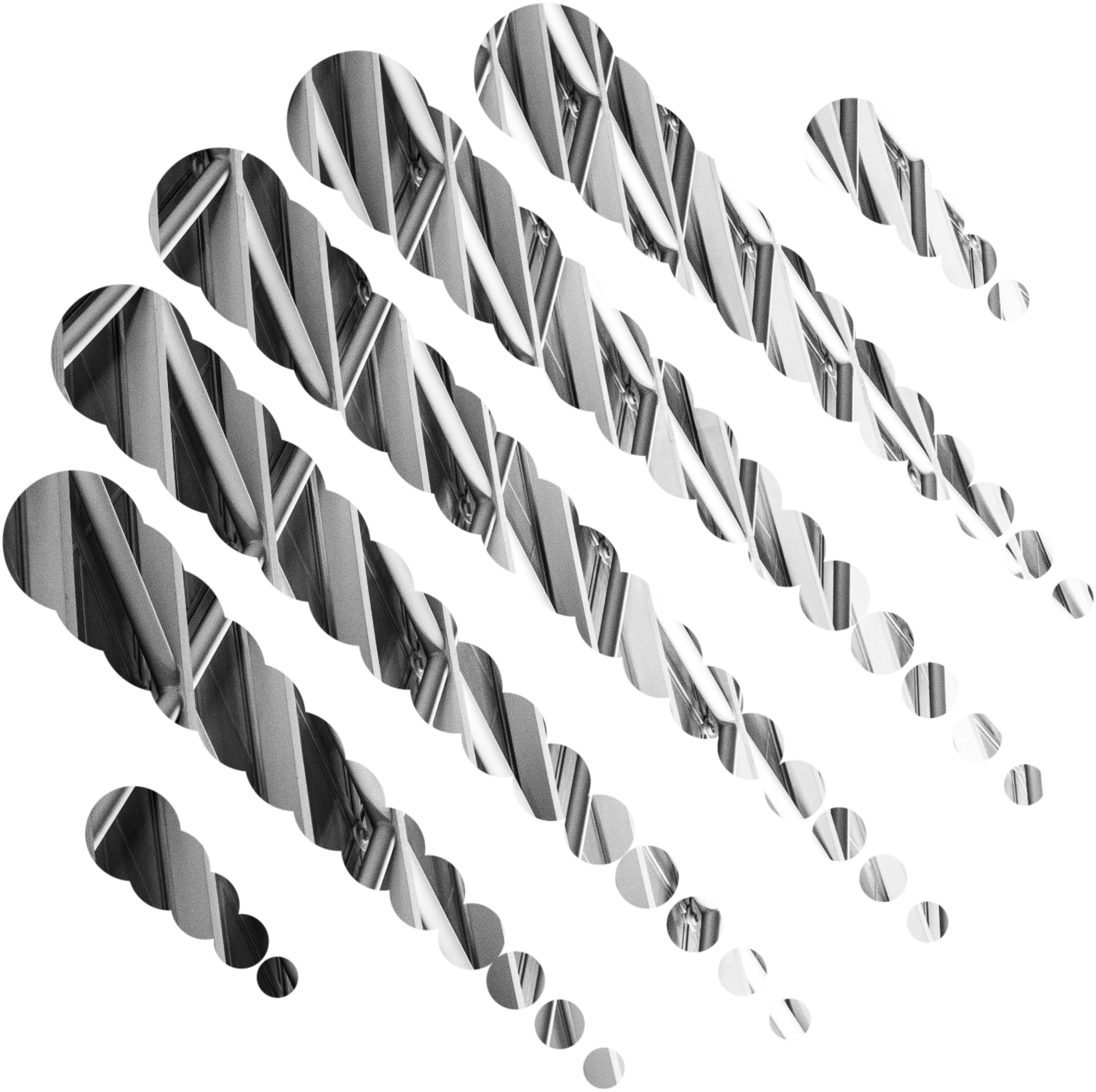
Carbon Performance assessment of steelmakers: note on methodology

October 2024



Simon Dietz, Ali Amin, Hayeon Cho and Antonina Scheer

Transition Pathway Initiative

LSE

Grantham Research Institute on Climate Change and the Environment

About the LSE Transition Pathway Initiative Centre

The Transition Pathway Initiative Centre (TPI Centre) is an independent, authoritative source of research and data on the progress of corporate and sovereign entities in transitioning to a low-carbon economy.

The TPI Centre is part of the Grantham Research Institute on Climate Change and the Environment, which is based at the London School of Economics and Political Science (LSE). It is the academic partner of the Transition Pathway Initiative (TPI), a global initiative led by asset owners and supported by asset managers, aimed at helping investors assess companies' preparedness for the transition to a low-carbon economy and supporting efforts to address climate change. As of October 2024, over 150 investors globally, representing over US$80 trillion combined Assets Under Management and Advice, have pledged support for TPI.[1]

The TPI Centre provides research and data on publicly listed equities, corporate bond issuers, banks, and sovereign bond issuers. The TPI Centre's company data:

- Assess the quality of companies' governance and management of their carbon emissions and of risks and opportunities related to the low-carbon transition.
- Evaluate whether companies' current and planned future emissions are aligned with international climate targets and national climate pledges, including those made as part of the Paris Agreement.
- Form the basis for the Climate Action 100+ Net Zero Company Benchmark Disclosure Framework assessments.
- Are published alongside the methods online and fully open access at www.transitionpathwayinitiative.org.

About the authors

Simon Dietz is the Research Director at the TPI Centre and a Professor of Environmental Policy in the Department of Geography and Environment at the London School of Economics and Political Science.

Ali Amin is a Research Project Manager at the TPI Centre.

Hayeon Cho is a Research Analyst at the TPI Centre.

Antonina Scheer is a Research Project Manager at the TPI Centre.

The views in this report are those of the authors and do not necessarily represent those of the host institutions or funders. The authors declare no conflict of interest in preparing this report. For the full disclaimer about the data and information published in this report, see page 31.

This paper was first published in October 2024 by the TPI Centre.

Suggested citation: Dietz S, Amin A, Cho H, Scheer A (2024) Carbon Performance assessment of steelmakers: note on methodology. London: Transition Pathway Initiative Centre, London School of Economics and Political Science.

[1] This figure is subject to market-price and foreign-exchange fluctuations and, as the sum of self-reported data by TPI supporters, may double-count some assets.

Contents

1. The TPI Centre's use of the Sectoral Decarbonisation Approach (SDA) 4
2. Applying the SDA to the steel sector 6
2.1. Deriving the benchmark pathways 6
2.2. Benchmark emissions reduction pathways 8
3. Carbon Performance assessment of steelmakers 15
3.1. Calculating company emissions intensities 15
3.2. Emissions reporting boundaries 15
3.3. Data sources and validation 16
3.4. Responding to companies 16
3.5. Presentation of assessment on the TPI Centre website 17
4. Specific considerations for the assessment of steelmakers 18
4.1. Measure of emissions intensity 18
4.2. Coverage of steelmaking facilities 18
4.3. Emissions from flaring and use of off-gases 19
4.3. Coverage of targets 20
4.4. Worked examples 20
5. Discussion 26
5.1. General issues 26
5.2. Issues specific to steelmakers 26
References 28
Appendix 1: Technology definitions 29
Disclaimer 32

1. The TPI Centre's use of the Sectoral Decarbonisation Approach (SDA)

The TPI Centre's Carbon Performance assessments to date have been predominantly based on the Sectoral Decarbonisation Approach (SDA).[2] The SDA translates greenhouse gas emissions targets made at the international level (e.g. under the 2015 UN Paris Agreement) into appropriate benchmarks, against which the performance of individual companies can be compared.

The SDA recognises that different sectors of the economy (e.g. oil and gas production, electricity generation and automobile manufacturing) face different challenges arising from the low-carbon transition, including where emissions are concentrated in the value chain and how costly it is to reduce emissions. Other approaches to translating international emissions targets into company benchmarks have applied the same decarbonisation pathway to all sectors, regardless of these differences [1]. Such approaches may result in suboptimal insights, as not all sectors have the same emissions profiles or face the same challenges: some sectors may be capable of faster decarbonisation, while others require more time and resources.

Therefore, the SDA takes a sector-by-sector approach, comparing companies within each sector against each other and against sector-specific benchmarks, which establish the performance of an average company that is aligned with international emissions targets.

The SDA can be applied by taking the following steps:

- A global carbon budget is established, which is consistent with international emissions targets, for example keeping global warming below 2°C. To do this rigorously, some input from a climate model is required.
- The global carbon budget is allocated across time and to different regions and industrial sectors. This typically requires an Integrated Assessment Model (IAM), and these models usually allocate emissions reductions by region and by sector according to where it is cheapest to reduce emissions and when. Cost-effectiveness is, however, subject to some constraints, such as political and societal preferences, and the availability of capital. This step is therefore driven primarily by economic and engineering considerations, but with some awareness of political and social factors.
- In order to compare companies of different sizes, sectoral emissions are normalised by a relevant measure of sectoral activity (e.g. physical production or economic activity). This results in a benchmark pathway for emissions intensity in each sector:

$$\text{Emissions intensity} = \frac{\text{Emissions}}{\text{Activity}}$$

- Assumptions about sectoral activity need to be consistent with the emissions modelled and therefore should be taken from the same economy–energy modelling where possible.

[2] The Sectoral Decarbonisation Approach (SDA) was created by CDP, World Resources Institute (WRI) and the World Wide Fund for Nature (WWF) in 2015. See: https://sciencebasedtargets.org/resources/files/Sectoral-Decarbonization-Approach-Report.pdf

- Companies’ recent and current emissions intensity is calculated, and their future emissions intensity is based on emissions targets they have set (this assumes companies meet their targets).[3] Together, these establish emissions intensity pathways for companies.
- Companies’ emissions intensity pathways are compared with each other and with the relevant sectoral benchmark pathway.

[3] Alternatively, companies’ future emissions intensity could be calculated based on other data provided by companies on their business strategy and capital expenditure plans.

2. Applying the SDA to the steel sector

2.1. Deriving the benchmark pathways

The TPI Centre evaluates companies against benchmark pathways, which translate the emission reductions required by the Paris Agreement goals into a measurable trajectory at the sectoral level. For each sector benchmark path, the key inputs are:

- A timeline for greenhouse gas emissions that is consistent with meeting a particular climate target (e.g. limiting global warming to 1.5°C) by keeping cumulative carbon emissions within the associated carbon budget.
- A breakdown of this economy-wide emissions pathway into emissions from key sectors (the numerator of sectoral emissions intensity), including the sector in focus.
- Consistent estimates of the timeline of physical production from, or economic activity in, these key sectors (the denominator of sectoral emissions intensity).

We previously assessed steel companies based on our Carbon Performance Methodology published in March 2022 [2]. The methodology derived three emissions intensity benchmarks (National Pledges, Below 2°C and 1.5°C) using inputs from the International Energy Agency (IEA), via its biennial Energy Technology Perspectives (ETP) reports, World Energy Outlook (WEO) reports, and its Net Zero by 2050 report [3–7].

However, there is a systematic difference between the emissions intensity of primary and secondary steelmaking, which investors may wish to take into account when evaluating steelmakers' approaches to the low-carbon transition. Specifically, because the emissions intensity of primary steelmaking is higher than secondary steelmaking, a combined benchmark that includes all steelmaking may be excessively strict when applied to a pure primary steelmaker and excessively lenient when applied to a pure primary steelmaker. This issue remains for steelmakers that make a mix of primary and secondary steel at a proportion that differs significantly from the global average, which is represented in the combined benchmarks.

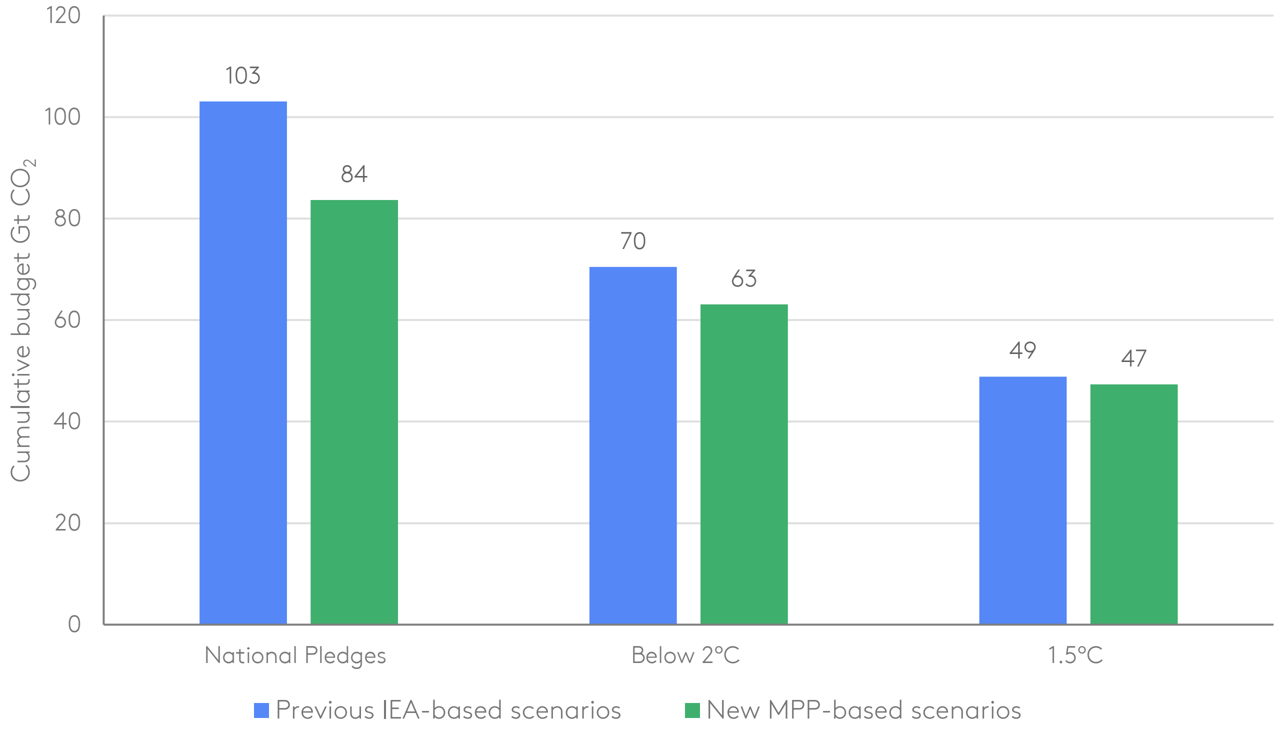
Therefore, under this new methodology, we provide supplementary 'split' emissions intensity benchmarks, which separately evaluate the alignment of primary and secondary steelmaking.

In order to derive the split benchmarks, detailed data on emissions and production by different technology types are needed. As these are not available from our primary data source (the IEA), we use the Mission Possible Partnership's (MPP) Steel Sector Transition Strategy Model (ST-STSM) as our new source of steel emissions and production data. The ST-STSM is an agent-based simulation model, in which production and emissions mitigation decisions are made at the level of individual steel plants. This model evaluates the potential technological, economic, and carbon impacts associated with the transition of over 700 steel plants across 12 geopolitical regions towards net zero production [8]. The MPP scenarios comparable to TPI's National Pledges, Below 2°C and 1.5°C benchmarks are Baseline, Tech Moratorium and Carbon Cost, respectively. The scenarios are considered to be consistent with TPI's benchmark categories because of consistency between the associated carbon budgets (see Figure 2.1).

Overall, as discussed in detail in our July 2023 discussion paper,4 the ST-STSM model roughly mirrors IEA's data on critical assumptions such as the share of secondary steel production. Most importantly, the cumulative carbon budgets of MPP's benchmark scenarios are approximately 11% lower than TPI's previous IEA-based benchmarks, making it consistent with – indeed slightly more ambitious than – the steel carbon budget in the IEA's economy-wide model.

[4] TPI Centre Carbon Performance assessment of steelmakers: Discussion Paper July 2023

Figure 2.1. Comparison of cumulative carbon emissions in the IEA and MPP scenarios.



The MPP's work is used to derive three emissions intensity benchmarks, consistent with the cumulative carbon budget of IEA scenarios, against which companies are evaluated:

1. A National Pledges scenario, which is consistent with the global aggregate of emissions reductions related to policies introduced or under development as of mid-2023. According to the IEA, this scenario does not take for granted that all government targets will be achieved. Instead, it takes a granular, sector-by-sector look at existing policies and measures. This scenario gives a probability of 50% of holding the global temperature increase to 2.4°C by 2100 [9].
2. A Below 2°C scenario, which is consistent with the overall aim of the Paris Agreement to limit warming, albeit at the lower end of the range of ambition. This scenario gives a probability of 50% of holding the global temperature increase to 1.7°C by 2100 [9].
3. A 1.5°C scenario, which is consistent with the overall aim of the Paris Agreement to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels" [10]. This scenario gives a probability of 50% of holding the global temperature increase to 1.4°C by 2100 [9].

2.2. Benchmark emissions reduction pathways

For each scenario, MPP's modelling output provides global Scope 1 and 2 emissions from the steel sector and associated estimates of production. Scope 1 emissions specifically cover: energy emissions from feedstock, fuel and energy consumption (excluding electricity), process emissions, and emissions from on-site electricity generation. Emissions are then divided by activity (tonnes of crude steel production) to derive sectoral pathways for emissions intensity.

Figure 2.2 shows the benchmark emissions intensity pathways for the steel sector, while Table 2.1 provides the underlying data on emissions and steel production. For example, under the National Pledges scenario in 2030, global Scope 1 and 2 emissions from the steel sector are projected to be 2,695 million metric tonnes of CO_2 (tCO_2). Under the same scenario in 2030, steel production is projected to be 2,175 million tonnes. Therefore, the average carbon intensity of a steelmaker aligned with the National Pledges benchmark is 2,695 / 2,175 = 1.24 tCO_2 per tonne of steel produced.

Please note the original emissions data from the MPP model have been adjusted as follows:

1. The emission intensity pathways for combined, primary, and secondary benchmarks are modified to exclude emissions from hot rolling. Since hot rolling is a post-processing step, this adjustment ensures the benchmarks reflect emissions from crude steel production, such as slabs, blooms, or billets. Although the change is minor, it better aligns with the boundaries used in many company disclosures, which report emissions per tonne of crude steel. Lifecycle assessment (LCA) studies are used to estimate the emissions from hot rolling compared to the direct crude steelmaking process [11-13]. As a result, the combined benchmarks are reduced by around 4%, with primary and secondary benchmarks adjusted by 3% and 14%, respectively. The larger adjustment for secondary pathways stems from the fact that secondary steel production generates lower overall emissions. Therefore, hot rolling accounts for a larger proportion of the total emissions in the secondary process, relative to primary steel production.
2. Since MPP do not model the decarbonisation of secondary steel production, secondary emissions intensity pathways are adjusted to reflect expected decarbonisation efforts in the steel sector (see section 2.2.1 for more detail).

Figure 2.2. Global emissions intensity benchmarks by warming scenario for the steel sector

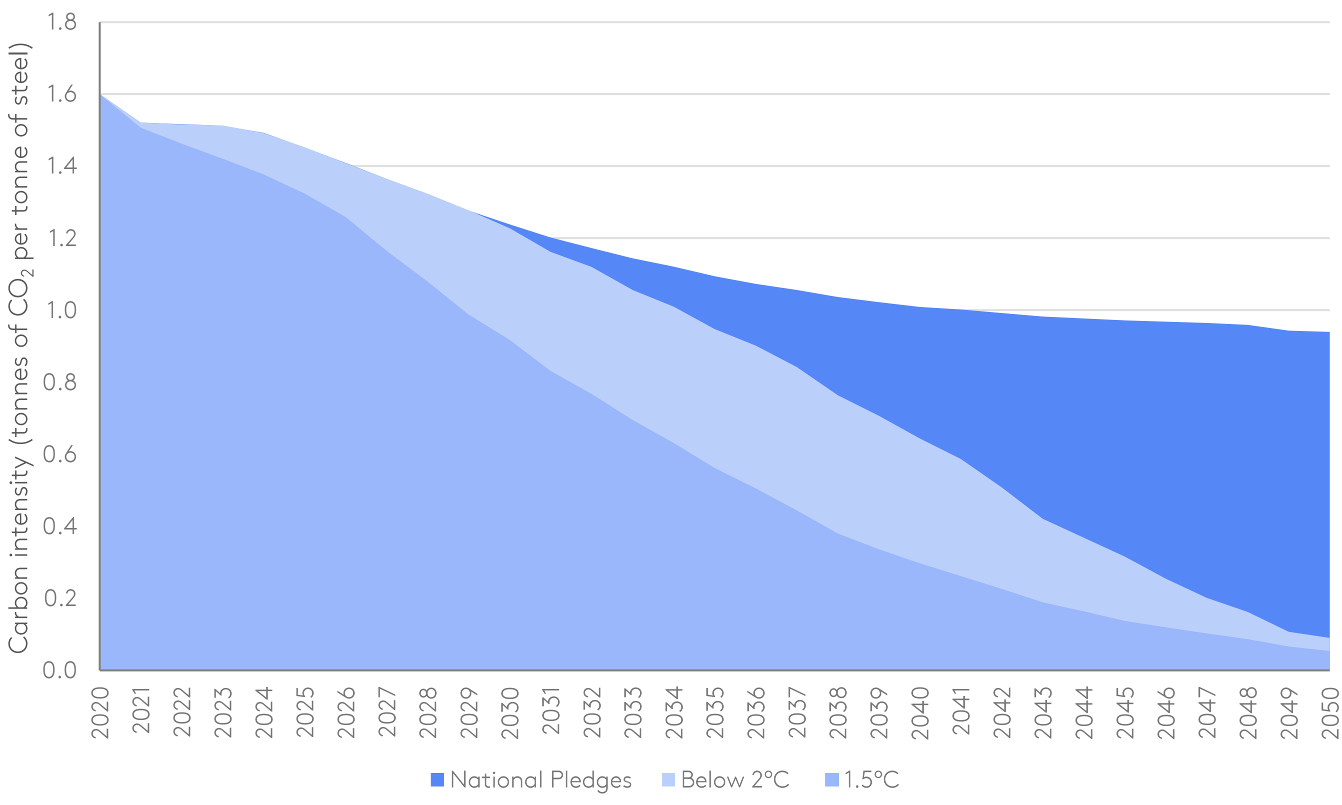


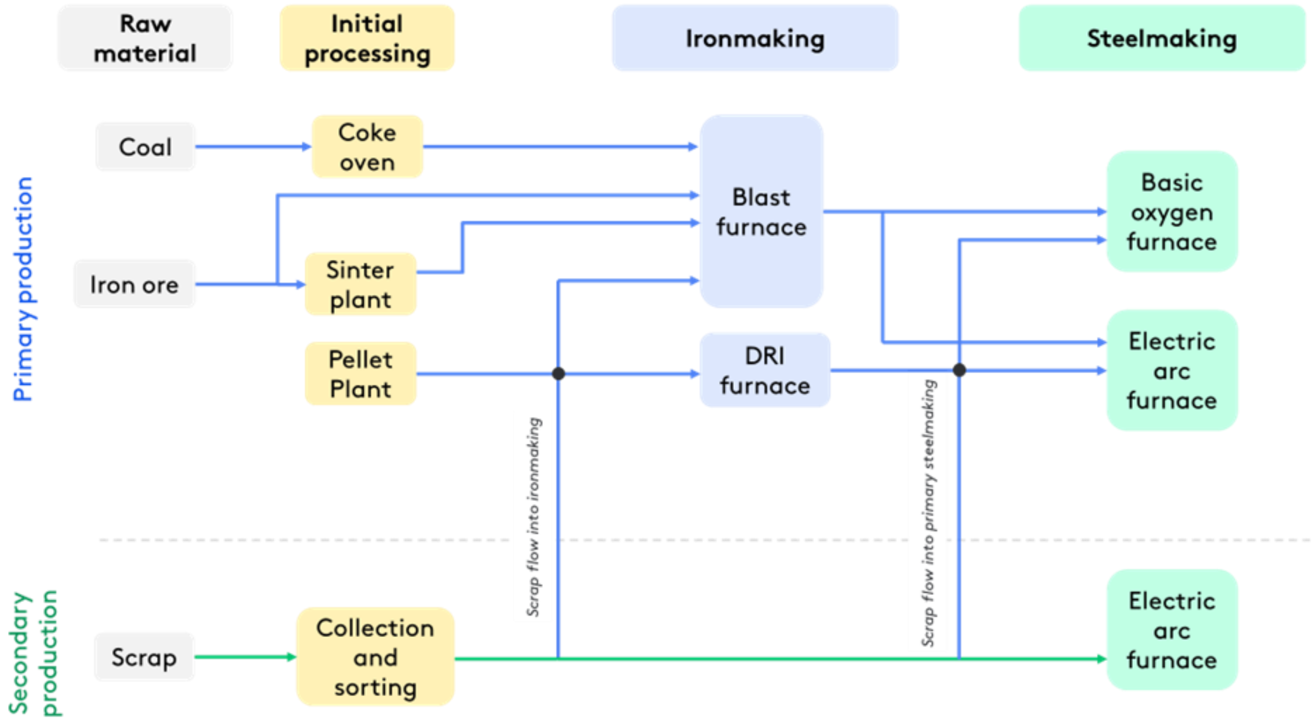
Table 2.1. Projections of emissions and crude steel production used to calculate emissions intensity benchmarks

	2020	2030	2040	2050
National Pledges scenario				
Scope 1 + 2 emissions (Mt)	3,001	2,695	2,306	2,395
Steel production (Mt)	1,875	2,175	2,285	2,547
Carbon intensity (tCO_2/t steel)	1.60	1.24	1.01	0.94
Below 2°C scenario				
Scope 1 + 2 emissions (Mt)	3131	2785	1559	306
Steel production (Mt)	1875	2007	1929	1998
Carbon intensity (tCO_2/t steel)	1.60	1.33	0.77	0.15
1.5°C scenario				
Scope 1 + 2 emissions (Mt)	3131	2083	749	252
Steel production (Mt)	1,875	2,022	1,964	2,065
Carbon intensity (tCO_2 / t steel)	1.60	0.99	0.37	0.12

2.2.1. Primary and secondary steel emissions intensity benchmarks

Steel is primarily produced via two technologies: Basic Oxygen Furnace (BOF) and Electric Arc Furnace (EAF). In 2021, crude steel production via these two routes accounted for 71% and 29% of global crude steel production, respectively [14]. Depending on the combination of technology type, processes and scrap share, steelmaking can be classified as primary or secondary (see Figure 2.3). Primary steel production involves using iron ore as the primary input, with scrap steel typically accounting for 15–25% of the metallic input. Given the presence of scrap as an input in primary production, steelmakers can increase their scrap share (up to a certain threshold) to decrease their primary steelmaking emissions, as scrap displaces the need for virgin iron ore and metallurgical coal, thereby reducing processing and smelting emissions. The blast furnace (BF) is a crucial piece of equipment used for primary steel production, with approximately 75% of global primary steel being produced using the BF-BOF combination route [14].

Figure 2.3. Simplified steel production via primary or secondary route and flow of materials.



In contrast, secondary steel is produced in EAFs, which use 100% scrap steel without any iron ore input. However, it should be noted that, not only can scrap be used in primary production, but iron ore can also be reduced using hydrogen and then processed in an EAF. Adopting this production route with green hydrogen is one way of decarbonising primary steel production. Thus, iron ore is not exclusively associated with blast furnaces, nor is the EAF exclusively associated with secondary production. As a result, establishing a boundary between primary and secondary steel production for split benchmarks and company assessments is challenging from both the modelling and disclosure perspectives.

A key challenge in creating separate benchmarks for primary and secondary steel production is obtaining the corresponding emissions and activity data. IEA, which was the previous data source for TPI Centre's steel methodology, did not provide separate emissions data for primary and secondary steelmaking. To address this data gap, MPP's ST-STSM mode was used, which evaluates 20 steelmaking technology archetypes, including those currently used or expected to become available for commercial deployment by 2050. We categorise technology and corresponding emissions and production data as primary or secondary steelmaking (see Figure 2.4). Only EAF utilising 100% scrap input is classified as secondary production and all other technologies are classified as primary production. Figures 2.5 and 2.6 present the technology-specific data on production and emissions, respectively, that are used to construct the primary and secondary emissions intensity benchmarks, illustrating the evolution of steelmaking technologies across different scenarios. Each scenario outlines which steel production technologies and processes are utilised in a given year to meet steel demand until 2050.

Figure 2.4. Categorisation of steelmaking technologies as primary or secondary[5]

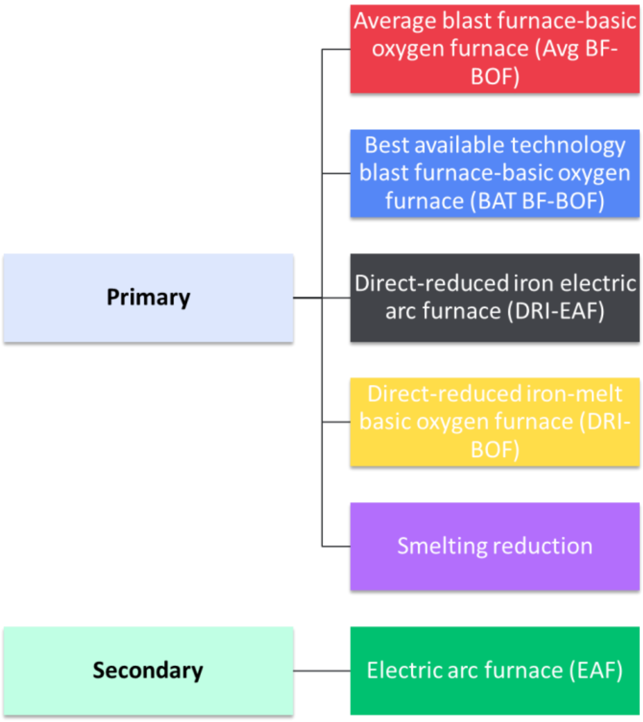
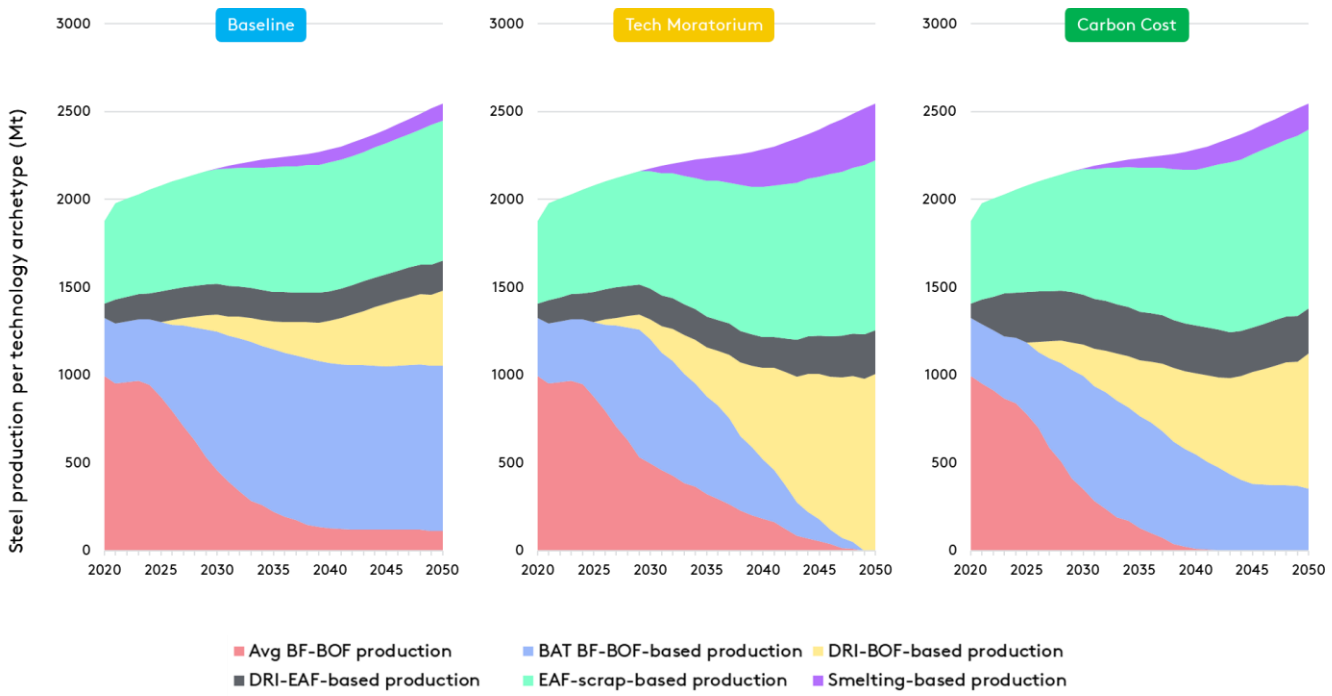
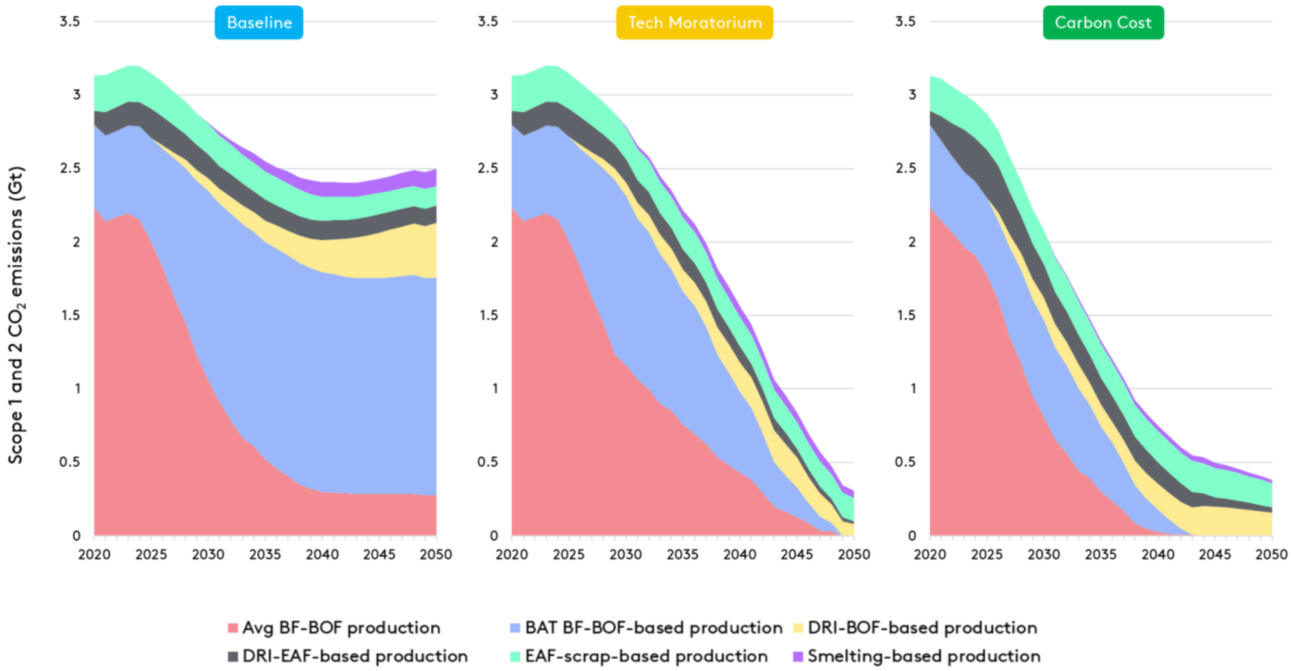


Figure 2.5. Projected steel production (2020 to 2050) by production route and MPP benchmark scenario



[5] See Appendix 1 for detailed technology definitions.

Figure 2.6. Projected steel Scope 1 and 2 emissions (2020 to 2050) by production route and MPP benchmark scenario



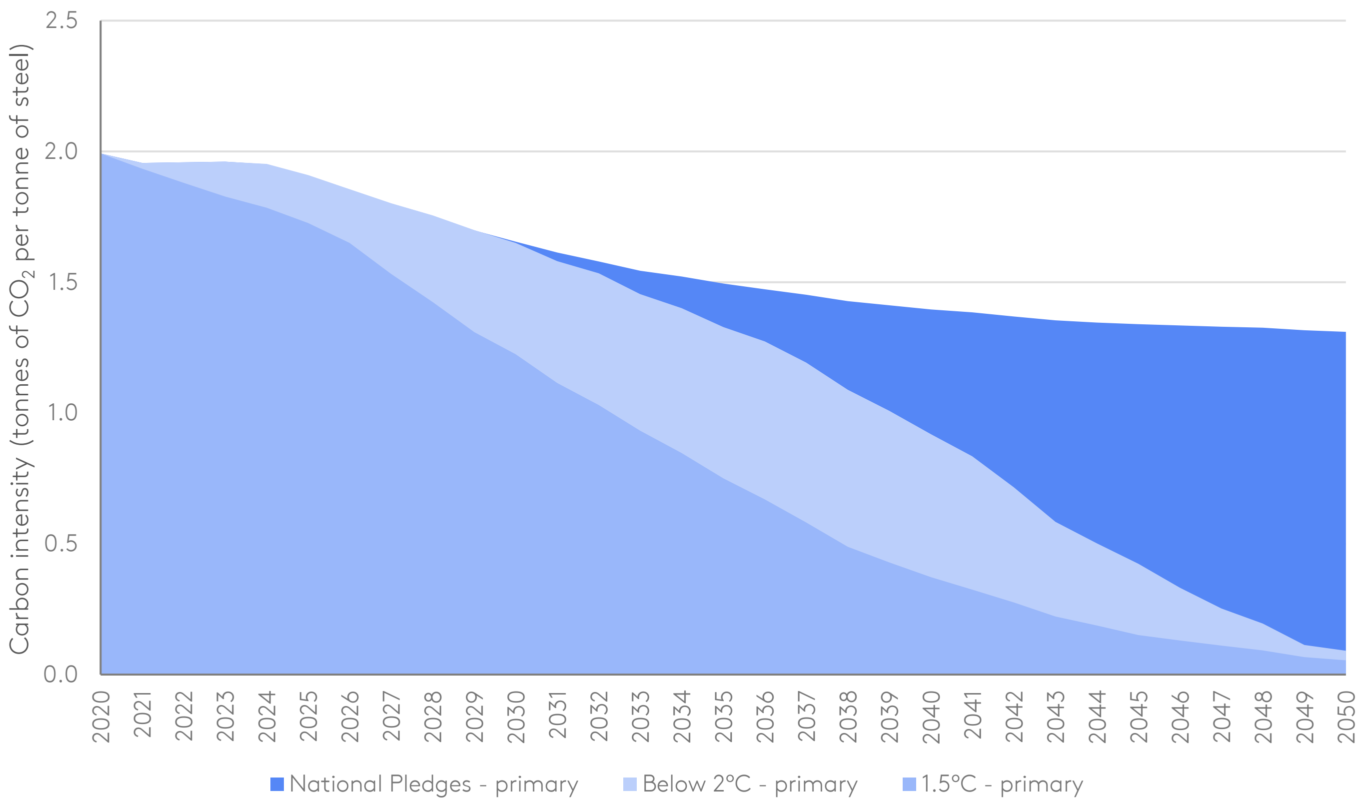
Based on Figure 2.5, secondary steel production using EAF-scrap-based production is expected to play a key role in all scenarios, but the dominant technologies for primary steelmaking vary amongst the scenarios. For instance, in MPP's Baseline scenario, the best available technology blast furnace-basic oxygen furnace (BAT BF-BOF) is expected to be the main method of steel production, whereas in Tech Moratorium and Carbon Cost, this changes to direct-reduced iron-melt basic oxygen furnace (DRI-BOF). This difference is reflected in the corresponding emissions profiles of the scenarios in Figure 2.6. Using the categorisation of the technology archetypes as primary or secondary (see Figure 2.4), the corresponding emissions and production data were used to construct the final split emissions intensity benchmarks (see Figure 2.7).

Secondary steel decarbonisation

In MPP's modelling of secondary steel production, the decarbonisation of direct emissions from the EAF process, which involves the use of natural gas to melt scrap steel, was not modelled, while indirect (Scope 2) emissions from power grid decarbonisation were considered. Due to the combination of primary production technologies with low-carbon solutions like carbon capture and the lack of EAF process decarbonisation in secondary steel production, the primary Below 2°C and 1.5°C scenarios eventually became slightly lower than the secondary benchmarks. To adjust for this, TPI converges the secondary pathways for Below 2°C and 1.5°C to corresponding primary pathways. The divergence in the secondary pathways begins only after 2030 when the sector is expected to decarbonise at a much greater rate due to the availability and deployment of technologies [15]. Although the impact of this adjustment on the overall secondary pathways is minimal, these adjustments better reflect the expected decarbonisation of secondary pathways for the more ambitious scenarios.

Figure 2.7. Emissions intensity benchmarks split by: (a) primary; and (b)secondary steelmaking

(a)



(b)

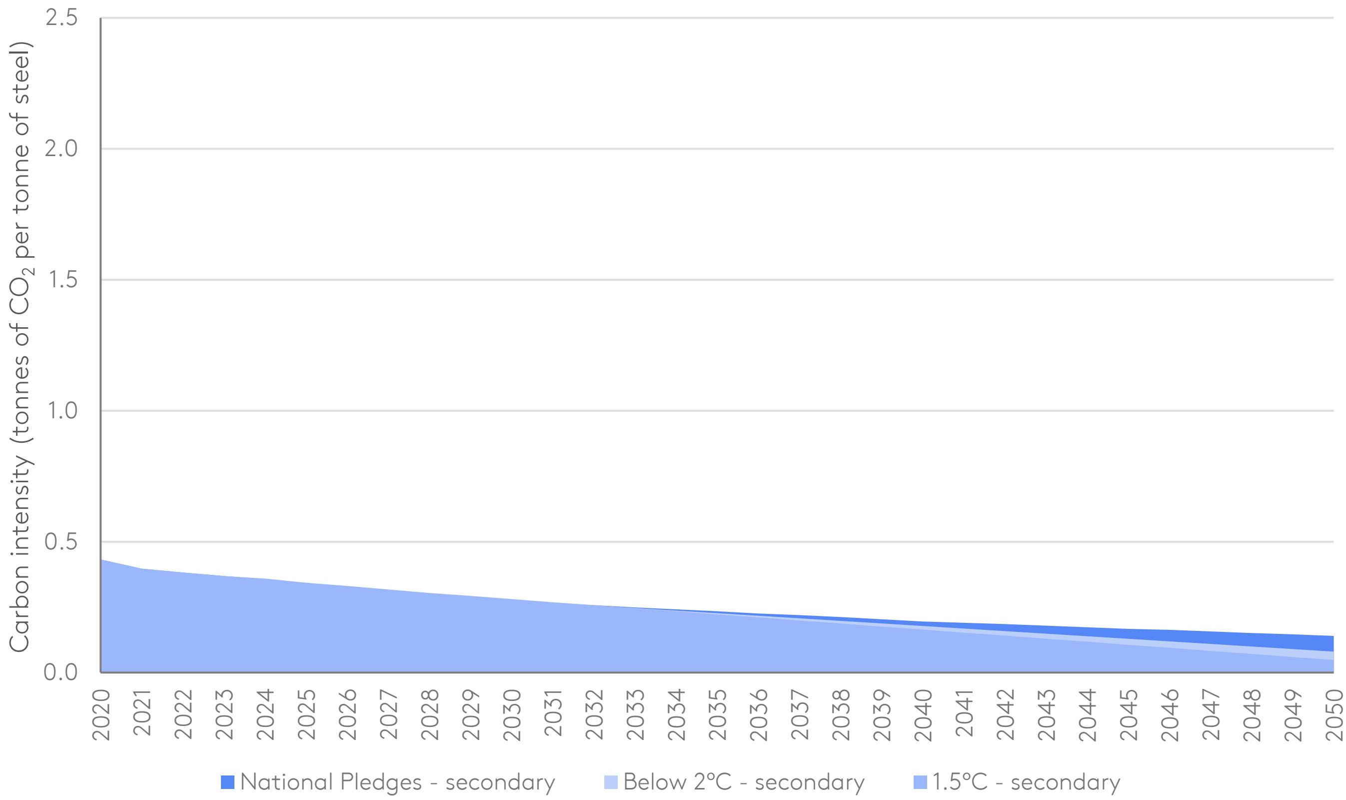


Table 2.2. Emissions intensity benchmark pathway by warming scenario (tCO_2e/t steel)

	2020	2030	2040	2050
Primary				
National Pledges	1.99	1.66	1.40	1.31
Below 2°C	1.99	1.65	0.92	0.09
1.5°C	1.99	1.22	0.37	0.05
Secondary				
National Pledges	0.43	0.28	0.20	0.14
Below 2°C	0.43	0.28	0.18	0.09
1.5°C	0.43	0.28	0.16	0.05

3. Carbon Performance assessment of steelmakers

3.1. Calculating company emissions intensities

TPI Centre's Carbon Performance assessments are based on public disclosures by companies. Disclosure that is useful to our assessments tends to come in one of three forms:

1. Emissions intensity. Some companies disclose their emissions intensity and some companies have also set future emissions targets in intensity terms. Provided these are measured in a way that can be compared with the benchmark scenarios and with other companies (e.g. in terms of scope of emissions covered and measure of activity chosen), these disclosures can be used directly. In some cases, adjustments need to be made to obtain estimates of emissions intensity on a consistent basis. The necessary adjustments will generally involve sector-specific issues.
2. Absolute emissions. Some companies disclose their emissions on an absolute (i.e. un-normalised) basis. Provided emissions are appropriately measured, and an accompanying disclosure of the company's activity can be found that is also in the appropriate metric, historical emissions intensities can be calculated.
3. Absolute emission targets. Some companies set future emissions targets in terms of absolute emissions. This raises the particular question of what to assume about those companies' future activity levels. The approach taken by the TPI Centre is to assume company activity increases at the same rate as the sector as a whole (i.e. assuming a constant market share), using sectoral growth rates from the same model that is used to derive the benchmark pathways, in order to be consistent. While companies' market shares are unlikely to remain constant, there is no obvious alternative assumption that can be made, that treats all companies consistently. Sectoral growth rates from the National Pledges Scenario (based on MPP's Baseline Scenario) are used.

The length of companies' emissions intensity pathways will vary depending on how much information companies provide on their historical emissions, as well as the time horizon for their emission reduction targets.

3.2. Emissions reporting boundaries

Companies disclose emissions using different organisational boundaries. There are two high-level approaches: (i) the equity share approach; and (ii) the control approach, within which control can be defined as financial or operational. Companies are free to choose which organisational boundary to set in their voluntary disclosures, and there is variation across the companies assessed by the TPI Centre.

The TPI Centre accepts emissions reported using any of the above approaches to setting organisational boundaries, as long as:

- The boundary that has been set appears to enable a representative assessment of the company's emissions intensity; and
- The same boundary is used for reporting company emissions and activity, to obtain a consistent estimate of emissions intensity.

Currently, limiting the assessment to one particular type of organisational boundary would severely restrict the breadth of companies that can be assessed.

When companies report historical emissions or emissions intensities using both equity share and control approaches, a reporting boundary is chosen based on which method provides the longest available time series of disclosures or is the most consistent with disclosure on activity and any targets.

3.3. Data sources and validation

All TPI Centre's data are based on companies' own disclosures. The sources for the Carbon Performance assessment include responses to the annual CDP questionnaire and companies' own reports, e.g. sustainability reports.

Given that our Carbon Performance assessment is both comparative and quantitative, it is essential to understand exactly what the data in company disclosures refer to. Company reporting varies not only in terms of what is reported but also in terms of the level of detail and explanation provided. The following cases can be distinguished:

- Companies that provide data in a suitable form and with enough detail for analysts to be confident that appropriate measures can be calculated or used.
- Companies that provide enough detail in their disclosures, but not in a form that is suitable for the assessment (e.g. they do not report the measure of company activity needed). These companies cannot be included in the assessment.
- Companies that do not provide enough detail on the data disclosed (e.g. the company reports an emissions intensity estimate but does not explain precisely what it refers to). These companies are also excluded from the assessment.
- Companies that do not disclose their greenhouse gas emissions or activity.

Once a preliminary Carbon Performance assessment has been made, it is subject to the following procedure to provide quality assurance:

- Internal review: the preliminary assessment is reviewed by an analyst who was not involved in the original assessment.
- Company review: the reviewed assessment is sent to the company, which has the opportunity to review it and confirm the accuracy of the disclosures used. This review includes all companies, including those who provide unsuitable or insufficiently detailed disclosures.
- Final assessment: feedback from the company is reviewed and incorporated if it is considered appropriate. Only information in the public domain can be accepted as a basis for any change.

3.4. Responding to companies

Giving companies the opportunity to review their Carbon Performance assessments is an integral part of the TPI Centre's quality assurance process. Each company receives its draft assessment and the data that underpins the assessment, offering them the opportunity to review and comment on the data and assessment. We also allow companies to contact us at any point to discuss their assessment.

If a company seeks to challenge its result or representation, our process is as follows:

- The TPI Centre reviews the information provided by the company. At this point, additional information may be requested.
- If it is concluded that the company's challenge has merit, the assessment is updated.
- If it is concluded that there are insufficient grounds to change the assessment, the original assessment is published.
- If the company requests an explanation regarding its feedback after the publication of its assessment, the TPI Centre explains the decisions taken.
- If a company requests an update of its assessment based on data publicly disclosed after the research cut-off date communicated to the company, the new disclosure is noted. For corrections,

we take this into consideration immediately, whereas general assessment updates will be incorporated in the next assessment cycle.

If a company chooses to further contest the assessment and reverts to legal means to do so, the company's assessment is withheld from the TPI Centre website and the company is identified as having challenged its assessment.

3.5. Presentation of assessment on the TPI Centre website

The results of the Carbon Performance assessments are posted on the TPI Centre's online tool (www.transitionpathwayinitiative.org/tpi/sectors). On each company page, its emissions intensity pathway is plotted on the same chart as the benchmark pathways for the relevant sector. Different companies can also be compared on the toolkit main page, with the user free to choose which companies to include in the comparison.

4. Specific considerations for the assessment of steelmakers

4.1. Measure of emissions intensity

In applying the SDA to the steel sector, a significant portion of lifecycle emissions stems from the production processes themself. Therefore, company assessment should account for both direct and indirect operational emissions (Scope 1 and 2). Unlike some other sectors assessed by the TPI Centre, such as cement, Scope 2 emissions from purchases of power are sufficiently important in the steel sector.

Hence, in the steel sector, the specific measure of emissions intensity used is:

- Scope 1 and 2 greenhouse gas emissions from steelmaking, per unit of crude steel produced, in units of (metric) tonnes of CO_2 equivalent per tonne of crude steel.

The objective is to measure emissions specifically from steelmaking, excluding emissions from any other activities to avoid overestimating a company's emissions intensity. However, some steel companies report their emissions as being operations-wide, rather than steelmaking-specific. In such cases, further assessment is needed to determine whether the company has included significant sources of emissions other than steel production, or if the operations-wide emissions are equivalent to, or approximately aligned with, those from steelmaking alone.

There is also variation between companies in terms of how steel production is quantified. It is common to disclose production of crude steel. However, some companies report production in a metric that may or may not be equivalent to crude steel. Examples of terminology in use include 'liquid steel', 'steel products', or simply 'product', or 'steel'. Under these circumstances, further assessment is also required of whether the production measure can be equated to crude steel, at least approximately.

Emissions from steelmaking of greenhouse gases other than CO_2 are negligible, so emissions measured in tonnes of CO_2 (tCO_2) and tonnes of CO_2 equivalent tCO_2e) are approximately equal.

4.2. Coverage of steelmaking facilities

While some steelmakers disclose emissions from all their facilities, others explicitly do not, or it is unclear from their disclosures. When it is explicitly incomplete or unclear, further assessment is required of whether coverage is incomplete, to what extent it is incomplete and whether the omission of some facilities is likely to bias the estimate of a company's emissions intensity. Ultimately, TPI makes a judgement on whether its estimate of a company's emissions intensity is likely to be biased, and sufficiently so for the company to be excluded from the assessment, in line with the principles set out in Section 3.2 above.

4.3. Emissions from flaring and use of off-gases

In steel production, off-gases are generated at various stages of steelmaking using blast furnace technology. Three main off-gases are generated in the following ways [16]:

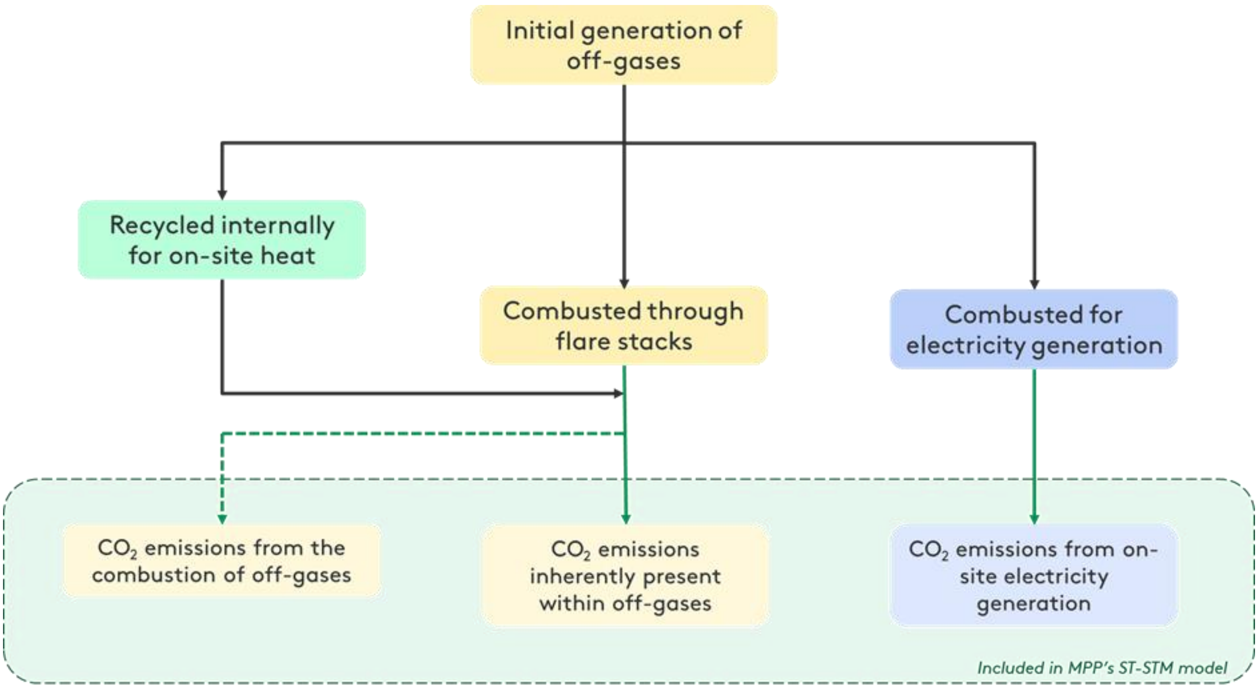
1. Coke Oven Gas (COG) is produced in the production of coke from metallurgical coal in coke ovens.
2. Blast Furnace Gas (BFG) is produced in the blast furnace where coke is heated with iron at high temperatures.
3. Basic Oxygen Furnace Gas (BOFG) is produced in the oxygen furnace where molten iron is introduced from the blast furnace.

Typically, the life cycle of these off-gases in the steelmaking process is comprised of three end-of-life fates [17]:

1. Consumption: used in various milling processes such as coking, sintering and blast furnace processing primarily for heat production.
2. Electricity generation: if the quality of surplus gas is sufficient, it is combusted to produce electricity.
3. Combustion: off-gases which aren't consumed or used for electricity generation are burned (flared) with resulting emissions.

Based on our analysis of steel company disclosures, many steel companies utilise steel off-gases for electricity generation. Around 60% of off-gases are used to fulfil on-site heat requirements, the emissions from which fall under companies' Scope 1 emissions disclosure and are included in the MPP emissions benchmarks. The remaining portion (40%) is used to produce power for the steel sector [18]. According to MPP, the ST-STSM model includes CO_2 emissions from on-site electricity generation as part of the projected Scope 1 steel sector emissions [8]. However, as mentioned above some off-gases are burned directly without being consumed internally or used for electricity generation – this is not captured by the aforementioned figures. We assume the CO_2 emissions resulting from the combustion of off-gases in flare stacks are included as part of the ST-STSM model's Scope 1 direct process emissions (see Figure 4.1 for an illustration on the type of CO_2 emissions accounted for in the model). TPI makes this assumption due to MPP's steel system boundaries for emissions coinciding with the World Steel Association approach, which includes estimates of the emissions from flared off-gases [19].

Figure 4.1. Emissions intensity benchmarks split by primary and secondary steelmaking



4.3. Coverage of targets

There are often differences in the scope of companies' emissions targets. In the steel sector, some companies have set specific targets for Scope 1 and 2 emissions combined, while others have set targets covering Scope 1, 2 and 3 emissions. Where a target covers more than just Scope 1 and 2 emissions from steelmaking, it is assumed – in the absence of any other specific information – that the percentage reduction in emissions is uniform across scopes, so the target percentage (e.g. a 20% cut) can be directly applied to Scope 1 and 2 emissions from steelmaking.

Some companies set targets that only apply to a subset of emissions in scope, e.g. 90% of Scope 1 and 2 emissions from steelmaking. Relevant emissions that are not covered by the target are assumed to be unchanged from the base year to the target year.

Companies often express targets relative to emissions in a base year (e.g. 2018), but they do not always report Scope 1 and 2 emissions from steelmaking in the base year, rather they sometimes report base-year emissions in a different scope (e.g. they include upstream Scope 3 emissions in 2018). If a company does not report Scope 1 and 2 emissions from steelmaking in the base year, these are estimated using the ratio of Scope 1 and 2 emissions from steelmaking to emissions in the company's chosen scope over the last three years (cumulatively).

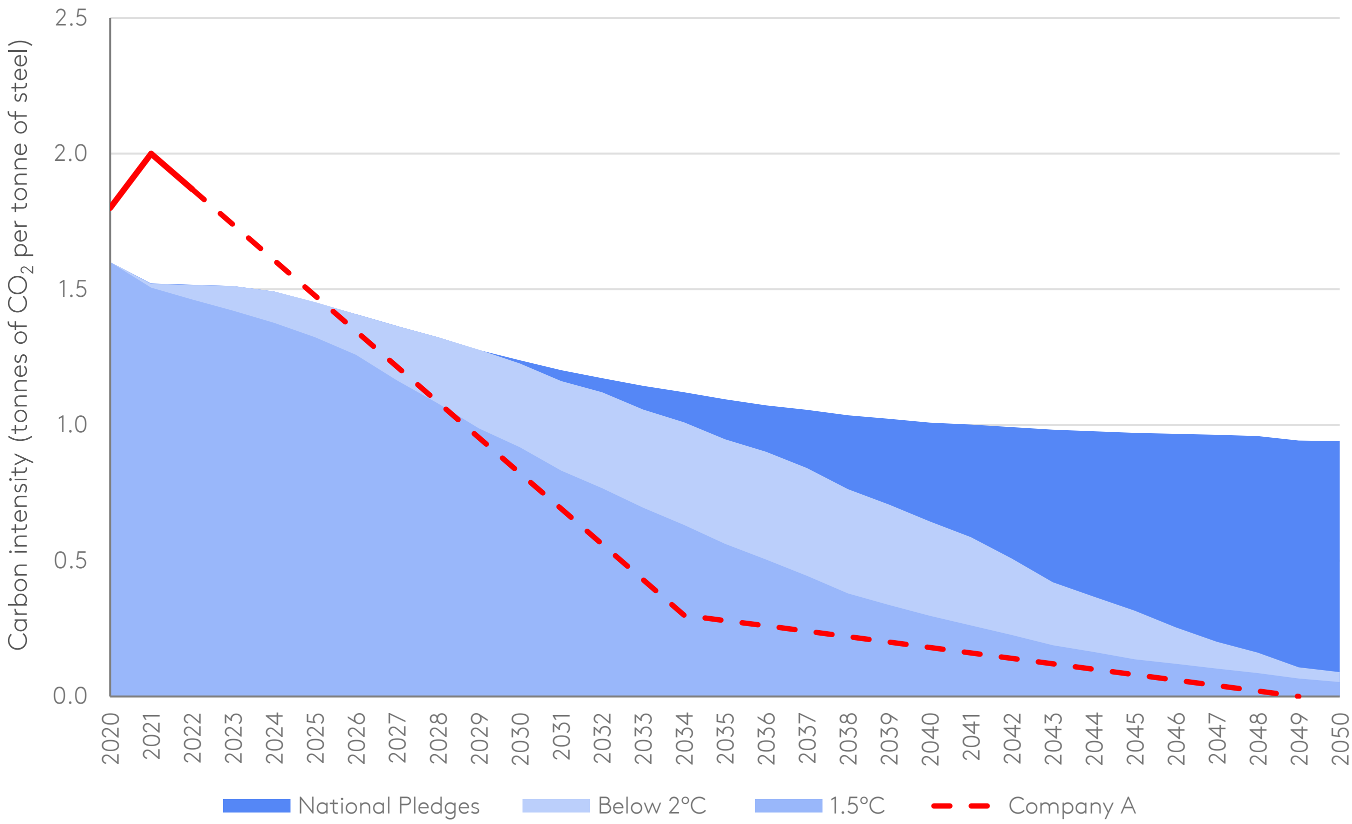
4.4. Worked examples

Company A: a straightforward calculation

Company A reports its emissions intensity in the required metric, i.e. Scope 1 and 2 emissions from steelmaking per tonne of crude steel. For example, in 2021 the company reported an emission intensity value of 2.0 tCO_2e/tonne of crude steel produced. These figures are used directly without adjustment.

Company A has also set a target to reduce its emissions intensity to 0.3 tCO_2e/tonne of crude steel by 2035 and achieve net zero by 2050. After verifying that the target emissions intensities are expressed in a manner consistent with the historical emissions intensity disclosures, the target figures are used without adjustment (see Figure 4.2).

Figure 4.2. Company A's emissions-intensity pathway compared to steel sector benchmarks



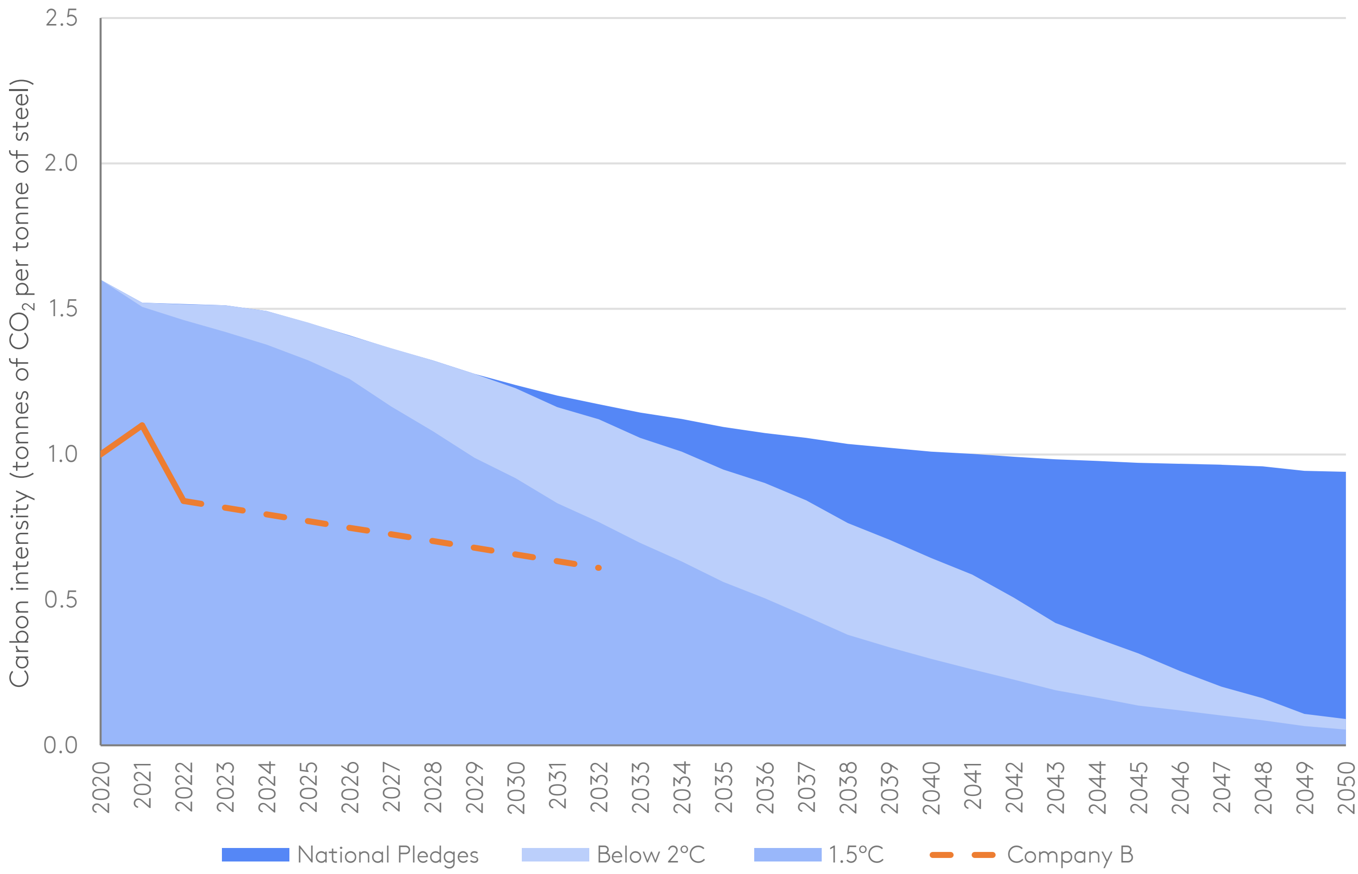
Company B: an absolute emissions reduction target

Company B reports an operations-wide emissions intensity of steel production per tonne of crude steel for 2020. In 2021, they report their intensity per tonne of 'production volume'. Further investigation indicates that there are no significant sources of company emissions other than steel production, so operations-wide emissions are taken to be equivalent to steelmaking-specific emissions. In 2022, the company's Scope 1 and 2 emissions intensity was 0.84 tCO_2e /tonne of crude steel.

Company B has a target to reduce the absolute quantity of its Scope 1 and 2 emissions by 7% below the 2013 level by 2030. This target can be shown to cover 83% of the company's total Scope 1 and 2 emissions in 2013. In order to translate this information into an estimate of emissions intensity in 2030, the following steps are taken:

- The company's target covers 83% of total Scope 1 and 2 emissions in 2013. The company reports that Scope 1 and 2 emissions covered by the target in the base year of 2013 were 13.2 $MtCO_2e$. This means that 2.7 $MtCO_2e$ of emissions were not covered by the target. We assume that those uncovered emissions remain constant between the base year and the target year.
- Total Scope 1 and 2 emissions in 2030, consistent with the target, can be estimated as 13.2 x (1 – 7%) + 2.7 = 15.0 $MtCO_2e$.
- As the company does not provide an intensity target, its steel production between 2022 and 2030 is assumed to grow at the same rate as global steel production according to the MPP Baseline scenarios. In particular, MPP projects that global crude steel production grows by 8.5% between 2022 and 2030. Therefore, the company's crude steel production in 2030 is its 2022 value, 22.5 Mt, multiplied by (1 + 8.5%) = 24.4 Mt crude steel.
- Dividing the company's estimated 2030 emissions by this estimate of steel production in 2030 gives an estimated intensity of 15.0 / 24.4 = 0.61 tCO_2e / tonne of crude steel in 2030 (see Figure 4.3).

Figure 4.3. Company B's emissions-intensity pathway compared to steel sector benchmarks



Company C, D and E: assessment against primary and secondary emissions intensity benchmarks

To illustrate the additional insights provided by the primary and secondary benchmarks, we have created three hypothetical example company emissions intensity pathways. The example companies represent the three main types of steelmakers: a company producing primary steel only (Company C), a company producing secondary steel only (Company D), and a company producing both primary and secondary steel (Company E). Table 4.1 provides a summary of these companies' alignment scores in 2027, 2035 and 2050 against the combined (Figure 4.4), primary (Figure 4.5), and secondary (Figure 4.6) benchmarks.

The principal Carbon Performance alignment scores for steelmakers will continue to be based on combined emissions intensity benchmarks, consistent with TPI centre's current approach of assessing companies at the entity level across all sectors. The assessment against primary and secondary benchmarks will be provided as a complementary analysis to deepen investors' understanding of a company's decarbonisation strategy. This approach enables several key insights:

- Additional insight is provided into the decarbonisation expectations on a primary steel producer. Relative to the combined benchmark, the primary benchmark gives primary steelmakers a higher threshold for alignment in the short (2027) and medium (2035) term. For example, Company C, a primary steelmaker, is 'not aligned' in 2035 when assessed against the combined benchmark but is aligned with the primary steel benchmark for Below 2°C in 2035.
- Additional insight is provided into the decarbonisation expectations on a secondary steel producer. For example, Company D, a secondary steelmaker, is 1.5°C aligned in the short and medium term when assessed against the combined benchmarks, but it is not aligned with any secondary steel benchmarks in those time frames.
- Additional insight is provided into the decarbonisation expectations on the primary and secondary steel business segments of the same company. For example, Company E's alignment scores are the same when assessed against the combined and primary benchmarks. However, secondary production is only 1.5°C -aligned in the long term (2050) and not aligned in the short (2027) and medium (2035) term.

Figure 4.4. Company C, D and E's emissions-intensity pathway compared to combined steel sector benchmarks

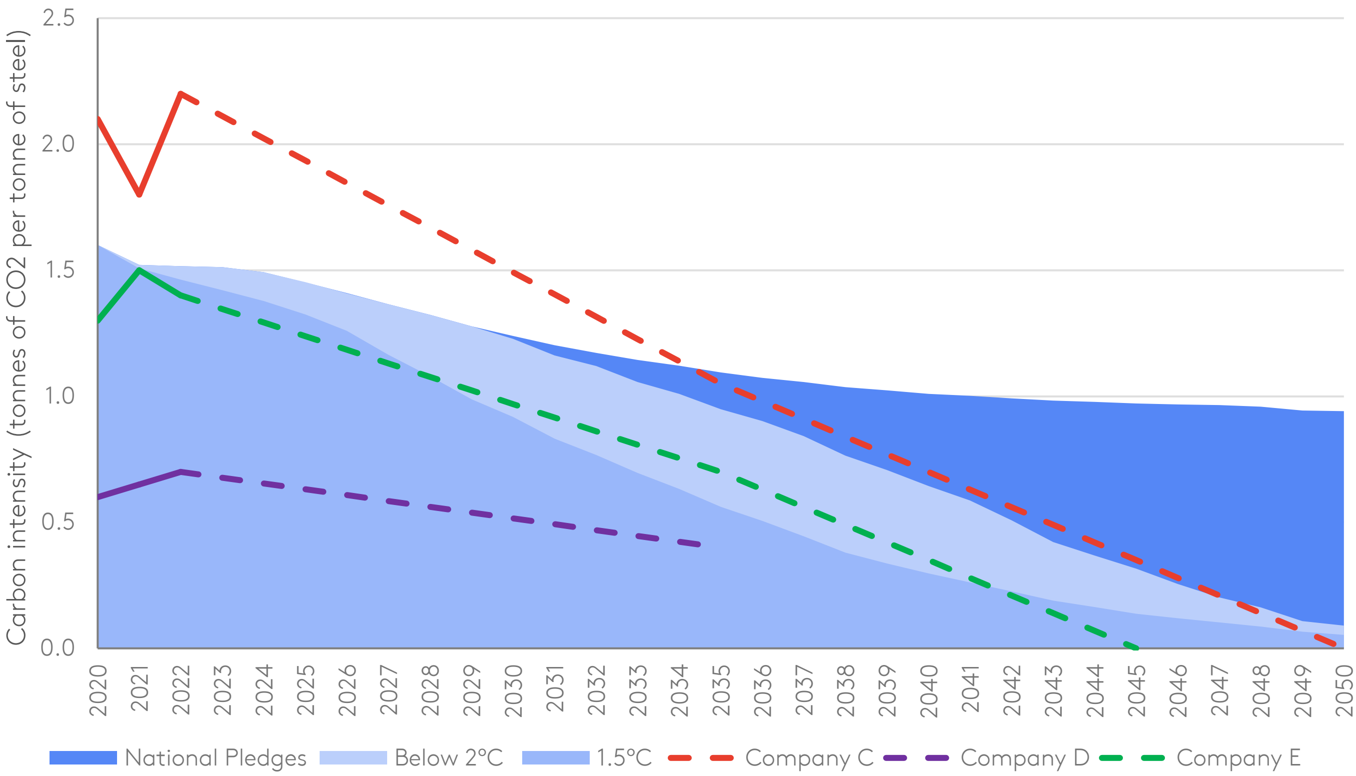


Figure 4.5. Company C and E's emissions-intensity pathway compared to primary steel sector benchmarks

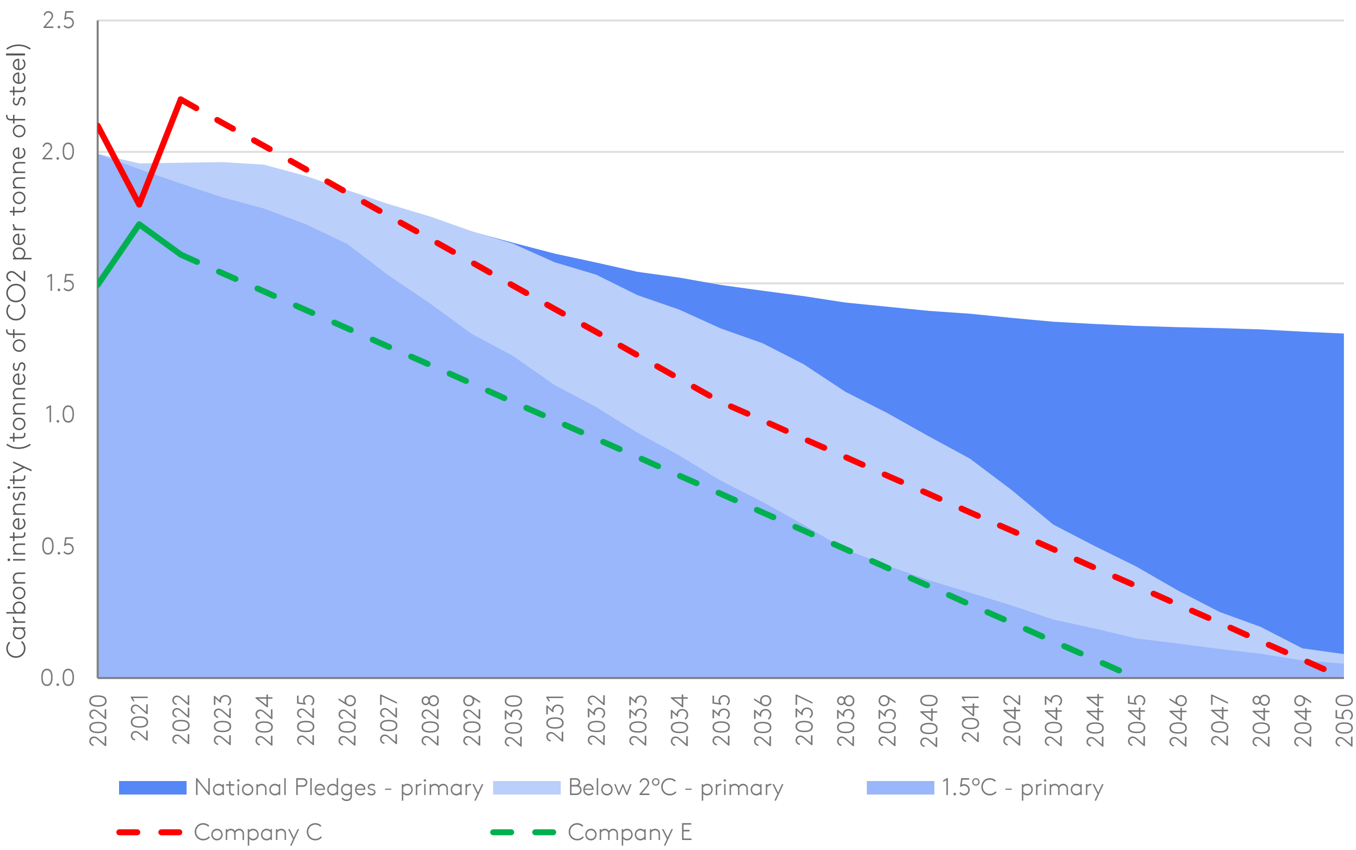


Figure 4.6. Company D and E's emissions intensity pathway compared to primary steel sector benchmarks

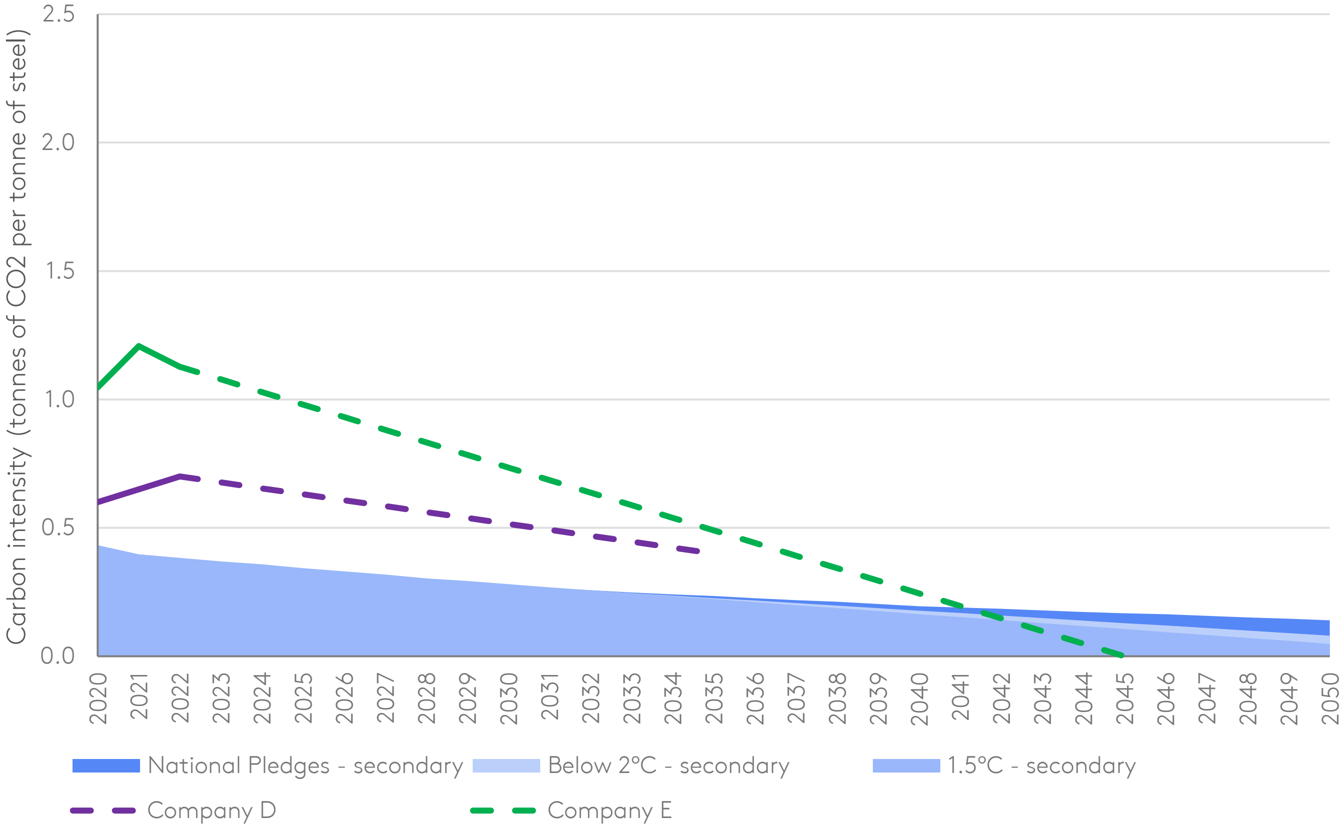


Table 4.1. Company alignment scores against combined, primary and secondary benchmarks

Benchmark	Alignment in 2027	Alignment in 2035	Alignment in 2050
Company C (primary producer only)			
Combined	Not Aligned	Not Aligned	1.5C
Primary	Below 2°C	Below 2°C	1.5C
Secondary	*Not assessed on secondary as the company produces primary steel only*		
Company D (secondary producer only)			
Combined	1.5°C	1.5°C	National Pledges
Primary	*Not assessed on primary as the company produces secondary steel only*		
Secondary	Not Aligned	Not Aligned	Not Aligned
Company E (primary and secondary producer)			
Combined	1.5°C	Below 2°C	1.5°C
Primary	1.5°C	1.5°C	1.5°C
Secondary	Not Aligned	Not Aligned	1.5°C

5. Discussion

This note has described the methodology followed by the TPI Centre in carrying out Carbon Performance assessments of steel companies. It also outlined a method used to separately assess steel companies on primary and secondary emissions intensity benchmarks. We will continue assessing steel companies on a combined emissions intensity benchmark when providing Carbon Performance alignment scores. However, where company disclosure allows, we will provide supplementary insights on the alignment of steel companies using separate primary and secondary emissions intensity benchmarks. This will enable investors and other stakeholders to better understand the different decarbonisation challenges facing each production route. As discussed in Section 4, the additional insights are particularly valuable when assessing steelmakers that exclusively produce either primary or secondary steel. The split benchmarks provide primary steelmakers with a higher threshold for alignment compared to the combined benchmarks, due to the removal of secondary steel emissions and production. Conversely, the split benchmarks enable a stricter assessment of secondary steelmakers who have a much lower emissions intensity starting point.

The Carbon Performance assessment is designed to be robust yet easy to understand and use. There are inevitably many nuances surrounding each company's individual performance, how it relates to the benchmarks, and why. Investors may wish to dig deeper into companies' assessments in their engagements with them to better understand these.

5.1. General issues

The methodology builds on the SDA, which compares a company's emissions intensity with sector-specific benchmarks that are consistent with international targets (i.e. limiting global warming to 1.5°C, well below 2°C, and the sum of National Pledges).

TPI Centre uses the modelling of the Mission Possible Project (MPP) to calculate the steel emissions intensity benchmarks. While such economy-energy models offer a number of advantages, they are also subject to limitations. In particular, model projections often turn out to be wrong. The comparison between companies and the benchmark pathways might then be inaccurate. Models tend to be regularly updated with the aim of improving their accuracy, and the TPI Centre updates its benchmark pathways accordingly. Nevertheless, in such a forward-looking exercise there is no way to avoid the uncertainty created by projecting into the future.

We use companies' self-reported emissions and activity data to derive emissions intensity pathways. Therefore, companies' pathways are only as accurate as the underlying disclosures.

Estimating the historical and especially the future emissions intensity of companies involves a number of assumptions. Therefore, it is important to bear in mind that, in some cases, the emissions pathway drawn for each company is an estimate made by the TPI Centre, based on information disclosed by companies, rather than the companies' own estimate or target. In other cases, the information disclosed by companies is sufficient on its own to completely characterise the emissions intensity pathway

5.2. Issues specific to steelmakers

The principal challenge in the steel sector, relative to other sectors whose carbon performance TPI Centre is assessing, is inconsistent reporting of emissions and steel production, particularly in terms of whether emissions disclosures are steelmaking-specific or operations-wide, whether production is measured in tonnes of crude steel, an equivalent measure or something different (which itself is not always clear), and whether disclosures cover all or merely a subset of a company's production facilities.

On the other hand, most of those companies with emissions targets have set them in intensity terms and with nearly or exactly 100% coverage of Scope 1 and 2 emissions from steelmaking, so relatively few assumptions are necessary in order to convert companies' stated emissions targets into intensity pathways.

The development of emissions intensity benchmarks for primary and secondary steelmaking acknowledges their distinct decarbonisation challenges. While increasing the share of scrap steel can lower carbon emissions, scrap steel alone cannot plausibly meet global steel demand. In addition to the approach proposed in this report, company-specific benchmarks could be designed based on a steelmaker's individual scrap share. This approach would offer a single alignment outcome, as opposed to the three alignment outcomes proposed in this methodology note. However, the use of company-specific benchmarks would require companies to disclose estimates of future scrap share, which may be considered commercially sensitive. Additionally, sector-wide benchmarks provide straightforward comparability across companies, mitigating any spurious claims for special treatment and reducing potential confusion among investors.

A challenge that this methodology raises is its reliance on additional disclosure from steelmakers that produce both primary and secondary steel. Specifically, for steelmakers to be assessed against the split primary and secondary benchmarks, they will need to disclose separate emissions and production data, as well as set emissions reduction targets that address primary and secondary production (the exception to this is that companies that exclusively produce either primary or secondary steel need not establish separate emissions data or production-based targets). The current landscape of steel company disclosures is limited and therefore limits our deployment of the split benchmarks approach.

References

[1] Randers J (2012) Greenhouse gas emissions per unit of value added ('GEVA'): a corporate guide to voluntary climate action. *Energy Policy* 48: 46–55 doi: 10.1016/j.enpol.2012.04.041

[2] TPI Centre (2022) Carbon performance assessment of steelmakers: note on methodology. London: Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science. www.transitionpathwayinitiative.org/publications/103.pdf?type=Publication

[3] International Energy Agency [IEA] (2021) *World Energy Outlook 2021*.

[4] IEA (2017) *Energy Technology Perspectives 2017*.

[5] IEA (2020) *Energy Technology Perspectives 2020*.

[6] IEA (2020) *World Energy Outlook 2020*.

[7] IEA (2021) *Net Zero by 2050*.

[8] Mission Impossible Partnership (2023) Model Overview - MPP Steel Model. Web Page. https://mpp.gitbook.io/mpp-steel-model/

[9] IEA (2023) *World Energy Outlook 2023*.

[10] United Nations Framework Convention on Climate Change [UNFCCC] (2015) *Paris Agreement*. https://unfccc.int/process-and-meetings/the-paris-agreement

[11] Zhao, Y., Zuo, H., She, X., Wang, G. and Wang, J. (2018). Key factors of CO2 emission analysis in iron and steel mill. https://doi.org/10.2991/iceesd-18.2018.313.

[12] Backes, J.G., Suer, J., Pauliks, N., Neugebauer, S. and Traverso, M. (2021). Life Cycle Assessment of an Integrated Steel Mill Using Primary Manufacturing Data: *Actual Environmental Profile*. *Sustainability, 13(6), p.3443*. https://doi.org/10.3390/su13063443.

[13] Maziar Ramezani Moziraji, Ghorban Ali Dezvareh, Majid Ehteshami, Mohammad Reza Sabour and Alireza Bazargan (2023). Life cycle assessment of gas-based EAF steel production: environmental impacts and strategies for footprint reduction. *The International Journal of Life Cycle Assessment, 28(12), pp.1605–1621*. https://doi.org/10.1007/s11367-023-02230-5.

[14] World Steel (2021) Fact sheet energy use in the steel industry. https://worldsteel.org/wp-content/uploads/Fact-sheet-energy-in-the-steel-industry-2021.pdf

[15] IEA (2023) *Steel and aluminium Net Zero Guide*. www.iea.org/reports/steel-and-aluminium

[16] Uribe-Sotto W, Porta J, Commenge J and Falk L (2017) A review of thermochemical processes and technologies to use steelworks off-gases. *Renewable and Sustainable Energy Reviews* 74: 809-823. https://doi.org/10.1016/j.rser.2017.03.008.

[17] Deng L and Adams T (2020) Comparison of steel manufacturing off-gas utilization methods via life cycle analysis. *Journal of Cleaner Production*. 277(123568). https://doi.org/10.1016/j.jclepro.2020.123568.

[18] IEA (2020) *Iron and Steel Technology Roadmap – Analysis*. www.iea.org/reports/iron-and-steel-technology-roadmap

[19] World Steel Association (2017) *Life cycle inventory methodology report - steel*. Brussels. https://worldsteel.org/wp-content/uploads/Life-cycle-inventory-methodology-report.pdf

Appendix 1: Technology definitions

Technology type	Technology description
Average blast furnace-basic oxygen furnace (Avg BF-BOF)	Classical vertically integrated steel production, from coke ovens till hot rolling of steel. Feed consisting of iron ore and coke (made on-site) is prepared via pelletising and sintering and then fed into a blast furnace, where it undergoes a set of reactions ending in stripping iron ore of oxygen, thus producing molten iron with relatively large carbon content, called Hot Metal. Energy-rich off-gases generated in the plant (Coke Oven Gas, Blast Furnace gas, and Basic Oxygen Furnace gas) are mixed together to form "Factory gas" which is then used to provide heat required for internal processes with surplus sent to integrated Combined Heat and Power plant to generate steam and electricity. Electricity is routed back to steel plant to supply the internal demand, surplus is sold to the grid, resulting in small revenue stream and carbon credit. Hot metal (HM) is refined in a basic oxygen furnace (BOF) using pure oxygen, which reacts with carbon and ore impurities, generating heat. Scrap steel is used as a coolant in the process and could also improve the economics of the process, depending on the market circumstances. Business case assumes a ~5.0% scrap ratio and 195 kg PCI/t HM (Pulverized Coal Injected per t of Hot Metal as coke replacement).
Best available technology blast furnace basic oxygen furnace (BAT BF-BOF)	Business case represents modernized BF-BOF route with several improvements to its operations, including increased PCI ratio (270 kg/t HM), scrap ratio (25%), and general heating efficiency gain (10%).
Best available technology blast furnace basic oxygen furnace (BAT BF-BOF) with CCU	BAT BF-BOF route in which PCI injection is fully replaced with high carbon biomass source (i.e., wood charcoal) and surplus off-gases are used to generate methanol to be used in chemicals industry rather than being burned in CHP plant. Carbon credit from use of biomass is given based on mass of biocarbon injected according to the formula: bio-PCI mass/t of steel * % biocarbon content * 44/12 (CO_2/C conversion factor). Emissions throughout the facility are calculated similar to BAT BF-BOF. Biomass is assumed to come from sustainable source (i.e. it is sustainably sourced wood, forest residue, or bio-organic fraction of municipal solid waste). One could argue that capturing, i.e., waste streams should come with additional carbon credit, hence we make assumption that credits and emissions from the biomass mix used in the facility cancel each other out and the upstream biomass emissions are net-zero. Surplus off-gases and CO_2 resulting from burning off-gases for internal heat supply are routed to methanol synthesis. Supply of hydrogen coming from Coke Oven Gas and Blast Furnace gas is grossly inadequate to process all carbon-bearing molecules (mainly CO and CO_2), therefore large amount of green hydrogen (~175 kgH_2/t casted steel) has to be supplied in order to trap all carbon atoms in methanol. Biomass credit is assumed to be allocated in full to steel industry, implying that methanol is later used to create products allowing for long-term storage of carbon, i.e., plastics. It is important to note that - as of now - there is no bio-based replacement for coke in Blast Furnace. Apart from providing reductants for reaction with iron ore, coke provides mechanical support which bio-based solutions like wood charcoal can't and thus would require significant changes to the furnace (esp. decrease in size) to replace both coke and PCI.
Best available technology blast furnace basic oxygen furnace (BAT BF-BOF) with CCUS	BAT BF-BOF route in which CO_2 emissions from all major parts of the process are captured using post-combustion amine-based CCS solution. Heating (3.6 GJ/tCO_2) required for regeneration of sorbent is assumed to be supplied with electricity. Internal consumption of power is high enough to warrant significant purchase of power from the grid (auto-generation is insufficient to cover the needs). Capture efficiency is assumed to be 90%, constant across analysed period In addition to CCS, business case assumes implementation of Top Gas Recycling, in which reductant-rich off-gas from Blast Furnace is recycled back to the furnace to utilize its leftover potential to reduce iron ore. We assume that recycling of 25% of the BF gas would allow 16% reduction in solid reductant input (both coke and PCI).
Best available technology blast furnace basic oxygen with part of carbon	BAT BF-BOF route in which PCI injection is fully replaced with highcarbon biomass source (i.e., wood charcoal). Top Gas Recycling is implemented and recycles 25% of BF gas, resulting in 16% reduction in required solid reductant input (spread equally across coke and PCI). Carbon credit from use of biomass is given based on mass of biocarbon

input replaced with biomass and with CCUS applied	injected according to the formula: bio-PCI mass/t of steel * % biocarbon content * 44/12 (CO_2/C conversion factor). Emissions throughout the facility are calculated similar to BAT BF-BOF. Biomass is assumed to come from sustainable source (i.e. it is sustainably sourced wood, forest residue, or bio-organic fraction of municipal solid waste). One could argue that capturing, i.e., waste streams should come with additional carbon credit, hence we make assumption that credits and emissions from the biomass mix used in the facility cancel each other out and the upstream biomass emissions are net-zero. CO_2 emissions from all major parts of the process are captured using post-combustion amine-based CCS solution. Heating (3.6 GJ/tCO_2) required for regeneration of sorbent is assumed to be supplied with electricity. Internal consumption of power is high enough to warrant significant purchase of power from the grid (auto-generation is insufficient to cover the needs). Capture efficiency is assumed to be 90%, constant across analysed period It is important to note that - as of now - there is no bio-based replacement for coke in Blast Furnace. Apart from providing reductants for reaction with iron ore, coke provides mechanical support which bio-based solutions like wood charcoal can't and thus would require significant changes to the furnace (esp. decrease in size) to replace both coke and PCI.
Best available technology blast furnace basic oxygen furnace (BAT BF-BOF) with biomass PCI	BAT BF-BOF route in which pre-treated biomass replaces PCI (Pulverized Coal Injection) in the blast furnace. Wood charcoal assumed as reference. Carbon credit from use of biomass is given based on mass of biocarbon injected according to the formula: bio-PCI mass/t of steel * % carbon content * 44/12 (CO_2/C conversion factor). It is important to note that - as of now - there is no bio-based replacement for coke in the Blast Furnace. Apart from providing reductants for reaction with iron ore, coke provides mechanical support which bio-based solutions like wood charcoal can't and thus require significant changes to the furnace (esp. decrease in size) to replace both coke and PCI.
Best available technology blast furnace basic oxygen furnace (BAT BF-BOF) with H_2 injection	BAT BF-BOF route in which part of injected coal is replaced with green hydrogen. It is assumed that hydrogen can replace only up to 120 kg coal/t HM (out of total 270 kg coal/t HM) due to endothermic nature of iron reduction with hydrogen, which may disturb the blast furnace temperature profile and render it inoperable.
Electric arc furnace (EAF)	Dominant steel recycling technology in which scrap steel is melted in an arc furnace using electric current with natural gas used to meet all other heat requirements (especially at hot rolling stage). Power consumption in EAF is assumed to be ~1.9 GJ electricity/t liquid steel with 100% scrap feed. EAF process decarbonisation was not modelled as part of this effort (aside from scope 2 emissions decrease due to power grid decarbonisation).
DRI-EAF	Steelmaking process replacing coal as carbon source with natural gas in shaft furnace rather than blast furnace. Modelling based on MIDREX® technology in which natural gas is first converted via Steam Methane Reforming process to mixture of carbon monoxide and hydrogen which is then fed into the shaft furnace as reductant. Assumed ~10 GJ/t DRI (shaft furnace consumption).
DRI-EAF with CCUS	CO_2 resulting from all main processes is captured using post-combustion amine-based CCS solution. Heating (3.6 GJ/tCO_2) required for regeneration of sorbent is assumed to be supplied with electricity.
DRI-EAF with 100% green H_2	DRI-EAF route in which natural gas is replaced with green hydrogen as reductant. Since the reaction of hydrogen with iron ore is endothermic, additional heating of the shaft furnace is required, along with preheating of hydrogen feed. All additional heating requirements are assumed to be met with electric heating. Hydrogen consumption is assumed to be 63 kg/t iron, which is ~17% higher than theoretical requirement for reduction of hematite (54 kgH_2/tFe) due to presence of impurities in ore, i.e., silica.
DRI-EAF with 50% green H_2	DRI-EAF route in which 50% of shaft furnace natural gas feed is replaced with green hydrogen. Since the reaction of hydrogen with iron ore is endothermic, additional heating of the shaft furnace is required, along with preheating of hydrogen feed. All additional heating requirements are assumed to be met with natural gas. Hydrogen is mixed only with shaft furnace feed, remaining processes (i.e., hot rolling) uses 100% natural gas for heating.
DRI-EAF with 50% biomethane	DRI-EAF route in which natural gas used across the plant is blended in equal proportions with biomethane.
DRI-Melt-BOF	Combination of DRI shaft furnace with Basic Oxygen Furnace. DRI is made using natural gas, similar to the DRI-EAF route, but then solid (still hot) sponge iron is fed into the melter where it is melted using natural 32 gas as source of heat. Liquid sponge iron is fed into BOF where it undergoes oxygen treatment similar to BF-BOF route.

DRI-Melt-BOF with 100% green H_2	DRI-BOF route in which natural gas in shaft furnace is replaced with hydrogen. Since the reaction of hydrogen with iron ore is endothermic, additional heating of the shaft furnace is required, along with preheating of hydrogen feed. All additional heating requirements are assumed to be met with electric heating. Hydrogen consumption is assumed to be 63 kg/t iron, which is ~17% higher than theoretical requirement for reduction of hematite (54 kgH2/tFe) due to presence of impurities in ore, i.e., silica. Since there is no carbon in the sponge iron coming from Hydrogen DRI process, there is less heat generated during oxygen treatment in BOF. In addition, heating in melter is assumed to be provided with electricity to avoid natural gas- related emissions.
DRI-Melt-BOF with CCUS	CO_2 resulting from all main processes is captured using post-combustion amine-based CCS solution. Heating (3.6 GJ/tCO_2) required for regeneration of sorbent is assumed to be supplied with electricity.
Smelting reduction	Type of process in which liquid hot metal is produced from iron ore without coke. Business case is based on HIsarna, a type of smelting reduction in which iron ore fines are injected at the top of Cyclone Converter Furnace along with pure oxygen, while coal powder is supplied at the bottom. The process reduces iron ore into liquid pig iron without coke production and iron ore agglomeration steps. Pig iron is fed into BOF where it undergoes oxygen treatment similar to BF-BOF route. Coal consumption is assumed to be 12.7 GJ/t pig iron, scrap ratio is assumed to be similar to BAT BF-BOF (25%). BOF gases are assumed to be utilised on-site for heat generation.
Smelting reduction with CCUS	Given high concentration of CO_2 in off-gases coming from CCF (>85%), CO_2 is assumed to be captured using cryogenic distillation using ~2.2 GJ electricity/tCO_2 with 90% capture efficiency

Source: Mission Possible Partnership (MPP) model specification

Disclaimer

1. Data and information published in this report and on the TPI Centre website is intended principally for investor use but, before any such use, you should read the TPI Centre's website terms and conditions to ensure you are complying with some basic requirements which are designed to safeguard the TPI Centre while allowing sensible and open use of the methodologies and of the TPI data processed by the TPI Centre. References in these terms and conditions to "data" or "information" on the website shall include the Carbon Performance data, the Management Quality indicators or scores, and all related information.
2. By accessing the data and information published in this report and on the website, you acknowledge that you understand and agree to the website terms and conditions. In particular, please read paragraphs 4 and 5 below which detail certain data use restrictions.
3. The processed data and information provided by the TPI Centre can be used by you in a variety of ways – such as to inform your investment research, your corporate engagement and proxy-voting, to analyse your portfolios and publish the outcomes to demonstrate to your stakeholders your delivery of climate policy objectives and to support the TPI Centre in its initiative. However, you must make your own decisions on how to use the TPI Centre's data as the TPI Centre cannot guarantee the accuracy of any data made available, the data and information on the website is not intended to constitute or form the basis of any advice (investment, professional or otherwise), and the TPI Centre does not accept any liability for any claim or loss arising from any use of, or reliance on, the data or information. Furthermore, the TPI Centre does not impose any obligations on supporting organisations to use TPI Centre data in any particular way. It is for individual organisations to determine the most appropriate ways in which the TPI Centre data can be helpful to their internal processes.
4. Subject to paragraph 3 above, the Management Quality and the Carbon Performance indicators that are part of the TPI online tool and available publicly on the TPI Centre's website are:
    - Free, if they are used for internal and not for commercial purposes, including for research, as one of the inputs to inform portfolio construction, for financial decision-making including cases of lending and underwriting, for engagement and client reporting, for use in proprietary models as part of climate transition analysis and active investment management.
    - Restricted, unless licensed where the use is for further commercial exploitation through redistribution, derived data creation, analytics, and index or fund creation (inclusive of where the index is used as the basis for the creation of a financial product, or where TPI data is a key constituent of a fund's construction).
    - For the terms of use of the sources supporting the TPI Centre's methodologies, please refer to the individual sectoral Carbon Performance methodology notes. To produce the TPI data, the Centre analysts may use CDP data as a secondary input for verification purposes, in addition to companies' published sources.
5. Notwithstanding any other provision of these website terms and conditions, none of the data or information on the website may be reproduced or made available by you to any other person except that you may reproduce an insubstantial amount of the data or information on the website for the uses permitted above.
6. The data and information on the website may not be used in any way other than as permitted above. If you would like to use any such data or information in a manner that is not permitted above, you will need the TPI Centre's written permission. In this regard, please email all inquiries to info@transitionpathwayinitiative.org.

LSE Transition Pathway Initiative Centre

Grantham Research Institute on Climate Change
and the Environment

London School of Economics and Political Science

Houghton Street

London WC2A 2AE, UK

T +44 (0)20 7107 5027

E tpi@lse.ac.uk

Transition Pathway Initiative

c/o UNPRI Association

5th Floor, 25 Camperdown Street

London E1 8DZ, UK

T +44 (0)20 3714 3141

E info@transitionpathwayinitiative.org

@tp_initiative

transitionpathwayinitiative.org

Transition Pathway Initiative

Grantham Research Institute on Climate Change and the Environment