks: heterogeneity in reduction objectives, fairness, abilities, incentives, time horizons and product quality. These factors are also relevant to inform complementary policies to foster the agreement and adherence to such definitions, emissions measurement methodologies and data frameworks. Taking these factors into account can help in finding common ground on definitions, methodologies, and data frameworks and to accelerate the delivery of a decarbonisation agenda for steel.

The analysis leads to the following recommendations:

1. In developing definitions of near zero and low-emissions steel production, emissions measurement methodologies and data collection frameworks **it is important to take the heterogeneity of steel industry structures and decarbonisation pathways well into account.**
2. This requires that differences across countries in **abilities, incentive structures, innovativeness, time horizons, product quality and other factors** discussed in this report inform decision making on definitions, emissions measurement methodologies and data collection frameworks. This is of particular importance for ensuring that such methodologies, definitions, and data collection frameworks are **fit for circumstances across industrialised economies as well as in developing and emerging economies** and for ensuring **a level playing field**.
3. The development of definitions, emissions measurement methodologies, and data collection frameworks is a key component for an effective and efficient global steel decarbonisation agenda that regards the creation of lead markets, procurement, technology scaling-up, financing and trade, which necessitates an **inclusive and comprehensive approach**.

4. Given the multifaceted nature of the steel decarbonisation agenda and the need for an inclusive and comprehensive approach, the development and implementation of such definitions, emissions measurement methodologies and data collection frameworks would benefit from a **sectoral approach** ensuring the involvement and expertise of steel industry organisations and other stakeholders as well as policy makers in relevant policy domains, including climate and energy, industry, and trade. This would also help foster policy support for steel decarbonisation and encourage that all countries and industries participate in the process.

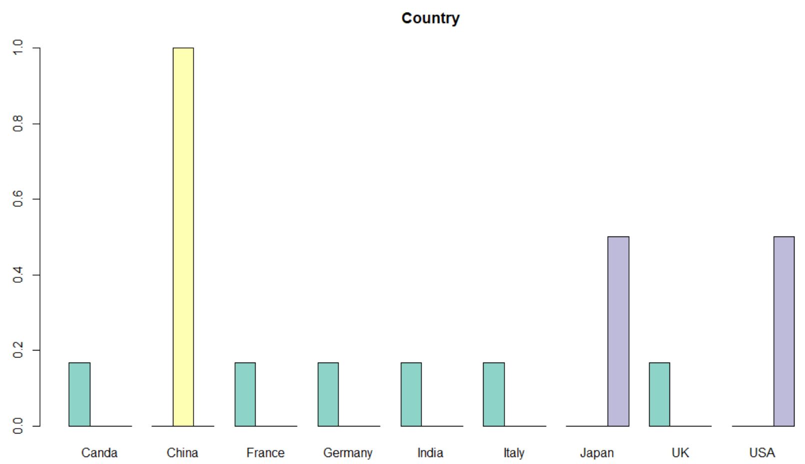
Annex A. Results of cluster analysis for Chapter 4

To interpret the data on indicators in Chapter 4, a cluster analysis was executed. This cluster analysis focused both on the indicators in each heterogeneity aspect as well as across the full set of indicators (all aspects).

The cluster analysis on the individual aspects only generated a significant result for aspect 1, not for the other three aspects. The reason for this lies in the more limited country coverage per indicator for aspect 2, 3 and 4 as compared to aspect 1. Also, the subject of the indicators under aspect 2, 3 and 4 is by nature probably less related than under aspect 1. For instance, the set of issues under aspect 3 (Market & Business Environment) and aspect 4 (Innovation) is more varied than the indicators on assets in aspect 1. This also explains why there were no significant results across the indicator set as a whole.

Figure A.1 shows the results of the cluster analysis on aspect 1.

Figure A.1. Results cluster analysis heterogeneity aspect 1 (assets characteristics)



The figure shows three clusters of countries with similarity in regard of assets characteristics:

- Group 1 (yellow): China
- Group 2 (purple): Japan and USA
- Group 3 (green): Canada, France, Germany, India, Italy, UK

To perform the cluster analysis, the following metrics were used:

- Capacity level and development: Capacity in 2022, and growth between 2000-2022
- Crude steel production process: Share of BOF divided by the share of EAF
- Apparent DRI production: subtract the sum of import and export amount from production, represents Direct Reduced Iron (DRI) production
- Age of assets: the difference between the start year and 2023 and the average of age.

Annex B. Assessment of the implications of heterogeneity on definitions, emissions measurement methodologies and data collection framework

Table B.1. Implications of Heterogeneities on Definitions: Synthesis and Recommendations

Implication of heterogeneity on definitions	Aspect of heterogeneity	Deployment stage of definitions to which the recommendation applies[12]	Recommendation	State of play with respect to existing definitions
Different starting points in terms of emission intensity	Asset Characteristics	Design	Ensure that definitions acknowledge differences in emission intensity that would result both from regional steel industries' legacy, differences in access to natural resources and product types.	Some of the existing definitions (e.g., IEA, ResponsibleSteel, German Steel Federation, FMC, ArcelorMittal, Steel Zero, IDDI) include: - a sliding scale that depends on the steel scrap use, enabling the coverage of different steel production routes and inputs, - a system of 'performance thresholds levels (or 'bands') that enables to consider a progressive decarbonisation approach, recognising various starting points and abilities to transform across assets Definitions that apply to specific steel grades (high-alloys, stainless steel) remain to be further developed. as raised (on-going work) by ResponsibleSteel or the German Steel Federation. Definitions that apply to steel products (hot rolled coils etc..) remain to be further developed. For Green Public Procurement (GPP) specifically, this is an on-going work undertaken by IDDI.
	Inputs for production			
	Market Structure			
Different capabilities to transform, resulting in differences in scale and pace of decarbonisation efforts:	Asset Characteristics	Design	Ensure that definitions acknowledge differences in the ability to transform towards near zero / low	See previous (sliding scale on steel scrap, bands, steel grades)

12 'Implementation' refers to the application of the definition. 'Design' refers to the definition content, how the definition is built.

Differences in the ability to comply to the same definition emission threshold, at the same time	Inputs for production Market Structure Business Environment Innovation		emission steel production.	
Some types of assets may be better positioned to comply with definition emission thresholds but cannot be the sole answer to meet global steel demand and different product types.	Asset characteristics	Design	Ensure that definitions are designed in a technology neutral way. Ensure that definition emission thresholds for near-zero emission steel production is achievable through various decarbonisation routes.	See previous (sliding scale on steel scrap, bands) Some of the existing definitions (e.g., IEA, German Steel Federation) present a comparison between the near zero emission thresholds and emission intensity of steel production through various routes. These comparisons show that several routes (both primary and secondary) can comply with the near zero emission threshold.
Some types of inputs may be better positioned to support the compliance to definition emission thresholds, but their access is uneven across regions, or with limited quantities at the global level (scrap)	Inputs for production	Design	Ensure that definitions are designed in a way that does not imply the use of only one specific input type.	See previous (sliding scale on steel scrap, bands)
Different capabilities to transform across firms, resulting in differences in scale and pace of decarbonisation efforts: Differences in the ability to comply to the same definition emission threshold, at the same time.	Business environment	Implementation	The implementation of the definitions should be accompanied by adjustments mechanisms that would acknowledge different capabilities across firms	Implementation of definitions remains to be developed
Innovation programs may imply longer term emission reduction results: inability to comply with definition emission thresholds in the short-term in spite of on-going decarbonisation efforts.	Innovation	Implementation	Ensure that innovations efforts are valued in definitions, and that the longer timeframe associated to the resulting emission reduction are considered. The implementation of the definitions could involve adjustment mechanisms based on the on-going innovation efforts undertaken.	Implementation of definitions remains to be developed
Uneven access to innovative technologies: Differences in the ability to comply with definition emission threshold.	Innovation	Implementation	Technology co-developments should be considered alongside the implementation of definitions.	Implementation of definitions remains to be developed
The export dimension implies implementing definitions of	Market Structure	Implementation	Define a framework for applying definitions to traded steel products.	Implementation of definitions remains to be developed

near zero and low emission steel production for trade			Establish mechanisms or equivalence system between trading partners to ensure interoperability of definitions that may differ across regions. Implementation arrangements between trading partners should adopt a flexible approach that considers differences in the ability to transform across regions.	

Table B.2. Implications of Heterogeneities on Emissions Measurement Methodologies (EMM) and Data Collection Frameworks (DCF): Synthesis and Recommendations

Implication of heterogeneity on EMM & DCF	Aspect of heterogeneity	Deployment stage of EMM/DCF to which the recommendation applies	Recommendation	State of play with respect to existing EMM & DCF
Various iron & steelmaking production routes to be covered	Asset characteristics	Design	Ensure that the diverse existing production routes are reflected in EMM & DCF	BF BOF, DRI EAF and EAF routes are already included in existing some EMM and data collection frameworks
Various types of production inputs to be covered	Inputs for production	Design	Ensure that the diverse inputs for production used for existing iron and steelmaking production routes are reflected in EMM & DCF	Some existing EMM & DCF cover the various inputs used.
New iron & steelmaking production routes and related production inputs to be covered	Innovation	Design	Complement EMM & DCF by including new production routes and their related inputs.	New routes such as hydrogen based or CCUS based routes are not included in all EMM/DCF yet.
		Implementation	Ensure that dedicated EMM that relate to new production inputs are otherwise established, so that they can be used when applying EMM for iron and steel production.	For instance, an agreed EMM for calculating emission from hydrogen production needs to be established.
Various types of steel products to be covered	Market Structure	Design	Ensure that EMM system boundaries enable to cover various product types.	Some existing EMM cover various product types
EMM and DCF as an input for applying definitions of near zero and low emission steel production for trade	Market Structure	Implementation	Consider a common emission measurement methodology and data collection framework to ensure data comparability across traded products, as well as interoperability of potential different definitions across regions.	Multiple EMM & DCF co-exist
Different capabilities across firms and countries to build the required data infrastructure, and/or to ensure a suitable data collection, measurement, reporting and verification.	Business Environment	Design	Develop a methodology to be used by default to fill data gaps, while prioritising primary data, where possible.	Multiple default factors or estimation methods co-exist
		Implementation	Deploy technical assistance and/or capacity building to support the implementation of EMM & DCF.	

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