Assessing the Credibility of Climate Transition Plans in the Steel Sector

Discussion Paper

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Executive summary

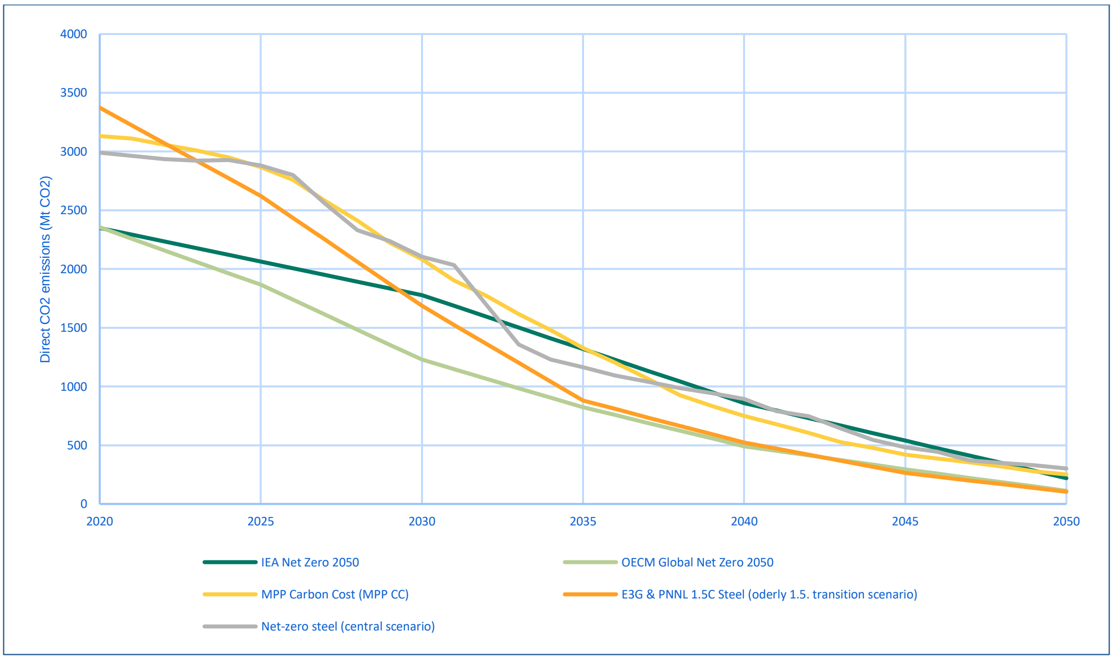
This paper contributes to current discussions about how to assess the credibility of steel companies' plans to reach net zero emissions by 2050. The focus of assessing steel companies' alignment with net zero benchmarks or the Paris Agreement has so far been mainly on evaluating the scientific credibility of voluntarily disclosed corporate-level CO_2 emission reduction targets. **What matters most from an alignment perspective in the steel sector today is how steel companies plan to reline[1] and operate existing, as well as invest in new steel production assets before 2030. Indeed, investment decisions and technology pathways will be the key determinant of a company delivering on its net zero targets.**

Emissions and technology pathways leading to net zero emissions

Figure ES 1 shows net zero scenarios for the steel sector. Though steel sector CO_2 emissions in all scenarios reach net zero by 2050 through immediate steep emissions reductions, the scenarios differ significantly with respect to the size of the global and sectoral carbon budgets as well as the reduction of direct (Scope 1) CO_2 emissions by 2030 (ranging from -24.3% in the net zero emissions to -50% in the E3G & PNNL 1.5°C Steel scenario). The scenarios also differ significantly in the extent to which steel production is shifted from primary to secondary production (based on the scrap-electric arc furnace [EAF] route), and which net zero technologies are utilized (and to what extent) to decarbonize steel production (Section 3.2). **However, there is a consensus on the need to exit production from unabated Blast Furnace-Basic Oxygen Furnace (BF-BOF) assets as soon as possible.**

[1] Relining involves removing and replacing the refractory lining inside furnaces, ladles, or other equipment used in the steelmaking process. The refractory lining serves as a protective layer between the molten metal and the steel structure, preventing damage and heat loss.

Figure ES 1. Selected net zero emission pathways for the steel sector



Sources: See Section 3.1.

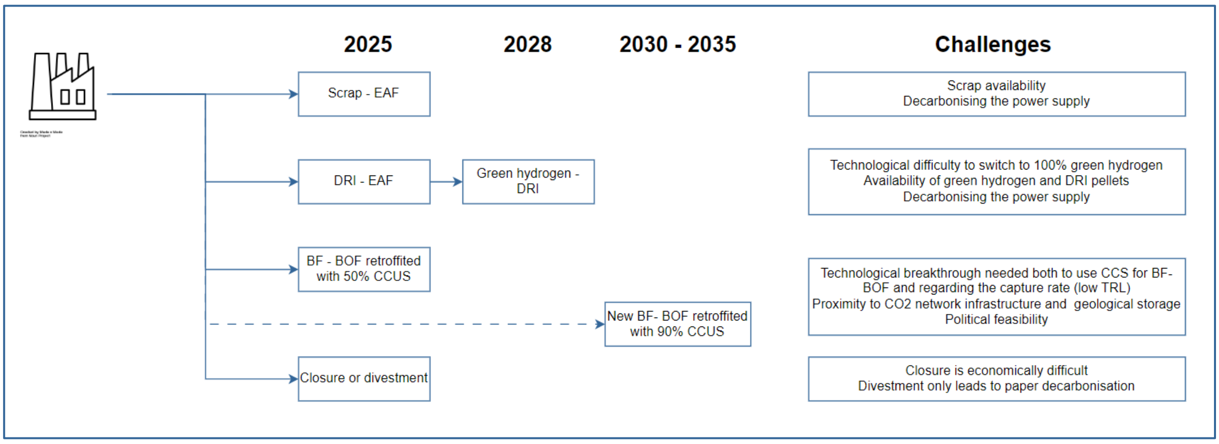
There are three main decarbonization levers that are widely recognized in the literature as being required for the steel sector to reduce Scope 1 and 2 CO_2 emissions and achieve net zero in Paris-aligned transition scenarios by 2050 (Bashmakov et al., 2022):[2]

1. **Leverage overall steel demand** reduction via increased material efficiency, circular material flows, and/or absolute demand reduction in final use, such as in building and manufacturing sectors.
2. **Increase secondary production of scrap-based steel** based on the scrap-EAF production route which enables “recycling” but requires decarbonizing the electricity input.
3. **Upgrade or replacement of existing blast furnace and blast oxygen furnace (BF-BOF) and Direct Reduced Iron (DRI)-EAF asset base** in primary steel production by increasing energy and material efficiencies as well as by developing and scaling new

[2] The steel sector is also responsible for a significant amount of GHG emissions (especially methane) resulting from upstream coal mining processes which are typically accounted for as Scope 3 emissions. While this is a crucial issue that needs to be examined in more detail, the discussion would go beyond the scope of this discussion paper.

production technologies, particularly switching from BF-BOF to DRI-EAF (and from gas to 100% green hydrogen), and/or carbon capture, utilization, and storage (CCUS) technologies to be used at fossil fuel-based production assets. This is challenging as highlighted below in Figure ES 2.

Figure ES 2. Potential pathways of the current steelmaking asset base towards low-carbon production routes



Direct and indirect actions to support steelmakers net zero targets

To focus on what steel companies will do with their existing primary steel production assets by 2030 is particularly pertinent for three reasons:

1. **61%–70% of the total capacity of the existing asset fleet is based on the highly carbon intensive BF-BOF production route** (Bataille, Stiebert, and Li, 2021; Swalec, 2022);
2. **30–77% of existing BF-BOF assets require relining before 2030 (Swalec, 2022; IEA, 2020a), which would result in significant carbon lock-in**[3] and pose a high risk of exceeding the remaining carbon budget if unabated coal-based primary steel production is renewed at scale, because steel sector CO2 emissions have to decrease by 48–50% in 2030 and by 95% in 2050 to reach net zero in Paris-compatible 1.5°C scenarios (Teske et al., 2022; Yu et al., 2021);

[3] Carbon lock-in occurs when highly emissive systems or assets delay or prevent the transition to low-carbon alternatives. In the context of steelmaking assets, it refers to having to keep using highly emissive assets because of their longevity and costs to replace.

3. **The main technological solutions proposed to largely decarbonize primary steel production – green hydrogen and carbon capture and storage (CCS) – are not available at commercial scale yet,** and unlikely to become available before 2028 (green hydrogen) and 2030 (CCS at 90% capture rate).[4]

This means that in the immediate future, steel companies will be facing stark choices in investment planning, research and development (R&D), and capital expenditure (CAPEX) spending with far reaching consequences for net zero transition. Assessing the credibility of steel companies in a scientifically rigorous manner requires assessing the credibility of corporate disclosure (e.g. transition plans) and the credibility of corporate actions to reach net zero.

Corporate actions that can have direct impacts on a steel companies' CO_2 emissions include CAPEX to shift from highly carbon intensive primary to relatively lower carbon intensive EAF secondary steel production, or R&D investments to develop, implement and scale net zero technologies in primary steel production (what we refer to as "direct actions"). "Indirect actions" on the other hand only have indirect impacts on corporate emissions, and include for instance climate lobbying, or the efforts steel companies undertake to decarbonize the power supply of scrap-EAF based secondary steel production and thereby reducing indirect (Scope 2) CO2 emissions.

Assessing the credibility of steel companies' disclosure and actions

Transition planning has become a key tool for assessing the credibility of steel companies' disclosure. Disclosure frameworks, including the sector-neutral disclosure framework and implementation guidance of the Transition Plan Taskforce (TPT), treat production asset-level planning of steel companies as "nice-to-have" elements of transition plans and alignment assessments. We propose that more comprehensive disclosure of asset level investment planning (that underpins targets and corporate-level strategies), or at least disclosure per asset type, is ultimately required to make transition plans of steel companies credible.

[4] The only commercially available technology to mitigate around 90% of CO2 emissions primary steelmaking is methane based DRI-EAF with CCS (Chris Bataille, Stiebert, and Li, 2021).

We propose that the steel-sector-specific minimum disclosure requirements for credible transition planning are:

1. **Disclosure of relevant information on all material steel production assets,** including production technology by main production route (i.e. BF-BOF, DRI-EAF, and scrap-EAF) and production capacity, current emissions, planned technology changes over time, and expected impact of technology changes on CO2 emissions (absolute and intensity based) at asset, production route, and corporate levels.
2. **Corporate policy with commitment to exit unabated coal-based primary steel production** and not reline existing or invest in new BF assets without CCS at a required capture rate of 90% after around 2025–2028 (Bataille, Stiebert & Li, 2021; Yu et al., 2021), with more stringent expectations for OECD countries and more latitude being given to emerging economies.

The credibility of a company's plan to shift to near-zero production technologies[5] could be reinforced by additional disclosure detailing how a company plans to overcome constraints related to the development of near-zero technologies and its assumptions regarding the development and growth rate of each technology in the company's production routes. Given how much net zero claims rely on geographical and national factors, a discussion on how a corporate net zero strategy fits in its local context or a national steel industry roadmap – if it exists – would reinforce the credibility of a net zero claim.

Besides, a net zero strategy in line with the Paris Agreement is only credible if a company's direct and indirect actions are aligned. A robust credibility assessment should examine steel companies' CAPEX plans as well as emission trajectories and carbon lock-in of the existing asset base using conservative assumptions on (changes to) technologies in primary steel production (including relining of BF-BOF assets) to reduce the risk of "alignment greenwashing".

[5] Technologies that achieve emission levels below a specified threshold, significantly reducing greenhouse gas emissions. For instance, in the MPP scenarios, the threshold is defined as an emission intensity below 0.25 tons of CO_2 per ton of crude steel for Scope 1 emissions.

By “alignment greenwashing”, we mean a situation in which steel companies improve net zero alignment assessments through means that have no impact on actual emission reductions in the real economy (see also Caldecott, Thomae et al., 2022; Caldecott, Clark et al., 2022), such as disclosing more ambitious (long term) net zero targets while continuing the operation of unabated high-emitting BF-BOF steel production assets. Rigorous and comprehensive credibility assessments of steel companies should foreground asset-level data-based assessments as well as other approaches that draw on independent data in addition to corporate disclosure to critically examine corporate direct or indirect actions.

Contents

1. Introduction

Decarbonizing the steel sector is an elemental part of transitioning the global industry sector to reach net zero emissions by 2050 as steel production is a highly emissions intensive process that accounts for 6 to 10% of global CO_2 emissions[6] (Bataille, Stiebert, and Li, 2021). However, compared to the power sector in which net zero technologies for electricity generation exist already in the form of renewables, decarbonizing steel production is challenging and technically more complex. This is because net zero technologies for coal-based primary steel production via the dominant blast furnace and basic oxygen furnace (BF-BOF) production route do not exist yet or are not available at commercial scale.

The BF-BOF route accounted for 71% of total crude steel produced in 2021 (World Steel Association, 2022b) and around 85% of the steel sector's direct (Scope 1) and indirect (Scope 2) CO_2 emissions (IEA, 2020a). While electrifying steel production to recycle steel scrap via the scrap-EAF accounts for 24% of global steel output and can reduce the CO_2 emission intensity per ton of steel produced compared to the BF-BOF route by around 62% (Fan & Friedmann, 2021a), the secondary steel production process causes significant indirect (Scope 2) CO_2 emissions from imported power generation which steel companies need to decarbonize. The third steel production process which feeds directly reduced iron (DRI) into the EAF to produce virgin crude steel (DRI-EAF) accounts only for 5% of the steel produced globally but holds the biggest promise of decarbonizing primary steel production via the substitution of natural gas (the currently dominant fossil fuel source of the DRI-EAF route) by green hydrogen, although it remains highly uncertain when and to what extent the abatement potential of green hydrogen could be realized (Section 3.2) (Fan & Friedmann, 2021a).

There are three main decarbonization levers that are widely recognized in the literature as being required for the steel sector to reduce Scope 1 and 2 CO2 emissions and achieve net zero in Paris-aligned transition scenarios by 2050 (Bashmakov et al., 2022):[7]

[6] Steel production accounts for 6 to 10% of global CO2 emissions, depending on the perimeter used and not accounting for methane emissions.

[7] The steel sector is also responsible for a significant amount of GHG emissions (especially methane) resulting from upstream coal mining processes which are typically accounted for as Scope 3 emissions. While this is a crucial issue that needs to be examined in more details, the discussion would go beyond the scope of this discussion paper.

1. **Leverage overall steel demand** reduction via increased material efficiency, circular material flows, and/or absolute demand reduction in final use, such as in building and manufacturing sectors.
2. **Increase secondary production of scrap-based steel** based on the scrap-EAF production route which enables "recycling" but requires decarbonizing the electricity input.
3. **Upgrade or replacement of existing BF-BOF and DRI-EAF asset base** in primary steel production by increasing energy and material efficiencies as well as by developing and scaling new production technologies, particularly switching from BF-BOF to DRI-EAF (and from gas to 100% green hydrogen), and/or CCUS technologies to be used at fossil fuel-based production assets which is challenging as highlighted in Section 3.2.1 and Figure 2.

The steel sector is highly capital intensive and is characterized by long investment cycles, while the abatement potential of each decarbonization lever is company specific (as it depends on steel companies' existing steel production asset base). That is why it is crucial for Financial Institutions (FIs) and other stakeholders to build a better understanding of how to hold steel companies accountable via (1) credible transition planning and (2) tracking how transition plans are put into action for the steel sector (as well as individual steel companies) to reduce GHG emissions in alignment with climate targets and steer the sector towards net zero.

The question that this paper sets out to discuss is: How can we assess if a steel company is likely to reach net zero by 2050 [8]or not? In other words, how can we assess the credibility of a steel company reaching net zero? To answer this question in a scientifically rigorous manner, we propose that a more comprehensive assessment framework is needed that enables scholars to combine the assessment of steel companies' corporate disclose with an assessment of the actions that steel companies are taking, such as planned CAPEX and investments in R&D of net zero steel production technologies.

[8] Reaching net zero by 2050 is not equivalent to 1.5°C alignment, and reaching net zero through immediate steep emissions reductions is more likely to be aligned with a temperature increase of 1.5°C than reducing emissions just before 2050, as the former implies smaller cumulative emissions.

1.1 Starting from the currently operational and planned steel asset base

We propose a perspective here that is fundamentally informed by previous work on asset-level data-based assessments of environmental and stranded asset risks (Caldecott, 2017; Ansar et al., 2013; Pfeiffer et al., 2016, 2018) as well as the development of a global asset-level dataset for the steel sector (McCarten et al., 2021). For this, it is essential to start first from principles of how to assess a steel company's credibility in reaching net zero to highlight some pressing issues that still need to be addressed. **Starting from first principles means focusing on what the existing base of steel production assets is that steel companies own and operate today, and how those production assets (and the operation thereof) have to change over time to reduce GHG emissions in line with net zero benchmarks.**

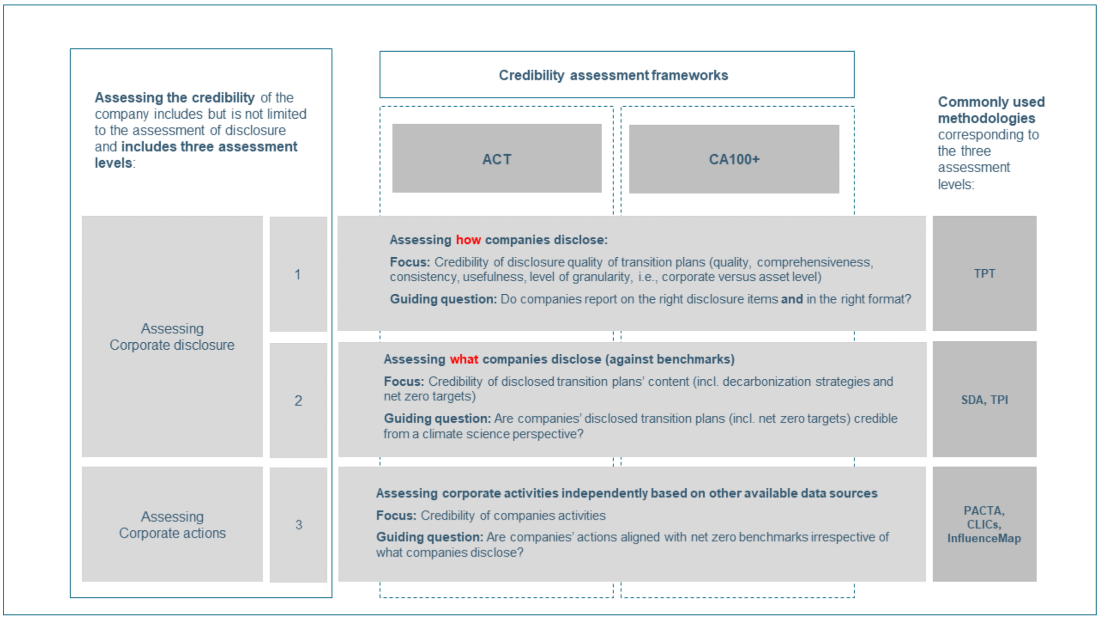
Key aspects for assessing the credibility of steel companies to consider for FIs (but also other stakeholders) are derived from this perspective as follows. Research indicates that the BF-BOF route accounts for around 61%–70% (Bataille, Stiebert & Li, 2021; Swalec, 2022) of the global capacity of operating asset base of primary and secondary steel production facilities. This means that FIs need to focus on reinvestment cycles of the currently operating and planned production asset base of the steel sector in general and of individual steel companies in particular to assess credibility. Research on the remaining economic lifetimes[9] of the steel production base at the asset level suggests that a significant share of global BF capacity will need to be relined by 2030 (~30%[2]–75%[7]) while the sector's CO2 emissions need to decrease by 48%–50% over the same time horizon compared to 2020 to reach net zero in 1.5°C compatible scenarios (Teske et al., 2022; Yu et al., 2021). This means that steel companies need to direct CAPEX spending towards abatement options within the next seven years to avoid carbon lock-in and stranded asset risks posed by relining the existing BF fleet, and in order to phase out coal-based primary steel production to reduce CO2 emissions in line with net zero targets.

[9] The lifetime of blast furnaces is typically assumed to be between 25 and 40 years.

2. Assessing credibility of steel companies: existing frameworks

The aim of this paper is not to propose a new assessment framework, but to stimulate the discussion among scholars and practitioners as to the most pressing research gaps and open questions when it comes to comprehensively assessing the credibility of steel companies reaching net zero. In our view, assessing the credibility of steel companies in a scientifically rigorous manner requires assessing (1) the credibility of corporate disclosure and (2) the credibility of corporate actions (Figure 1).

Figure 1. Overview of existing frameworks to assess credibility of corporates to reach net zero



Note: Author's analysis.

There has been significant work in the areas of assessing transition plan disclosure and assessing the alignment of steel companies' corporate actions with net zero benchmarks.

As for transition plan disclosure, we mostly focus on the Transition Plan Taskforce (TPT) Disclosure Framework as it reviews all the relevant elements of a climate transition plan, although the framework is sector neutral, and is set to have a strong international influence.

As the objective of the TPT framework is to provide guidance for companies "to disclose credible, useful and consistent transition plans" by specifying disclosure items and metrics (TPT, 2022) i.e. *how* companies should disclose, neither the assessment of *what* steel companies disclose (i.e. the question if disclosed CO_2 emission reduction targets are aligned with net zero benchmarks), nor the assessment of steel companies' corporate actions are within its remit.[10]

A significant body of work has also addressed the question of how to assess the content of disclosure, or what steel companies disclose. Here the focus has been on assessing net zero targets. Existing methodologies to do that are for instance the Sectoral Decarbonization Approach (SDA) (Krabbe et al., 2015) which underpins methodologies of the Science Based Targets initiative (SBTi). The SDA is also used by the Transition Pathway Initiative (TPI) to assess the "carbon performance" of steel producers by evaluating disclosed emission reduction targets against emission intensity benchmarks, which are typically taken from the IEA scenarios (though the SDA is scenario agnostic) (Dietz, 2017). Those approaches typically draw on corporate disclosure as the primary source of information on which the assessments are based to enable a larger degree of coverage of listed corporates that can be included in the assessment. While this should in principle ensure a certain degree of comparability and consistency across company assessments, the data quality of voluntary disclosure is severely limited as not all companies disclose the necessary information and where disclosure is available, it often remains incomplete.

Furthermore, there is a growing body of research that developed scientific methodologies and tools for financial practitioners which aim to assess the alignment of steel companies' actions with net zero benchmarks. Those include methods to assess the alignment of CAPEX (e.g. the PACTA tool) (2DII, 2020), lock-in of expected CO_2 emissions resulting from existing steel production assets (e.g. the CLICs methodology) (Davis & Socolow, 2014; Pfeiffer et al., 2018; Davis et al., 2015; Caldecott, McCarten, and Triantafyllidis, 2018), and climate lobbying efforts (e.g. InfluenceMap's climate policy alignment assessment; see InfluenceMap, 2022) with net zero benchmarks. What sets these approaches apart from the approaches listed in the previous paragraph is that they typically draw on asset-level data and other independent information that are not derived from corporate disclosure and

[10] Although the TPT framework highlights the potential usefulness of asset-level disclosure (esp. with regards to the phase-out of high carbon assets), it also lacks clear recommendations on how steel companies should disclosure crucial information on installed technology, production capacity, input factors, production output, and CO2 emissions at the level of individual production facilities or production routes. The item 2.1 Business planning and operations includes "Plans and timelines to manage or phase-out GHG or carbon-energy intensive assets" (Transition Plan Taskforce, 2022).

companies' voluntary or mandatory financial reporting. This is crucial because these approaches can serve as external consistency checks to prevent the risk of "alignment greenwashing"[11].

There are two alignment assessment methodologies which aim to combine the assessment of disclosure and corporate actions to conduct a more comprehensive analysis of steel companies' credibility[12]: the assessment frameworks developed by the Assessing Low-Carbon Transition (ACT) Initiative as well as by the investor initiative Climate Action 100+ (CA100+). We focus on these methodologies as they are bottom up and sector specific, allowing for an assessment more tailored to the specificities of the steel industry. Both frameworks draw on several of the approaches outlined above to derive aggregated company-level scores based on a weighting system (ACT, 2022) or a traffic light system (CA100+, 2022) for steel companies. While the ACT and CA100+ credibility assessment frameworks and underlying methodologies differ, what they have in common is that they seek to reduce the complexity of assessing multiple indicators across the three different assessment levels – i.e. assessing (1) *how* steel companies disclose, (2) *what* they disclose, as well as assessing (3) steel companies' actions (Figure 2)–to derive either a *single* company score (ACT) or traffic light scores for each indicator to capture a steel company's alignment with net zero in its entirety (CA100+).[13]

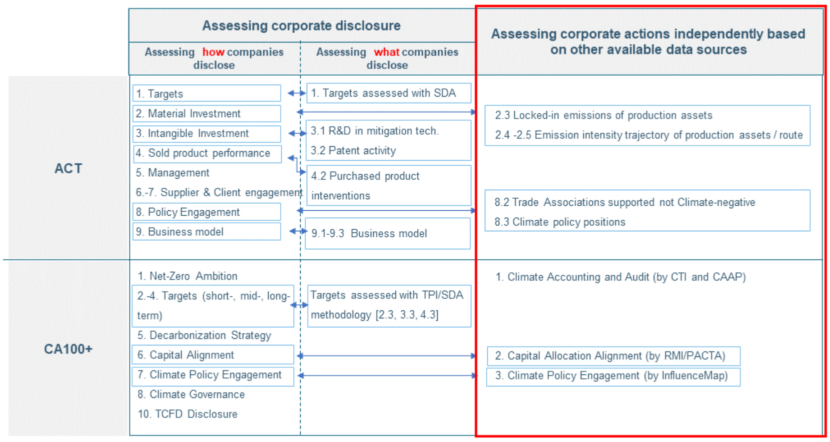
By drawing on the three levels of assessing credibility, we compared the two credibility assessment solutions provided by ACT and CA100+ to identify commonalities and differences (Figure 2). While both frameworks do an admirable job in incorporating a wide range of different methodologies to assess steel companies in a comprehensive manner, these types of aggregated assessments inevitably suffer from shortcomings and limitations as a result of the vast scope of different assessment items and indicators that are covered (also highlighted below).

[11] Situations in which steel companies improve net zero alignment assessments through means that have no impact on actual emission reductions in the real economy (B. Caldecott, Thomae et al., 2022; B. Caldecott, Clark et al., 2022)

[12] It is important to note here that none of the two assessment frameworks explicitly uses the term credibility assessment in the way we introduced the idea in this discussion paper.

[13] The CA100+ assessment only covers the eight publicly listed steel producers with the highest CO2 emissions. The ACT framework can in principle cover all for which required data is available.

Figure 2. Overview of ACT and CA100+ frameworks to assess the credibility of steel companies to reach net zero



Note: Authors' analysis.

Both the ACT and CA100+ frameworks assess the credibility of steel companies across all three levels including corporate disclosure and actions. Disclosed emission reduction targets are key items of both frameworks and are assessed with regards to the time horizon and the scope of emissions covered (Level 1).[14] The disclosed targets themselves are assessed in terms of their scientific validity by using the SDA (Level 2). In addition to this, both frameworks assess the alignment of steel companies' CAPEX and CO_2 emission trajectories based on asset-level data independent of corporate disclosure based on the PACTA tool (CA100+: Alignment Assessment 2) as well as carbon lock-in calculations based on absolute emissions and emission intensity benchmarking (ACT: IS 2.3, 2.4, and 2.5) (Level 3).

The strength of the ACT framework is its comprehensive coverage of numerous assessment items, which is at the same time the source of the framework's major shortcomings and may lead to ACT suffering from "aggregated confusion" (Berg, Kölbel, and Rigobon 2022).

[14] The CA100+ framework includes four assessment items related to how steel companies disclose emission reduction targets (Disclosure Indicators 1–4), which the ACT framework assesses companies' target time horizon under IS 1.2.

The assessment itself is difficult to conduct (as a high level of expert knowledge is required) and risks becoming overly complicated while the final company scores include a performance score (that is based on and reflects 29 assessment items), a narrative score (which is derived from an analysis of a company's business model, strategy, risk and reputation), and a trend score (which represents the change compared to previous scores). The final score can be challenging to communicate to non-experts as it is not intuitively clear what the scores mean for the credibility of steel companies.

The CA100+ framework on the other hand – which combines a significantly smaller number of assessment items than the ACT framework – provides a traffic light for each of the ten disclosure indicators and three alignment assessments without combining them into a single company score though considering them equally relevant. As a result, the CA100+ framework lacks the prioritization of what constitutes fundamental items to assess the credibility of steel companies as it does not have a clearly defined hierarchy of assessment items. A potential solution would be to adopt a scoring approach which includes an aggregated score which includes safeguards on key elements such as having ambitious short-term and long-term targets, commitments to shift toward near-zero production routes, or commitments to exit the BF-BOF route.

While both assessment frameworks acknowledge that the disclosure of asset-level investment planning should be part of credible transition plans in the steel sector, asset-level planning is treated as a "nice-to-have" item of transition plans rather than a fundamental element (ACT)[15] or has only recently been set onto the agenda (CA100+).[16] Further, both frameworks draw on asset-level data-driven assessments of steel companies' actions in the form of PACTA's CAPEX plan assessments (CA100+) as well as emission trajectories and carbon lock-in (ACT), the frameworks do not set those asset-level assessments as external consistency checks for corporate disclosure. Steel companies can in principle still pass with relatively good assessments even if independent asset-level assessments produce results that would render the respective steel company less credible.

[15] The ACT framework Steel Sector Methodology states under item IS 5.3 LOW-CARBON TRANSITION PLAN that transition plans fall into the highest scoring category ("low carbon aligned") if they "Contains a detailed and comprehensive vision of what the far-future company could look like in terms of physical assets and business model".

[16] The updated version of the CA100+ Net Zero Company Benchmark 2.0 Framework published in March 2023 highlights "Net-zero transition planning, assessing key levers for company decarbonization, corresponding capital allocation, and asset-level changes" as one of the major updates (Carbon Tracker Initiative, 2022).

That is because the CA100+ framework does not feature an explicit hierarchy between the assessment items (e.g. assessment of actions > assessment of disclosure), while the ACT framework assigns asset-level assessments of emission trajectories and carbon lock-in a maximum weighting of 32%, which means that a “weak” asset-level assessment can be overcompensated by “strong” scorings in other assessment categories (ACT 2022, 131).

3. Emission and technology pathways

3.1 Emission pathways

The first element to assess when considering the credibility of a corporate net zero claim is a company’s ambition to decarbonize through emissions reduction targets. There are several available steel-sector-specific CO_2 emission pathways that can be used as net zero benchmarks for steel companies’ corporate CO_2 emission trajectories. The key question that FIs should ask when assessing steel companies’ credibility is if a firm’s emission trajectory is consistent with net zero benchmarks. There are several steel-sector-specific transition scenarios that include sector-specific emission pathways, but which differ in terms of key emission pathway characteristics, as well as emission drivers and technology assumptions (Table 1).

Table 1. Selected net zero transition scenarios for the steel sector

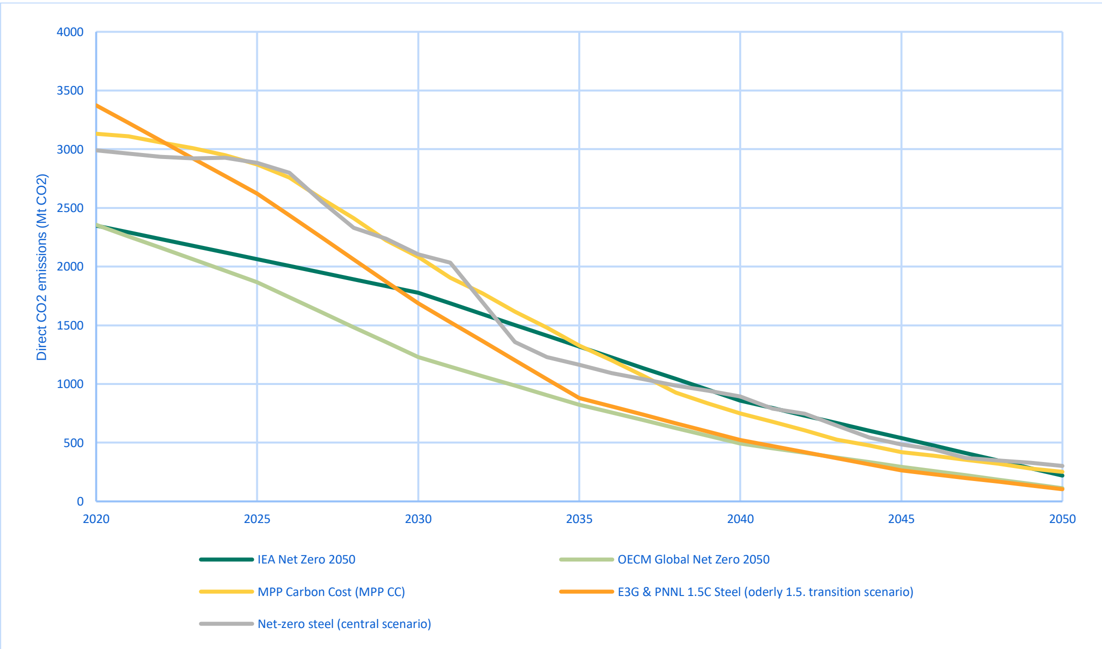
								Exiting coal-based production	Switching to secondary production	Hydrogen-based DRI-EAF		CCS/CCUS	
Scenario name	Temp. target (in °C)	Likelihood of limiting global warming to temperature target	Global carbon budget (in GtCO2)	Steel sector carbon budget in GtCO2	Steel demand growth until 2050 (compared to 2020)	Reduction of direct (Scope 1) CO2 emissions by 2030 (in %)	Reduction of direct (Scope 1) CO2 emissions by 2050 (in %)	Last year of building new or relining existing unabated BF-BOF plants	Share of secondary steel production by 2050 (scrap-EAF route)	Introduction at commercial scale (year)	Share of total steel production	Introduction of BF-BOF with CCS (year)	Share of total production capacity equipped with CCS
IEA Net Zero 2050	1.5	50%	500	40	11.6%	-24.3	-90.6	NA	46%	2030	29% (of primary steel production only)	2030	53% (of primary steel production only)
UTS OECM Global Net Zero 2050	1.5	67%	400	31	48.6%	-47.8	-95.2	NA	48%	NA	NA	NA	NA
MPP Carbon Cost (MPP CC)	1.5	50%	500	47	35.8%	-33.0	-90.3	2028	40%	2026	22%	2028	31%
E3G & PNNL 1.5°C Steel (oderly 1.5. transition)	1.5	50%	470	40	8.9%	-50.0	-95.0	2025	47%	2025	19%	2025	27%
Net-Zero Steel (central scenario)	NA	NA	NA	47	15.6%	-29.6	-89.9	2025	46%	2028	29%	2030	17%

Notes: Data from sources listed in the text below and from respective additional scenario data. Steel sector boundaries differ between the scenarios. The MPP CC scenario does not differentiate between Scope 1 and Scope 2 CO2 emissions, which is why the numbers in the Table and Figure 3 below include both.

Transition scenarios that are based on a temperature target of 1.5°C (with limited or no overshoot) that are used as net zero benchmarks include the IEA's Net Zero by 2050 scenario (IEA, 2021), the University of Technology Sydney (UTS) OECM Global Net Zero 2050 (Teske et al., 2020; 2022), the industry-led Mission Possible Partnership Carbon Cost (MPP CC) scenario (MPP, 2022a), the E3G & PNNL 1.5°C Steel scenario (Yu et al., 2021). **Though steel sector CO_2 emissions in all four scenarios reach net zero by 2050 through immediate steep emissions reductions, the scenarios differ significantly with regard to the size of the global and sectoral carbon budgets as well as the reduction of direct (Scope 1) CO_2 emissions by 2030 (ranging from -24.3% in the net zero emissions to -50% in the E3G & PNNL 1.5°C Steel scenario). Delayed and/or less ambitious emissions reduction implies more stress on climate systems, or on other sectors to decarbonize faster or on negative emissions solutions whose potential is limited and with unknown feedbacks from biosphere sinks** (Keller et al., 2018)**. The scenarios also differ significantly when it comes to the extent to which steel production is shifted from primary to secondary production (based on the scrap-EAF route), and which net zero technologies are utilized (and to what extent) to decarbonize steel production (Section 3.2).**

However, there is a consensus on the need to exit production from unabated BF-BOF assets. Since all four scenarios lack specific information at the corporate and facility levels that are crucial to inform transition planning in the steel sector, the Institute for Sustainable Development and International Relations (IDDRI) developed the Net-Zero Steel scenario (Bataille, 2021) to close this gap. We discuss this briefly in Section 4.2 below because the scenario is geared towards deriving insights on aligning steel companies' actions with net zero.

Figure 3 Selected net zero emission pathways for the steel sector



Assessing company's pathways using national-level pathways, or at least regional pathways, is relevant as it acknowledges that different countries will follow different pathways. Several scenarios include country-level data such as the MPP CC scenario or the Net Zero Steel scenario, accounting for the diverse current state of the steelmaking asset bases, and the cost and availability of inputs such as electricity, hydrogen, or iron pellets which will induce different marginal abatement costs (MPP, 2022b; Bataille, Stiebert, and Li 2021). However, designing regional pathways is complex as they are not only defined by cost effectiveness and technological criteria, but equity concerns on how the burden of decarbonizing is shared between countries is also important to ensure a fair transition (Chen et al., 2021). Even accounting for regional pathways, all countries are required to engage in steep emissions reductions to meet net zero targets.

3.2 Technology pathways

The extent to which steel companies are able to shift from primary to secondary as well as develop and scale up net zero technologies in primary steelmaking are key determinants of the likelihood of following a net zero emission pathway. Planning the transition of steel production needs to account for the current iron and steelmaking asset base, which is mostly made up of BF-BOF assets (61% (Swalec, 2022) **–70%** (Bataille, Stiebert, and Li 2021)**), and how this asset base can evolve towards net zero.**

Table 2. Breakdown of the current steel production per production route and related carbon intensity

Production route	Share of global production	Carbon intensity in tCO2e/t steel
BF-BOF	70%	2.1
Scrap-EAF	25%	0.5
DRI-EAF	5%	1.3

Source: Mission Possible Partnership, 2022a.

3.2.1 Short to mid-term decarbonization levers (before 2030)

Decarbonization levers which are available in the short term to all production routes include energy efficiency and material efficiency, as well as increased production from secondary steelmaking. Overall, the IEA Net Zero scenario assumes that 85% of the emissions savings between now and 2030 will come from these three levers. An estimated 15% energy efficiency improvement is achievable in BF-BOF production route (Bashmakov et al., 2022) and material efficiency could reduce steel demand by around 20% (IEA, 2021; Yu et al., 2021). Switching from primary to secondary production could contribute to reducing cumulative Scope 1 and 2 CO_2 emissions by 2050 by 0.8 Gt of CO_2 (MPP, 2022a), but its potential is constrained by the availability of scrap steel and low-carbon electricity supply.

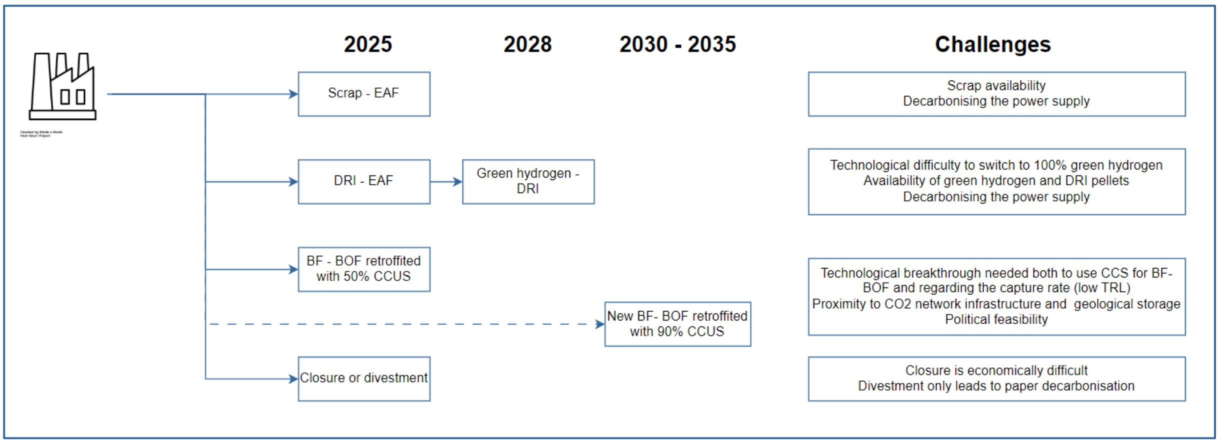
Given the importance of these levers in the short term, companies should disclose how much they engage with each lever and quantify how improvements along them will bring down the carbon intensity of their production. The targeted carbon intensity could be compared to the ones modelled by the IEA (International Energy Agency, 2020).

To refine the analysis, the assessment could be computed per production route, though it would mask the gains from shifting from BF-BOF to other production routes, and per region, acknowledging that not all levers have the same potential depending on location.

3.2.2 Long-term decarbonization levers (after 2030)

Despite the relevancy of the above decarbonization levers, net zero scenarios assume that in 2050 steel production will mostly come from production routes which rely on technologies that are not available at a commercial scale yet (except for DRI-EAF with CCS). **Improvements in ironmaking and steelmaking technologies to include hydrogen-based technologies and CCUS are expected to be key decarbonization levers. Contributions to emissions reduction of these technologies vary significantly across scenarios:** the E3G & PNNL 1.5°C Steel scenario estimates that hydrogen-based production will account for 17% of cumulative Scope 1 and 2 emissions reduction between 2020 and 2050, while CCU and CCUS contribute 14%. This is respectively 30% and 17.5% in the MPP Carbon Cost scenario and even goes up to 99% and 60% in some scenarios considered by the IPCC.

Figure 4. Potential pathways of the current steelmaking asset base towards low-carbon production routes



While these technologies are assumed to play a significant role in steel decarbonization, it is important to note that several economic, technical and political constraints threaten the credibility of their ability to replace the current BF-BOF dominated asset base.

Ultra-low carbon steelmaking technologies are currently far from being mature and have low technology readiness levels (TRL), mostly below 9.[17] The TRL of hydrogen-based technologies relevant to the iron and steel industry ranges from 4 to 6 and the TRL of CCS/CCUS-based technologies is around 5 for technologies in the BF-BOF route and up to 9 for technologies in the DRI route (International Energy Agency, 2022). In the following paragraphs, we outline the different constraints on the deployment of hydrogen-based technologies first, and then CCS-CCUS technologies, and discuss some gaps to bridge to go from the current state of these technologies to what it assumed in some net zero scenarios.

Hydrogen can be used in ironmaking and replace natural gas as a reducing agent in the DRI process. The literature identifies three main constraints to its development: the availability of green hydrogen, the technical challenge to incorporating hydrogen in existing production routes, and the availability of high-quality iron pellets. Hydrogen is currently mostly produced from fossil fuels, making it one of the energy carriers with the highest carbon footprint at around 15 $kgCO_2e/kg$ (Chaar, Rouault, and Schuller 2022). To be relevant, it needs to come from low-carbon production such as electrolysis using low-carbon electricity. The annual hydrogen demand from the steel sector is expected to grow from 5 Mt in 2020 to 19 Mt in 2030 and 54 Mt in 2050 (IEA, 2021) while the sector will compete with other sectors where low-carbon hydrogen is also considered a relevant decarbonization lever such as ammonia and methanol production, shipping, or aviation (Chaar, Rouault, and Schuller 2022). The IEA also assumes a large increase of on-site electrolyzer capacity going from 0 GW in 2020 to 295 GW in 2050 (IEA, 2021).

In addition to the availability of affordable low-carbon hydrogen, another technical challenge is to incorporate hydrogen in the production process, with more potential in the DRI route. While fuel change is important to decarbonize steel production, technical challenges constrain its potential. First, hydrogen can only play a limited role in decarbonizing production through BF-BOF, for instance through hydrogen injection in blast furnaces. This can be done to some extent in the current BF-BOF asset base but with significant limits (Lyu et al., 2017). Using hydrogen in gas-based DRI production is simpler, as it can replace at least part of the natural gas input in current DRI assets. Switching to 100% hydrogen poses two technical challenges, one related to heat and one being that the iron output of a 100% H2-DRI process is less suitable for Electric Arc Furnaces (Midrex,

[17] Technology readiness level (TRL) is a concept developed by NASA to assess the maturity of a technology. The IEA tracks the TRL of different energy-related technologies, scoring technologies from 1, where the basic principles and general idea have been formulated, to 11, where the technology is stable, and its growth can be predicted. One major threshold to reach is 9, as it indicates commercial feasibility.

2020). Given the potential of hydrogen-based DRI production, some scenarios make strong assumptions regarding its role, with MPP Carbon Cost assuming that DRI could go from 5% of the current steelmaking production to between 70 and 80% of the global steel production in 2050. However, since DRI only accounts for a small share of total production, the challenge to unlock the potential of hydrogen to decarbonize steel production is less to enable fuel switching from natural gas to hydrogen in DRI assets rather than to shift the asset base from BF-BOF to DRI-EAF.

Nonetheless, this shift to DRI might be constrained by the availability of high-quality iron pellets. The DRI-EAF route, whether it relies on natural gas or hydrogen, requires high-quality iron ore and the increased use of DRI in low-carbon scenarios amplifies the pressure on high-grade iron availability. In 2019, DRI production yielded 108 Mt of steel using 157 Mt of iron ore, the IEA SDS scenario assumes that this will go up to 411 Mt of steel for 596 Mt of iron ore in 2050 and World Steel Dynamics assumes that this will be around 272 Mt and 394 Mt respectively (IIMA & Barrington, 2022). However, high-quality iron ore accounts for a small share of the world's iron ore production and overall iron ore quality has been declining over the past two decades. As a result, the International Iron Metallics Association estimates that there will be a significant shortage of high-grade iron pellets by the beginning of the next decade (IIMA & Barrington, 2022). Steelmakers are trying to develop various DRI production technologies which require lower-quality levels of iron ore to work around this issue, but these projects are still at very early stages. For instance, BlueScope and Rio Tinto signed an agreement in 2021 to investigate a DRI-Melter-BOF steelmaking route to allow the use of lower-grade ores (BlueScope, 2021), Primetals launched a pilot plant in 2021 using a hydrogen-based fine ore reduction technology (Primetals, 2021).

Credible strategies which rely on hydrogen-based DRI production should disclose their procurement strategy regarding securing a supply of green hydrogen, for instance through on-site generation projects using electrolysis and renewable energy, and iron pellets. Companies should also provide information on the rate of replacement of natural gas by low-carbon hydrogen and its impact on the production carbon intensity of its assets. Regarding all these dimensions, companies rely on external factors such as the decarbonization of the electricity grid, the local development of hydrogen, the supply of iron pellets and the development of new technologies enabling the use of a more diverse supply of iron pellets and to switch to hydrogen.

Carbon capture also has potential to decarbonize steel production, as it can be applied to BF-BOF and DRI assets but is subject to several challenges as well.

Carbon capture holds a significant role in net zero scenarios, with the IEA assuming that CO_2 captured in the steel industry goes from 1 Mt in 2020 to 670 Mt in 2050 and that more than 53% of the global steel production comes from CCUS-equipped plants. As for hydrogen, many constraints threaten the credibility of CCUS playing such a significant role in steel decarbonization. The MPP Carbon Cost and the Net Zero Steel scenarios both assume that carbon capture plays a significant role in steel decarbonization, with most of that potential being unlocked with effective capture rates from CCS of 90%. The Net Zero Steel scenario even states that "Reaching net-zero requires crystal clear communication to steel makers that no more BF-BOFs without 90% CCS can be built past 2025".

Current capture rates are far from 90%. According to the IEA, the most mature steel-CCUS technology, chemical absorption of CO_2 in the DRI process, is already mature enough to be commercially available (TRL of 9) (IEA, 2022). However, the associated projects described by the IEA are far from meeting the expectations of net zero scenarios. The IEA only mentions two plants in Mexico capturing 5% of emissions for use in the beverage industry, and one natural gas-based DRI plant equipped with CCUS for enhanced oil recovery in the United Arab Emirates with a capacity of 0.8 Mt CO_2/yr. **Besides, while being a solution to abate emissions from the existing BF-BOF asset base, retrofitting BF-BOF plants to include CCS has a limited potential with potential capture rates below 50% because emissions sources are more scattered, making CCS an unlikely option to shift the existing BF-BOF asset base toward near-zero production** (Fan & Friedmann, 2021b). Finally, CCS reduces the energy efficiency of the plant (De Ras et al., 2019). Overall, there are many different types of carbon capture technologies but all of them have low TRLs (International Energy Agency, 2022) and are far from meeting the expectations of steel net zero scenarios.

Beyond the technological challenges to integrating carbon capture in steelmaking assets, other geographic constraints limit the potential of carbon capture. Suitable geological formations for CO_2 storage, such as depleted oil and gas reservoirs or saline aquifers, need to be in close proximity to steel plants to minimize transportation costs. Regional infrastructure, including CO_2 transport pipelines and access to low-carbon energy sources, also plays a vital role in connecting steelmaking assets to CO_2 reservoirs. This means that part of the current steelmaking asset base is less eligible for carbon capture, if eligible at all. Net Zero Steel's modelling finds that there is limited global potential for CCS without assuming the possibility of building CO_2 pipeline networks of 200 km to reach a potential reservoir (C. Bataille, Stiebert, and Li 2021). Finally, another key challenge to the deployment of CCS is the public acceptance of the technology in some countries (Jones et al., 2017).

Several CCS projects were cancelled in Germany after public protests regarding the uncertainties surrounding CO_2 storage, even leading several German states to completely ban storing CO_2 under residential areas (Wettengel, 2023; Patonia, 2022).

Credible strategies which rely on carbon capture should justify why carbon capture is relevant for their assets, showing close proximity to geological formations and expected development of regional CO_2 transport infrastructure. Companies should also provide information on their assumptions on the evolution of the carbon capture rate and its impact on the production carbon intensity of its assets.

Overall, steel companies should back their net zero claims with commitments to increase the share of their production coming from near-zero emissions production route. Depending on their strategy and chosen technology pathway, companies need to give evidence on how they are addressing the challenges linked to each production route. Since their decarbonization strategies have to rely on very strong assumptions regarding the development of different technologies, they need to be clear on the assumptions determining their transition plans and the associated steelmaking production routes. Companies should be transparent regarding the technology paths they are relying on, and regarding the anticipated timeline of commercial availability of each technology. In addition, companies should provide quantitative estimates of how new production routes will contribute to delivering on the company's targets. A more detailed plan would also include a timeline for pilot projects per technology and put forward the growth rate of adoption of each technology in the company's production routes. To give tangible elements on a company's plan regarding its planned production routes despite the uncertainty surrounding technology development, companies should disclose information on the development of new production technologies: where they will be deployed, what are the barriers, what are the underlying cost and technological assumptions, what will be the impact on the overall production.

Using this information on future production, it is possible to infer whether a company is on track to meet its emissions targets. To assess this, it is possible to compute a company's future emissions using the forecasted volume of steel produced in each route multiplied by the average emission intensity of each route. The resulting emissions should be aligned with the company's emissions reduction target. ACT conducts a similar analysis on the trend in future emissions intensity by computing the expected emissions intensity of all the steel production assets five years after the reporting year (ACT, 2022). Given the lack of near-zero production routes in the short term, assessing the company's performance over the next five years is not enough. However, it is more feasible in terms of data availability and more credible as an assessment in the longer term would rely on higher levels of uncertainty.

Overall, a high emissions intensity shows that the company has an important action gap to overcome to make its transition plan credible.

Steelmaking assets exhibit considerable longevity, necessitating periodic relining approximately every 20 years, with more substantial refurbishments required every 40 years. Consequently, steelmakers face the imperative of utilizing their current emissive steelmaking infrastructure for extended durations, unless they proactively choose to expedite the retirement of these assets. It is therefore possible to partly verify the credibility of companies' transition plan regarding their emissions reduction targets and production routes by assessing how locked-in emissions respect these claims. The ACT methodology makes this a key component of its assessment and computes locked-in emissions using a company's cumulative emissions from its current and planned steelmaking plants between the reporting year to 15 years later (ACT, 2022). Comparing these cumulative emissions to a carbon emissions budget derived from a net zero scenario allows to assess if the company is at risk of overshooting its budget simply from its existing and planned infrastructure.

In addition, research on remaining economic lifetimes of the steel production base at the asset level suggests that a significant share of global BF capacity will need to be relined by 2030 (~30%[2]–75%[7]). This, combined with long investment cycles and the limited availability of low-carbon production technologies, implies that the steel industry is at risk of locking in highly emissive assets and developing stranded assets. **To exit unabated coal-based primary steel production by around 2045, companies should therefore stop investing in new BF-BOF production capacity in the short term, especially given the challenges to retrofit them with CCS. According to three net zero scenarios (Table 1), building new or relining existing unabated BF-BOF should stop by 2025/2028, depending on the scenarios, to stay on a net zero pathway. Given that countries might face different challenges to decarbonize (Section 5.1.1), assessment could be stricter for OECD countries than for emerging economies, with the former being expected to stop now investing in building new/relining unabated BF-BOF assets while the latter would have to stop by 2028** (Ashley, Gillespie, and Hansbrough 2023)**. Shortening investment cycles and/or conducting partial relining could also contribute to limiting carbon lock-in.**

Overall, net zero claims made by companies that intend to continue production using highly emissive assets without acknowledging the carbon lock-in resulting from their existing and planned plants are not credible. A critical element to assess the credibility of a company's technology pathway is a comprehensive breakdown of production by route and the corresponding emissions intensity, considering potential gains achieved through energy and material efficiency.

Additional elements which outline how a company plans to develop new production technologies and obtains emissions reductions per production route, such as asset-level data detailing projects for new plants and relining existing plants, also reinforce the credibility of a transition plan.

4. Action pathways: direct and indirect

4.1 Direct action pathways

To make a chosen technology mix materialize, a company needs to support its decarbonization strategy through action, especially through credible operational and financial planning. In this section, we delve deeper into the question of what actions steel companies should be taking to finance, develop, implement, and scale technology options. We first focus on already available levers, namely material efficiency, energy efficiency and increased use of scrap steel, and then discuss less mature technologies.

4.1.1 Operational and financial planning regarding available decarbonization levers

As discussed in Section 3.2, material efficiency, energy efficiency and increased use of scrap steel can unlock short-term climate gains. Regarding material efficiency and energy efficiency, companies should disclose the share of capital expenditures invested in mitigations solutions, as well as their planned expenses over future periods. A company should provide quantitative information on how these capital expenditures will contribute to lower the emissions intensity of their steel production. While having asset-level data is useful to make the analysis more precise, the reported information should give a comprehensive view of how the overall intensity of the company will change. Limiting reporting to flagship projects that are not representative of the overall strategy weakens a transition plan's credibility.

To assess the right level of investment in these technologies, it is possible to compare the share of capital expenditure in mitigation with a benchmark. However, benchmarks providing a range of the ideal level of investment in such technologies are not available. If it is not possible to assess the alignment of capex in energy efficiency and material efficiency with the rest of the decarbonization strategy, other approaches can be considered.

Considering the past trend in capex in mitigation projects and the past trend in Scope 1 and 2 emissions can contribute to reinforcing the credibility of a strategy.

The discussion is similar regarding secondary steelmaking as companies need to disclose clearly the related capital expenditure to show that a commitment to increase production from scrap steel is credible. Some net zero scenarios offer information on the sector-wide investment required to increase secondary steelmaking to the level required by a net zero pathway. This could be used to compute a company-level benchmark of the right level of investment in secondary steelmaking. In its Carbon Cost scenario, MPP assumes that investment in secondary steelmaking will amount to 93 billion USD of cumulative investment by 2050, around 20% of the cumulative investment required from steelmakers to reach net zero by 2050 (MPP, 2022a). This is much lower in the net zero scenario designed by Net Zero Steel (C. Bataille, Stiebert, and Li 2021).

Overall, the company should discuss how its operational planning supports steel circularity, both in terms of material efficiency, for instance by extending the lifetime of its products and reducing demand, and in terms of steel recycling. Operational targets along the steelmaking value chain can reinforce the credibility of a transition plan. Such targets can cover steel waste collection and improvement of collection systems, increase of the use of scrap steel, or change in products' design to improve material efficiency.

4.1.2 Financial planning in new production technologies

As reaching net zero relies on technologies that do not exist yet, investment strategies need to focus on R&D expenses in non-mature technologies, in addition to investing in more readily available short-term gains in material efficiency and energy efficiency. While companies and major steel-producing countries seem to agree on the main technology development needs in a net zero steel industry, there is limited quantified information on the corporate investment required to develop these technologies. Determining the correct level of investment per technology is complex for many reasons. First, reaching net zero for the steel industry implies major technological breakthroughs with most scenarios assuming that key net zero technologies such as hydrogen-based DRI-EAF or CCUS will only be commercially viable around 2030. The outcome of this research and development expenditures and the level required to yield the expected breakthroughs are hard to predict, by definition of R&D expenditures and especially in non-mature fields.

Second, companies do not need to invest in all technology pathways as they can specialize in a specific production route. Besides, not all strategies have the same probability of success as TRL differ across production routes, meaning that financial planning and investment might not be enough to materialize the company's transition plan. It is important to acknowledge that some transition strategies could fail to deliver the expected results, and therefore require companies to be transparent on how they will manage uncertainty on future technologies' availability. However, assessment should not penalize companies for considering less mature technologies, nor for specializing in a particular production route, as the steel industry as a whole needs to investigate and invest in all possible decarbonization routes.

Third, another difficulty in evaluating if steel producers' investments are sufficient to deliver on their net zero target is that most of these investments are not directly linked to steelmaking assets. The Carbon Cost scenario from Mission Possible Partnership estimates that investment in enabling infrastructure such as CO_2 storage, hydrogen infrastructure, and zero-carbon electricity production is likely to dwarf that of the steel assets themselves. The MPP scenario provides a breakdown of cross-value chain capex per technology and production route (MPP, 2022a) which highlights that investment in low-emissions primary steelmaking and scrap-based steelmaking will only account for 7% of the total cumulative cross-value-chain investment while most of the required investment is linked to electricity generation and networks, and somewhat to hydrogen production, transport, and storage and then to CO_2 transport and storage. Steelmakers might expand their industrial expertise outside of steelmaking, with many actors developing on-site low-carbon hydrogen production. For instance, Liberty, Paul Wurth and SHS are investigating the feasibility study for a DRI plant in France, which will include a 1 GW hydrogen plant. Collaboration with other actors, especially public actors, will also determine the likelihood of success of deploying net zero steelmaking, and current pilot projects receive significant public funding. For instance, the construction of a hydrogen-based DRI pilot plant was half funded by the Swedish Energy Agency. The Course50 project, a project to develop carbon capture in blast furnaces, in Japan is also funded by a mix of public and private funds (IEA, 2022).

Assessment methodologies often evaluate the credibility of capital expenditures and R&D expenses compared to estimated ideal levels from a benchmark. As a result of the complex investment profile of the steel industry, this exercise is much harder if possible at all. For instance, ACT assesses R&D strategies by analyzing the patenting activity of a company over the last 5 years, focusing on the share of mitigation patents over total patents.

It also considers the last 3 years of R&D spending, based on the share in mature mitigation/low-carbon R&D and on the share of non-mature mitigation/low-carbon R&D. While this approach is limited to assess the relevance of a company's financial planning regarding the net zero transition, the methodology gives more weight to R&D expenses in non-mature technology, to reward actors who commit to the riskier bet of making the much-needed technological breakthroughs happen.

While it is hard to identify relevant thresholds, indicators such as the share of capital expenditures and R&D spending in low-carbon and mitigation methodologies remain essential and still provide useful information on the level of ambition and commitment to reaching net zero of a steel producer. Further work is needed to determine quantitative thresholds to assess whether CAPEX and R&D expenses are sufficient to enable a company to deliver on its net zero strategy. Companies should ensure consistency in their disclosure by allocating significant CAPEX and R&D expenses to the technologies they plan to rely on.

4.1.3 Financing the decarbonization of the steel industry

Shifting away from the unabated BF-BOF asset base will have significant costs, both in terms of capital expenditures and production costs (Yu et al., 2021; International Energy Agency, 2023; Bataille, Stiebert, and Li, 2021; MPP, 2022b)**. Companies should demonstrate enough financial flexibility to fund their decarbonization,** whether they will fund their transition using operational cash flows – especially thanks to an increased demand for low-emission steel – the balance sheet, and/or capital markets. In order to enable the transition towards net zero, FIs will therefore have to provide sufficient capital to develop near-zero production technologies as well as cleaner power generation and to constrain financial services to companies which are building new unabated BF-BOFs assets or relining existing ones. Financial actors will face different risk profiles, with short-term decarbonization levers such as material and energy efficiency offering short payback periods while financing the shift toward near-zero technologies will require more capital, include higher technological risks, and take longer to pay back (Gardiner & Lazuen, 2021).

Public actors can also play a significant role in giving more financial flexibility to steel actors by supporting R&D early-stage investment and innovative cleaner technologies, for instance through project-based carbon contracts-for-difference which guarantee stable revenue from carbon savings (Richstein & Neuhoff, 2022). Since steel is globally traded, producers will struggle to pass the additional costs of investing in near-zero production technologies without becoming less competitive.

Through carbon pricing mechanisms such as a carbon tax or mechanisms to prevent carbon leakage, regulators can make cleaner production more competitive. Support from public actors will vary across geographies which will impact the ability of each company to decarbonize. Therefore, disclosing how the regulatory environment supports a company's decarbonization plan could increase credibility.

4.2 Indirect action pathways

This section delves deeper into the question of what actions a steel company should be taking (or not) to support the decarbonization of the steel sector in general which indirectly impacts a companies' direct CO_2 emissions. The key question for FIs that seek to assess steel companies' credibility of reaching net zero is to what extent policy and public engagement actions support net zero.

Engagement with policymakers and regulators

Given the importance of policymakers' and regulators' action on the steel industry, companies engage with them to defend their interests but there is little transparency on how they interact with these actors. Active engagement with climate policy is hard to monitor because the information is poorly disclosed, as companies rarely advertise lobbying against climate change policies, especially given that these lobbying activities can occur through third-party entities such as industry associations. Besides, lobbying activities are hard to keep track of given the number of existing or potential climate regulations.

Companies should disclose and be assessed on their position regarding key climate policies (such as carbon pricing), on their governance regarding lobbying activities, and on their membership to industry associations and trade unions and their respective positions. Section 3.3 from the TPT Disclosure framework or section C12.3 in CDP's climate change questionnaire provides specific guidelines to report on these issues.

Lobbying against climate policies indicates that companies are not serious about climate action, raising questions about the credibility of their own climate commitments. It also makes a policy environment that supports net zero less likely. Therefore, for transition plans to be credible, they need to include disclosure regarding a company's lobbying activities. The Global Standard on Responsible Climate, was launched in 2022 by a group of investors including AP7, BNP Paribas Asset Management and the Church of England Pensions Board.

It sets out 14 indicators to clarify exactly what investors expect from companies regarding disclosure, governance and oversight processes to ensure company alignment between climate policy engagement and the 1.5°C goal of the Paris Agreement.

While this standard outlines the disclosure expected from companies, engagement with climate policy is hard to assess given the lack of information and constant evolution of lobbying activities. InfluenceMap specializes in the assessment of these activities, using the Global Standard on Responsible Climate Lobbying, and its scoring is now fully integrated in the assessment conducted for CA100+ companies. Incorporating InfluenceMap's scoring in the CA100+ assessment seems efficient as assessing lobbying relies on different sources of information – often outside of the company's disclosure – and requires specific expertise, especially regarding knowledge of industry associations and public policies. Quantitative assessment of engagement, for instance using spending in lobbying activities, is limited and assessment is more qualitative, for instance by looking at the position of the company regarding specific climate policies. The task is complex, as it involves following how large international corporations engage with policies and public actors in each of the countries where they operate, while it covers an issue which seems less material than the assessment of emissions reduction targets or capital expenditures.

5. Deep dives and specific issues

5.1 Regional variation

Steel production and decarbonization strategies will differ across countries depending on several dimensions such as regional demand and supply, energy prices, input availability, the relative price competitiveness of each technology, the state of the current steelmaking asset base and its evolution, or even the public acceptance of different technologies. Uncertainty along all these dimensions makes the computation of regional pathways complex. In this section, we discuss these criteria and how they might have regional impacts on steel decarbonization.

First, prices and availability of inputs such as iron ore or scrap steel vary across regions. For instance, scrap availability is expected to increase in China (Xylia et al., 2018) as there was a significant boost in Chinese production in the early 2000s and steel-based products are expected to reach the end of their life in the coming decades (World Steel Association, 2022a).

However, scrap availability is already constraining production in India and despite plans to increase scrap availability, the growth of scrap steel availability is unlikely to match India's ambition to grow steel production (Ministry of Steel, 2019). Availability of scrap steel is expected to have a limited growth in the US, the EU and Japan, making it a less relevant decarbonization lever in these regions than in China. However, it is important to note that scrap steel use is already very high in these regions, reaching 70% in the US and 50% in Europe (IEA, 2020b). The credibility of strategies based on the increased use of scrap steel will vary across countries.

Steel production assets also differ significantly across regions. Steel plants in India use 40% more energy per ton of steel produced than the global average (Hall, Spencer, and Kumar 2020) meaning that the potential to reduce future emissions by energy efficiency improvement is higher than in other regions. As India plans to grow its steel production capacity in the short term, the country will develop new plants despite the lack of availability of near-zero production technologies. Given the lifetime of these plants, there will be significant challenges to retrofit them to make them switch to low-carbon production technologies or to decommission them. Countries will also adopt different strategies to deal with their ageing BF-BOF assets. According to the IEA, Europe, which has an old but recently refurbished blast furnaces asset base, is more likely to invest in a diverse portfolio of technologies including relining and retrofitting the existing blast furnaces with low-carbon technologies, while the United States are expected to switch more to DRI assets because of the availability of cheap natural gas and CCUS potential (IEA, 2020b).

Companies' transition pathways are likely to be influenced by national pathways. Whether a company is privately owned or state-owned, it is important to address how governments' net zero strategies and commitments could be taken into account when assessing steel companies' credibility in decarbonizing steel production. A first channel through which government influence is transmitted is through significant levels of subsidies that steel companies often receive from governments for developing net zero steel production technologies, particularly in the pilot and pre-commercial stage of technological development. Given that most of the investment to make net zero steel happen takes place outside of the steelmaking value chain, public policy regarding the energy sector and CCS will also significantly impact decarbonization levers available to steel companies. For instance, the ambition of a country to develop CCS through industrial clusters, extensive pipeline infrastructure and geological storage potential will determine to what extent CCS is an option for steelmakers.

Finally, a country's ambition to decarbonize will also impact the ambition of steel producers. Increased regulation is pushing companies to move faster for instance through carbon pricing mechanisms such as the European Union Emission Trading System, which covers EU steel producers and is being extended to non-EU producers with the Carbon Border Adjustment Mechanism, or the Chinese Emission Trading System which is scheduled to be expanded to the steel industry. However, countries' influence can go both ways as 70% of the world's steel production in 2021 is located in countries that aim to reach net zero later than 2050 (or not at all in the case of Iran, Mexico, Malaysia, and Egypt). This discrepancy heavily threatens any scenario where the steel industry reaches net zero by 2050. Future work needs to address to what extent the regional concentration of steel production in China and India influences the assessment of credibility in the steel sector.

Given how much net zero claims rely on geographical and national factors, a discussion on how a corporate net zero strategy fits in its local context or a national steel industry roadmap – if it exists – would reinforce the credibility of a net zero claim. Countries, on the other hand, need to provide more clarity to steelmakers regarding their industrial policies and the national goals they plan to reach. These national plans should themselves be assessed to ensure that they are internally consistent – for instance planning on developing sufficient low-carbon hydrogen production to meet the expected consumption from all the sectors – and ambitious enough. More robust and publicly available industrial roadmaps could allow stakeholders to account for regional characteristics when assessing corporate claims. However, while being strong determinants of corporate decarbonization pathways, national roadmaps are not accounted for in ACT's and CA100+'s assessments.

5.2 External consistency checks using asset-level data

Applying analysis of asset-level data at the steel production level to assess the credibility of steel companies independently of corporate disclosure holds great potential as an external consistency check of steel companies' disclosed transition plans. Asset-level data on steel production facilities is already available from a number of different sources, including Global Energy Monitor (Global Energy Monitor, 2022), the Spatial Finance Initiative (McCarten et al., 2021), net zero steel (Bataille, Stiebert, and Li 2021), as well as the datasets underpinning the PACTA tool maintained by the Rocky Mountain Institute.

The key principle for such "external consistency checks" should be that if steel companies are not willing to disclose relevant data points at the asset level (such as

production technology, volume, changes over time, and expected asset lifetimes), a robust credibility assessment should examine steel companies' CAPEX plans as well as emission trajectories and carbon lock-in of the existing asset base based on conservative assumptions on (changes to) technologies in primary steel production (including relining of BF-BOF assets) to reduce the risk of "alignment greenwashing". By "alignment greenwashing", we mean situations in which steel companies improve net zero alignment assessments through means that have no impact on actual emission reductions in the real economy (Caldecott, Thomae et al., 2022; Caldecott, Clark et al., 2022), such as disclosing more ambitious (long term) net zero targets while continuing the operation of unabated high-emitting BF-BOF steel production assets.

5.3 How to ensure consistency in "aggregated" transition plans

A knowledge gap with regards to assessing the credibility of steel companies that future research needs to address (and that current frameworks for assessing credibility also neglect) is how to assess the aggregated transition plans of *all* steel companies (ergo, of the steel sector). One obvious issue that will almost inevitably arise from the large-scale adoption of transition planning is how to make sure that the transition plans of steel companies "add up" across all steel companies at the sector (or portfolio) level since so far consistency checks are still lacking. For example, we could assume that a bank may have ten different steel companies among its clients in its loan book or portfolio which together account for 10% of global production. If the transition plans of all ten steel companies include certain levels of utilization of green hydrogen or high-grade DRI pellets, which mechanisms or tools could the bank use to make sure that in aggregate all assumptions add up to the assumptions of a realistic transition scenario? What would this mean for the bank's approach to assess the credibility of its clients to reach net zero?

6. Concluding remarks

In this discussion paper, we proposed that what matters for assessing the credibility of steel companies to reach net zero by 2050 in Paris-aligned 1.5°C scenarios is the disclosure and assessment of detailed investment planning, preferably at the asset level or at least at the asset type level, rather than emission reduction targets and trajectories at the corporate level alone.

Beyond short-term decarbonization, the key question that FIs and other external stakeholders should use to guide the assessment of steel companies' credibility of reaching net zero is: Which steel production technology will company X utilize once the companies' existing BF-BOF assets need to be relined? Rather than a "nice-to-have" element of transition plans, we propose that more comprehensive disclosure of asset-level investment planning (that underpins targets and corporate-level strategies) is ultimately required to make transition plans of steel companies credible.

The steel-sector-specific minimum disclosure requirements for credible transition planning of steel companies should be:

1. **Disclosure of relevant information on all material steel production assets, including production technology by main production route (i.e. BF-BOF, DRI-EAF, and scrap-EAF) and production capacity, current emissions, planned technology changes over time, and expected impact of technology changes on CO2 emissions (absolute and intensity based) at asset, production route, and corporate levels.**
2. **Corporate policy with commitment to exit unabated coal-based primary steel production and not reline existing or invest in new BF assets without CCS at a required capture rate of 90% after around 2025–2028**, with more stringent expectations for OECD countries and more latitude being given to emerging economies.

At the same time, this type of transition plan disclosure can significantly enhance the assessment of corporate direct actions that is typically conducted with tools such as PACTA or CLICs because the disclosed information on facility-level production enhances the precision of the overall assessment. It also incentivizes steel companies to disclose realistic assumptions on future steel production to not be "punished" by independent assessments that would otherwise choose the most conservative assumptions (e.g. for remaining economic lifetimes or emission factors of assets) at the facility level based on already publicly available global asset-level datasets covering the steel sector. It is in this way that independent asset-level data assessments can serve as "external consistency checks" of disclosed transition plans to reduce the risk of "alignment greenwashing".

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