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Climate targets by major steel companies: An assessment of collective ambition and planned emission reduction measures

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ABSTRACT

This article systematically assesses the status, robustness, and potential impact of greenhouse gas emission reduction targets set by the largest steel producer companies as of mid-2022. The assessment covers the 60 largest steel companies by volume, accounting for more than 60 % of global steel production. Data on company-level greenhouse gas emission reduction targets and emission reduction measures were collected from publicly available documents.

We found that only 30 companies have their own greenhouse gas emission reduction targets of varying timeframes between 2025 and 2060. Even when excluding the 15 Chinese state-owned companies that are under the national 2060 net zero target, 15 companies had no emission reduction targets. Twenty-one companies had long-term targets (2040 or after), of which 18 were net zero emission targets; all but one also had interim targets. If all climate targets identified among the 60 companies are achieved, annual CO_2 emissions for the 60 companies could be reduced by up to 12 % by 2030 and up to 39 % by 2050 in comparison to a baseline scenario. Assuming a gradual increase in global crude steel demand from 1.9 Gt in 2019 to 2.5 Gt in 2050 and assuming similar trends for the rest of the global iron and steel sector as observed for the 60 companies, we estimate that the current ambition of the global iron and steel sector on emission reductions would lead to a reduction of 38 % to 53 % by 2050 from 2019 levels (3.4 $GtCO_2$ to 1.6–2.1 $GtCO_2$), or compared to a 32 % to 43 % reduction in a baseline scenario in 2050.

Steel companies are also lagging in setting clear emission reduction plans to achieve their targets. We found that 14 out of the 30 steel producers with targets did not provide an emission reduction plan. The most popular measures amongst the 16 companies that identified at least one measure to achieve their target in their emission reduction plans were hydrogen-based DRI ($n = 14$), enhanced use of renewable electricity ($n = 13$) and Carbon Capture Utilisation and Storage (CCU/S) for blast furnaces ($n = 9$). While it is encouraging that the steel companies have started acting toward long-term deep decarbonisation, our findings suggest that there is a long way ahead and the action needs to be accelerated considerably.

Introduction

The iron and steel sector has a crucial role in the transition towards long-term decarbonisation. To achieve the Paris Agreement's 1.5 °C temperature goal, global carbon dioxide (CO_2) emissions needs to be reduced to net zero by around 2050 [1,2]. While immediate and drastic greenhouse gas (GHG) emission reductions need to take place in all sectors to achieve mid-century net zero emissions, emissions are more difficult to reduce in some sectors than in others. Amongst those hard-to-transition sectors is the iron and steel sector, a major emitter that is estimated to emit about 3.7–4.1 $GtCO_2e$ annually depending on the accounting of value chain emissions [3]. With limited decarbonization options, a long economic lifetime of production plants, and a further demand increase in the coming decades, the iron and steel sector has a challenging road towards decarbonisation [4,5].

For these reasons, the iron and steel sector was considered a 'hard-to-abate' sector for a long time [6]. However, this view is quickly changing as advanced low-emission steel technologies have become closer to commercialisation and the political and consumer pressure increases. Even for these industry sectors, the construction of high-emitting

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conventional plants needs to be avoided to keep warming below 1.5 °C with no or limited overshoot [7,8]. Since the adoption of the Paris Agreement, an increasing number of studies on the decarbonisation of steel production have been published.

Global level emission scenario studies show that reaching near zero CO_2 emissions in 2050 is possible, even though challenging, through a combination of multiple existing and emerging options for both demand (i.e. reducing final demand through improved product design, increasing material efficiency and through circular economy) and supply (i.e. improving energy efficiency, switching to new processes that use low to zero emissions energy carriers and feedstock) [3,4,6,8–10]. Emerging country-level studies also drew similar conclusions [11–13]. There is consensus amongst scholars that the iron and steel sector needs to move from incremental to transformational changes to achieve full decarbonisation around mid-century. Implementing this array of options would require intensive innovation, commercialisation, and policy to ensure its uptake [3,6]. Therefore, it is important to understand if and how the sector is transitioning. As the momentum for long-term decarbonisation rises, we also see an increasing number of projects that track transition progress in the iron and steel sector by looking at various indicators such as the global iron and steel fleet, emissions intensity from steel production, new and announced low-carbon steel projects [9,14,15].

Partially in sync with the wave of net zero emission targets announced by national governments, companies have also started taking action towards decarbonisation in the past several years [16,17]. Many steel companies have also signalled their willingness to reduce their GHG emissions and have set climate-related targets [14]. While some studies suggest that the industry is lagging by focusing only on conservative measures such as fuel switching [6], we find that the literature on GHG emission reduction targets and plans by individual steel companies is relatively scarce. Comprehensive assessments on the adoption, metrics, and stringency of existing corporate GHG mitigation targets published to date considered manufacturing industries in aggregate terms [18–21]. Day et al. [22], and Mooldijk et al. [23] propose a method to evaluate the integrity of corporate net zero targets and estimate long-term GHG emission target trajectories for companies with long-term net zero emission targets including a few steel companies. The Green Steel Tracker project [14] regularly tracks the development of low-carbon steelmaking projects and GHG emission reduction targets by steel companies but does not assess the aggregate corporate effort against the global climate goal. Vogl et al. [6] estimated the global GHG emissions resulting from operating global primary steel production infrastructure through its economic lifetime and found that failing to phase out blast furnaces risks achieving the global climate targets.

However, no study to date comprehensively assessed GHG emission reduction targets and plans by the major steel companies and estimated their potential impact on future GHG emissions and their consistency with the global 1.5 °C goal under the Paris Agreement. Against this backdrop, this article systematically analyses the status, robustness, and potential impact of greenhouse gas emission reduction targets set by the world's 60 largest steel producer companies as of mid-2022. Our research focuses on the target-setting and the transition plans of major steel companies towards decarbonisation, both individually and collectively. We aim to obtain insights into the integrity of emission reduction target-setting and planning by the major steel companies in the light of required actions to enable the necessary transition of the global iron and steel sector in line with keeping warming to 1.5 °C.

Data and methods

Overview of assessment indicators

Informed by the literature on corporate climate action integrity [22,24] as well as by the recommendations of the United Nations High-Level Expert Group on the Net Zero Emissions Commitments of Non-State Entities (UN HLEG) [25], we assess the following components of corporate climate action integrity related to target-setting and planning:

- Target setting: Landscape assessment of GHG emission reduction targets for the short-term (2029 or earlier), mid-term (2030–2039) and long-term (2040 or after);
- Target ambition (collective): Quantification of emission trajectories up to 2050 in the global iron and steel sector under the existing company-level targets, in comparison with 1.5 °C-consistent pathways;
- Implementation plan: Qualitative assessment of publicly-available corporate documents about how companies plan or intend to achieve their short-, mid-, and long-term decarbonisation targets, including a concrete set of emission reduction measures.

Other components of corporate climate action integrity such as just transition and lobbying are not considered in this study [25]; transparency and accountability concerning companies' climate action and progress were integral to the research presented here, but they were only assessed indirectly through the above-mentioned integrity components. Our analysis focuses on CO_2 emissions from the steelmaking processes, which is by far the most dominant GHG from the steel companies. Detailed methodology and data sources used for the assessments are described in the following sections.

Selection of companies and their main characteristics

We selected the 60 largest steel producing companies for the analysis based on the crude steel production in 2020 [26]: Ansteel Group, Anyang Steel, ArcelorMittal, Baotou Steel, Benxi Steel, CELSA Steel Group, China Baowu Group, China Steel Corporation, CITIC Pacific, Delong Steel Group, Donghai Special Steel, Erdemir Group, EVRAZ, Fangda Steel, Gerdau, HBIS Group, Hyundai Steel, Iranian Mines & Mining Industries Development & Renovation (IMIDRO), JFE Steel, Jianlong Group, Jindal Steel and Power Ltd (JSPL), Jingye Steel, Jinxi Steel, Jiujiang Wire Rod, Jiuquan Steel, JSW Steel, Liberty Steel Group, Liuzhou Steel, Magnitogorsk Iron & Steel Works (MMK), Metinvest Holding, Nanjing Steel, Nippon Steel Corporation, Novolipetsk Steel (NLMK), Nucor Corporation, POSCO, Puyang Steel, Rizhao Steel, Ruifeng Steel, Salzgitter Group, Sanming Steel, Severstal, Shaanxi Steel, Shagang Group, Shandong Steel Group, Shenglong Metallurgical, Shougang Group, Sinogiant Group, SSAB, Steel Authority of India Ltd. (SAIL), Steel Dynamics, Inc., Tata Steel Group, Techint Group, thyssenkrupp, Tsingshan Holding, United States Steel Corporation, Valin Group, voestalpine Group, Xinyu Steel, Yingkou Plate, Zenith Steel. Headquarters location and production data for 2020 can be found in Table S-1 in the Supplementary Data. These 60 companies accounted for 64 % of global primary steel and 52 % of secondary steel production in 2019.

The main production route amongst the 60 largest companies was the blast furnace–basic oxygen furnace (BF-BOF) route with a 78 % share in total crude steel production in 2019, which is slightly higher than the world average (72 %) [27]. This was followed by 19 % from the scrap-electric arc furnace (scrap-EAF) route and 3 % from the direct reduced iron-(DRI-)EAF route. Nearly half of the companies are headquartered in Asia (44 companies, which produced 47 % of global crude steel in 2019), followed by European Union (seven companies), North America (three companies), South America (two companies), and Middle East and Africa (one company each). Most companies are headquartered in China (31 companies), followed by India and Russia (four companies each), the US (three companies), Japan, Germany and South Korea (two companies each). The rest of the countries have only one company each.

Collection of emission reduction targets data

We collected information on historical global and company-specific crude steel production, from the World Steel Association [26] and companies' documentation. Amongst the existing sources for corporate GHG emissions reduction targets, the Green Steel Tracker database is the most comprehensive source for steelmakers [14]. Therefore, we used the Green Steel Tracker as a starting point and complemented it with information from companies' public documentation. This includes, for example, annual reports, sustainability reports and sustainability web pages. Other data sources, such as voluntary initiatives like the CDP (formerly Carbon Disclosure Project) and the Science Based Targets initiative (SBTi) were used to cross-check where relevant [28,29]. We collected climate-related targets and emission reduction plans as of July 2022.

For the 60 companies selected, we systematically collected information on the climate targets of companies, the target year(s), their emissions scope(s), and the underlying target assumptions. We considered only publicly available information provided in English. For those with (a) climate target(s), we also collected information on which technologies or measures the companies consider for realising their GHG emission reduction target(s): the emission reduction plans.

Long-term GHG emission trajectories under the targets

The global GHG emission scenarios up to 2030 developed in this analysis considered both direct and indirect CO_2 emissions from the global iron and steel sector. The system boundary applied in this study is based on Hasanbeigi [30], which includes: coke production, pelletising, sintering, ironmaking, steel making and casting, hot and cold rolling and processing (e.g. galvanising and coating). Energy use and CO_2 emissions associated with imported iron and coke are also included. The defined system boundary is also largely consistent with the accounting of 'direct and indirect' emissions by the IEA and by the World Steel Association [4, 31].

Global GHG emission scenarios were developed bottom-up by collecting production activity and emissions data, both historical and scenario-specific future estimates, taken from various sources and our own assessments. We assessed two GHG emissions scenarios. The first is the *baseline scenario*, which is partially based on the IEA Stated Policies Scenario (STEPS) [4]. The IEA STEPS considers the energy and climate policy commitments of countries, including the nationally determined contributions under the Paris Agreement, and has 2019 as a base year [4]. The second is the *corporate targets scenario*, in which all existing GHG mitigation targets set by individual companies are assumed to be achieved. Details of the development of emission projections under the two scenarios are described below in detail.

Baseline scenario

CO_2 emissions from steel production are estimated based on crude steel production or expected demand and the emission factor of the production route. Our baseline scenario has 2019 as a base year. We then develop CO_2 emissions projections between 2020 and 2050. Global iron and steel sector CO_2 emissions in year t ($E(t)$: $MtCO_2$/yr) were calculated as follows:

$$E(t) = \sum_i \sum_j \left[CSP_i(t) * PRS_{\,i,j}(t) * EI_{i,j}(t)\right] \quad \text{(Eq. 1)}$$

where $CSP_i(t)$ is annual crude steel production of company i in year t [Mt crude steel/yr]; $PRS_{\,i,j}(t)$ is the share of steel production route j in total crude steel production in company i in year t [dimensionless] and $EI_{i,j}(t)$ is the emission factor of the steel production route j in company i in year t in [t CO_2/t crude steel]. Emissions from the steel companies outside the top 60 are referred to as Rest of the World (RoW).

For the baseline scenario projections, we made a general assumption that the future production levels and the share of steel production routes of a company follow the trends of the country where the companies are headquartered. This is based on our finding that, with a few company exceptions, the vast majority of over 400 steel plants were located in the companies' headquartered countries [32]. We identified 24 of the 60 largest steel companies in the Global Steel Plant Tracker database. Exceptions to this general modelling assumption are described in the subsequent sections.

We considered the following steel production routes (j) in the baseline scenario: BF-BOF route (primary steel), DRI-EAF route (primary steel), open hearth furnace route (OHF[1]; primary steel), and the scrap-EAF route (secondary steel). Emissions intensity values vary across companies, production routes, and geographies. They are also expected to change over time without stringent policies to reduce emissions.

Crude steel production (CSP). The global annual steel demand is assumed to increase from 1.9 Gt in 2019 to 2.5 Gt in 2050, which agrees well with the values assumed or projected in the recent literature (range: 2.3–2.7 Gt) [4,33–36]. While at aggregate country level, our steel demand projections also agree with others in the literature, the future of individual steel companies is highly uncertain especially in countries where the demand has peaked or is close to peaking. Some companies may keep or even increase the market shares through merger and acquisition and geographic expansion of operations, while others may focus on high-added value products while reducing their production levels, or they may diversify their business in other sectors. Therefore, we explored two cases for company-level future steel production. In the first case, we assumed that the market shares of the 60 largest companies in terms of annual crude steel production remain constant at 2019 levels until 2050, meaning that all companies will increase their production levels over time. In the second case, we assumed that the crude steel production levels reduce by 25 % from 2019 levels for companies headquartered in East Asia (China, Japan, South Korea, and Taiwan), in line with the estimates by the Mission Possible Partnership [37], while the production levels remain constant at 2019 levels through 2050 for the companies headquartered elsewhere.

For companies headquartered in all other countries and regions (i.e. India, Iran, Africa, Middle and South America, rest of Asia, and Russia), we assume that their shares in global total steel production will remain at 2019 levels until 2050. The crude steel production levels for RoW were assumed to fill the gap between the global total as projected in IEA STEPS and the sum of the 60 largest companies.

Production route shares at company level (PRS). Historical production shares for different production routes for 2019 were collected in a two-tiered approach. First, we collected shares per production route reported by companies (available for 5 companies) and calculated the production route share with information of the Global Steel Plant Tracker [32] (available for 6 companies). When company-specific data were not available, we assumed the average shares of the country in which a company is headquartered; data were collected from [27,32] (see Table S-2 in the Supplementary Data).

For future years up to 2050, production route shares per company were assumed to linearly converge to the projected shares in 2050 for the region where they are headquartered under the IEA [4] STEPS. As with total production levels, exceptions were applied to ArcelorMittal, for which global average projected shares were assumed for 2050. IEA STEPS projections show that the share of primary steel production using the BF-BOF route – the most common route – will decrease in 2050 in most countries and regions (e.g. China, the European Union, the Middle East, the United States) but will increase in others (e.g. India, Africa,

[1] Ansteel Group does not specify a year for carbon neutral emissions, but mentions the national 30-60 strategy, we have therefore interpreted as 2060 in line with the national climate commitment.

Central and South America) compared to 2019 values (a 27 % decrease globally). The share of DRI-EAF will overall increase by around 70 % globally. The share of secondary steel with the scrap-EAF route will also increase in most countries and regions by more than 60 % (See Table S-3 in the Supplementary Data for global estimates of the technology shares development through 2050). For companies with OHF steel production, we assumed OHF shares to phase out in 2030; note that IEA STEPS does not consider the OHF route (as the global shares are small and will likely only decrease in coming years). The crude steel production levels per production route for RoW were assumed to fill the gap between the global total as projected in IEA STEPS and the sum of the 60 largest companies.

Emissions intensity (EI). CO_2 emission intensity values under the baseline scenario were estimated per production route and company headquarters location. 2019 estimates for the BF-BOF and scrap-EAF routes per country are taken from Hasanbeigi [30]. We did not use CO_2 emissions data reported by the companies themselves because they often include emissions from business operations other than steelmaking, which are outside our research scope. For future years, the average CO_2 intensity for the BF-BOF route was assumed to converge globally by 2050 for the entire global production. We investigated the high and low convergence levels of 1.8 tCO_2/t-cs and 1.6 tCO_2/t-cs; these values are based on the literature on the best available technologies (BATs) and other baseline scenarios [4,38–40]. This means a roughly 10–20 % reduction in average CO_2 intensity just for China (above 2 tCO_2/t-cs in 2019) and a 0–10 % reduction for Germany (1.8 tCO_2/t-cs in 2019) [30] (see Table S-3 in the Supplementary Data for detailed estimates).

For the scrap-EAF route, CO_2 intensity is assumed to gradually decline as the electricity CO_2 factor reduces as projected in the IEA STEPS scenario [41] and with a gradual reduction in energy intensity towards the level of Japan, the best-performing country as assessed by Oda [42], by 2050 (see Table S-4 in the Supplementary Data for detailed estimates). For companies based in China, where a significant amount of pig iron is used as an EAF feedstock, we assumed that the pig iron-fed EAF steel production would completely shift to scrap-fed by 2050. For the DRI-EAF route we assumed that vast majority of global production is natural gas-fed and that the emission intensity to decrease from 1.6 tCO_2/t-cs to 1.3 tCO_2/t-cs by 2050 for all countries except India [40,43]; for India where the DRI-EAF route is predominantly coal-fed, we assumed an emission intensity of 3.4 tCO_2/t-cs based on IEA [4] throughout the modelling period. The CO_2 emission intensity of OHF steel is assumed to be four times as high as that of China's BF-BOF steel CO_2 intensity in 2019 and remains constant over the modelling period [44].

Corporate targets scenario

We identified four types of emission reduction targets:

1. Carbon neutrality target, climate neutrality and net-zero emission targets: a company wants to achieve (net) zero CO_2 or GHG emissions.
2. Absolute emission reduction target: a company aims for a percentage decrease in CO_2 or GHG emissions, compared to a base year.
3. Emission intensity target: a company aims to reduce the emission intensity of steel production by a certain percentage or achieve a specific emission intensity level.
4. Peak emissions target: a company aims to start reducing emissions after the target year (i.e., peak emissions in the target year). This target type is unique for Chinese companies and in particular for state-owned ones.

We categorized GHG emission reduction targets by time frame based on the target year. We applied the terminology "only or final target" and "interim targets" in case a company adopted only one or more target(s). If a company adopted more than one target, the target that is furthest away in the future (i.e., the highest target year) was listed as "only or final target". The other target(s) was/were characterised as "interim target".

Emission reduction target values were collected specifically for scope 1 and 2 emission reduction targets. For interim targets, whenever available we collected the reduction target values for their own emissions. When the emission scope coverage was not clarified, we assumed that a target covered scope 1 and 2 emissions.

The quantification of absolute emission levels under the targets was done as follows: for climate neutrality, carbon neutrality, and net-zero emission targets, decarbonisation scenario studies indicate that there will be some residual emissions for all production routes even in 2050 with advanced technologies [37]. For these corporate targets, we assumed their emissions intensity to reduce by 90 % from the baseline scenario emission levels without carbon dioxide removals and offsets; this assumption is consistent with the literature on the iron and steel sector decarbonisation pathways [34,37,43]. For other targets, we assume that emission levels to remain constant after the final target year until 2050. For intensity targets, we quantified the absolute emission levels by multiplying the intensity values by the crude steel production levels as described in section 0. For companies with multiple targets, we have assumed linear emissions reduction between the two target years. For companies with targets in 2030 but without intermediate targets between 2020 and 2029, we have assumed emissions will start linearly decreasing after 2025 until 2030.

Additionally, we investigated the CO_2 mitigation potential of Chinese state-owned enterprises (SOEs) in the top 60 that do not have a climate target. Of the 60 top steelmakers, 31 are headquartered in China, 21 out of these are SOEs, where 19 are fully state-owned, and two have more than 50 % state ownership [45]. Chinese SOEs are subject to China's national, regional and sectoral emission reduction targets, and therefore fall under China's national steel target of achieving net-zero carbon emissions by 2060 and peaking emissions by 2030 [46]. For the baseline scenario, we extrapolated the emissions trend between 2030 and 2050 until 2060. As with the target type (1), we estimated residual emissions in the target year, 2060, to be the product of crude steel and 10 % of the emissions intensity in the base year.

The estimated emission reductions for the 60 largest companies were extrapolated to the global iron and steel sector by applying the emission reduction rate against the baseline scenario to the steel production outside the 60 largest companies. We estimated the emission reduction rate as the share of emissions covered by targets under the targets scenario compared to the baseline scenario for the largest 60 companies.

Emission reduction measures considered in the climate action plans

To assess the concreteness of the companies' emission reduction plans, we also collected information on the emission reduction measures described in their emission reduction action plan documents. We also collected emission reduction measures that were not explicitly linked to the GHG emission reduction targets. We analysed whether they contained one or more of the following nine emission reduction measures identified as key options in the literature [4,34,37,47], which are categorised by their emission reduction potential compared to a conventional BF-BOF (see S4 of the SI for details):

- Limited mitigation potential (10–30 %)
  1. Increased deployment of best available technologies (BATs, including top gas recycling without CCU/S) and energy efficiency
  2. Use of hydrogen in BF-BOFs
  3. Increased use of renewable electricity
  4. Smelting reduction (without CCU/S)
  5. Enhanced use of biomass
- Moderate to deep mitigation potential (50–100 %)
  6. Carbon Capture Utilisation and Storage (CCU/S) in blast furnaces

7 Hydrogen-based DRI
- Production route switch
  8 Increased share of scrap-EAF in total crude steel production
- Others
  9 Planned use of offsets

Emission reduction plans can contain more than one measure. All considered technologies or measures were collected and presented except ‘direct electrification’ which was not mentioned by companies. In the case of ‘enhanced use of biomass’, the data collection did not distinguish between sustainable or unsustainable biomass, due to a lack of detail provided by the companies. A few emission reduction measures that would not fall in the above eight categories include e.g. recycling within the process, were listed, but were not highlighted in the results as they are not expected to generate deep emission reductions and are therefore seen as negligible.

As most steelmakers in the 60 largest steel producers use the BF-BOF route, emission reduction measures targeting the BF-BOF route gained specific attention and were highlighted in the results. During the analysis process, however, we accounted for the specific steelmaking routes.

In case companies were not clear about their emission reduction plans, we assigned them the category “unspecified or unclear”. In some cases, this was related to a clear lack of publicly available information. In other cases, we could not deduct the meaning of the publicly available documentation: companies would not present a real plan, but rather list mitigation options and possibilities, or state that several options are being researched.

Results

Landscape of climate target-setting by steel companies

Of the 60 largest crude steel producers, we found that 30 have a GHG emission reduction target[2] (Fig. 1). Twenty-three of them were from companies headquartered outside China, including three each from India, Russia and the USA. These 30 companies accounted for over 746 Mt or 65 % of the 60 largest companies’ total crude steel production in 2019 [48]. Amongst the top 10 producers, eight companies had net zero emission targets with six of them having 2050 as the target year (China Baowu Group, Arcelor Mittal, HBIS Group, Nippon Steel, POSCO, and Shandong Steel Group); two in 2060 (Jianlong Group, Ansteel Group[3]); the other two were Chinese (one private-owned, one state-owned). We have considered the targets of Shandong Steel Group and Benxi Steel to be the same as their parent company China Baowu Group and Ansteel Group respectively, as they were recently acquired [49,50]. For Chinese state-owned steel companies, not having a climate target does not mean a lack of work towards decarbonisation as they are aligned with the national climate targets of peaking carbon emissions in 2030 and achieving carbon neutrality by 2060. When adding Chinese state-owned companies, which are collectively under the national sectoral net zero target, 45 of the 60 largest steelmakers have a GHG emission reduction target of some form (Fig. 1). They collectively accounted for over 933 Mt or 81 % of the 60 largest producers’ crude steel production and 50 % of global total production in 2019.

The companies with long-term net zero emission targets were disproportionately more common ($n = 10$) in developed economies, i.e. European Union member states, Japan, South Korea, the UK, and the US. The remaining eight were found in China and India. By contrast, no net-zero emission target was found for companies headquartered in e.g. Argentina, Brazil, and Russia.

2030 and 2050 are the most common target years for the mid-term (2030–2039) and long-term (after 2040) targets, respectively (Fig. 2). Most of the long-term targets set to date were net-zero emission targets. (Fig. 2). Eighteen companies accounting for almost 600 Mt of the 60 largest steelmakers’ crude steel production in 2019 have net-zero emission targets (Fig. 1); three companies for 2060, 12 for 2050, one for 2040, one for 2045, and one for 2030. Liberty Steel, which committed to carbon neutrality by 2030, has clarified that it intends to use offsets to compensate for residual emissions [51]. All companies with a long-term GHG emission reduction target ($n = 20$), covering over 600 Mt of crude steel produced in 2019 (Fig. 2), have set at least one interim target and an interim target for the mid-term (Fig. 1).

About the interim target types, absolute emission reduction targets ($n = 23$) were found to be more popular than emission intensity targets ($n = 7$) also covering a larger share of crude steel production on a 2019 basis (Fig. 2). The observed trends may partially be explained by the fact that many of these companies operate in countries where the steel demand is not expected to grow significantly.

Potential mitigation from climate targets

Baseline scenario

We estimate CO_2 emissions from the global iron and steel sector under the baseline scenario to decline slightly by 2030 to 3.3–3.4 $GtCO_2$ and then further decrease to 2.8–3.1 $GtCO_2$ in 2050. We project emissions to peak around 2025. Our projected emission reductions despite the continued demand growth until 2050 can be explained by two factors: (1) the increased share of secondary steel in total crude steel production due to the increased scrap recovery and (2) the emission intensity of major steel production routes due to incremental energy efficiency improvement and reduced emission intensity of fuels (e.g. reduced grid electricity CO_2 factor, low-carbon hydrogen in BF-BOF).

Our baseline emission projections for the global iron and steel sector lie in between those from the recent literature [4,33,37]. Specifically compared to the IEA projection, our baseline considers the adoption of the best available technologies (BATs) for BF-BOFs and scrap-EAFs whereas the IEA considers it under a deep decarbonisation scenario (SDS).

We estimate that the emissions coverage of the 60 largest companies will continuously decrease from 2.2 $GtCO_2$ in 2019 to 1.8 to 2.2 $GtCO_2$ in 2030 (a 1–21 % reduction) and 1.1–1.9 $GtCO_2$ in 2050 (14–52 % reduction). The wide projection range in 2050 is mainly due to the large uncertainty on their future shares in the global steel market, whether their production levels would grow proportionally to the global demand growth or remain constant or even decrease in some regions. The share of BF-BOF production in the 60 largest companies is projected to decrease from 77 % in 2019 to 56 % in 2050. In comparison, the share of BF-BOF steel production in the Rest of the World was projected to decrease from 62 % in 2019 to 49 % to 52 % in 2050.

Mitigation potential of climate-related targets

We estimate that the aggregate annual CO_2 emissions of the 60 largest steel producers under the Targets scenario, considering only the 30 companies with their own targets, to range between 1.7–1.9 $GtCO_2$ in 2030 and 0.71–1.2 $GtCO_2$ in 2050 (Fig. 3); they equal to a reduction of 7–12 % in 2030 and 32–43 % in 2050 when compared to baseline scenario projections. The upper bound projections reflect a high BF-BOF emission intensity convergence level in 2050 and high total steel production from the 60 companies, whereas the lower bound projections reflect a low BF-BOF emission intensity convergence level in 2050 and low steel production for the 60 companies. When also including the 15

[2] Two of this companies, Shandong Steel Group and Benxi Steel, did not have own targets but were acquired by companies with targets within the last year (China Baowu Group and Ansteel Group respectively). For those companies we assumed the new acquisitions to be included in the target and quantified them in the corporate targets scenario, but we did not include the measures mentioned in the parent company.

[3] Ansteel Group does not specify a year for carbon neutral emissions, but mentions the national 30-60 strategy, we have therefore interpreted as 2060 in line with the national climate commitment.

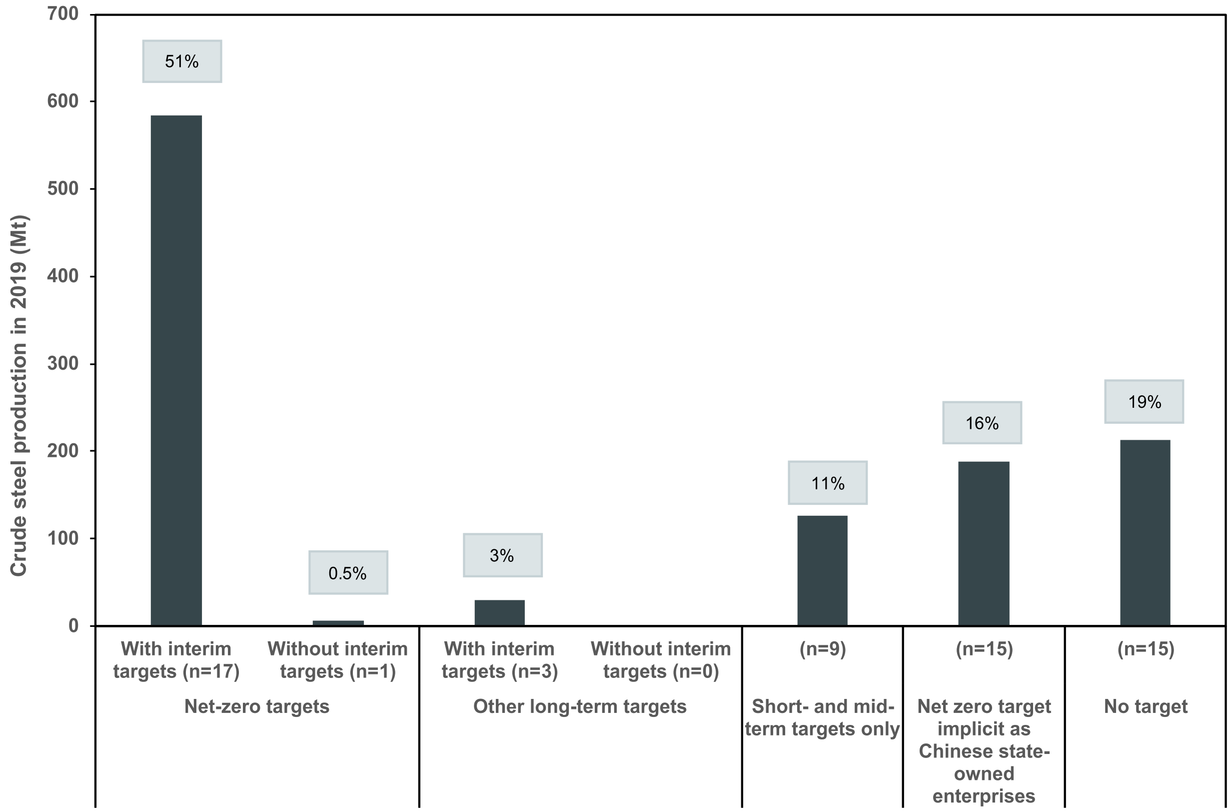

Fig. 1. Overview of GHG emission reduction targets set by the 60 largest steel companies. The percentage figures represent the shares in the total crude steel production of the 60 largest companies in 2019.

Chinese state-owned companies under the national 2060 net zero target, the emission projections for 2050 ranged between 0.65 and 0.98 $GtCO_2$, adding another 0.1 to 0.3 $GtCO_2$ of emission reductions if fully implemented (equal to a total reduction of 40–48 % in 2050 when compared to the baseline scenario projections). Most of the emissions mitigation potential for the 60 largest companies is driven by the 18 companies that set net-zero emissions and emissions neutrality targets (Fig. 3).

If we extrapolate the findings for the 60 largest companies to the entire global iron and steel sector, we estimate that the global iron and steel sector could potentially reduce CO_2 emissions by 6–13 % from 2019 levels to 3.0 to 3.2 $GtCO_2$ in 2030 and by 38–53 % and 1.6–2.1 $GtCO_2$ in 2050 (Fig. 4). Compared to the baseline scenario projections,

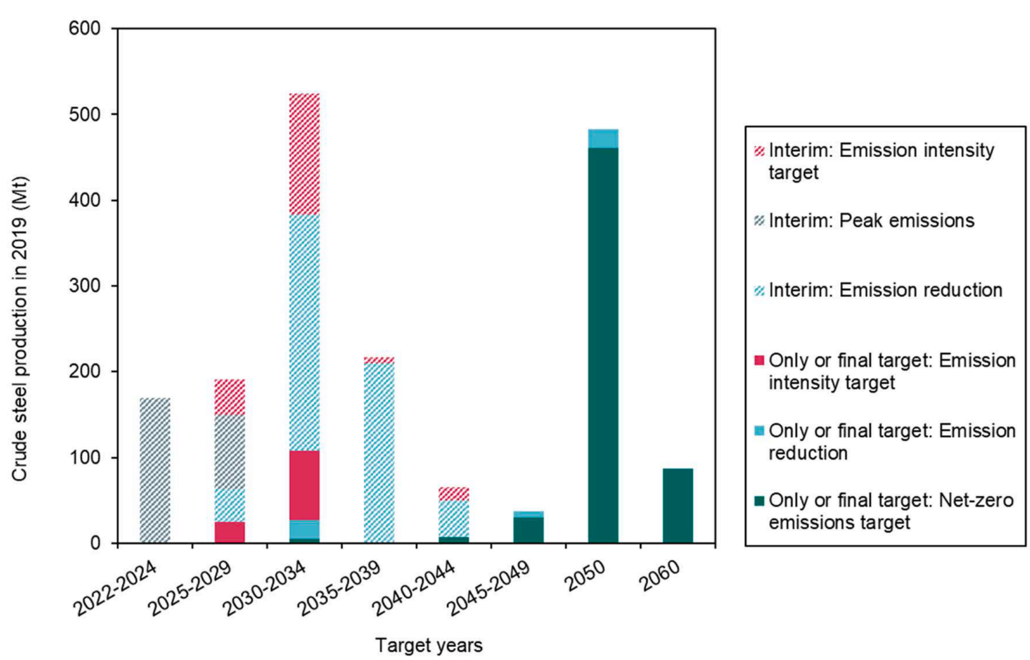

Fig. 2. Interim and only or long-term targets and target types of 26 steel companies with GHG emission reduction targets (excluding Chinese state-owned companies with no separate targets).

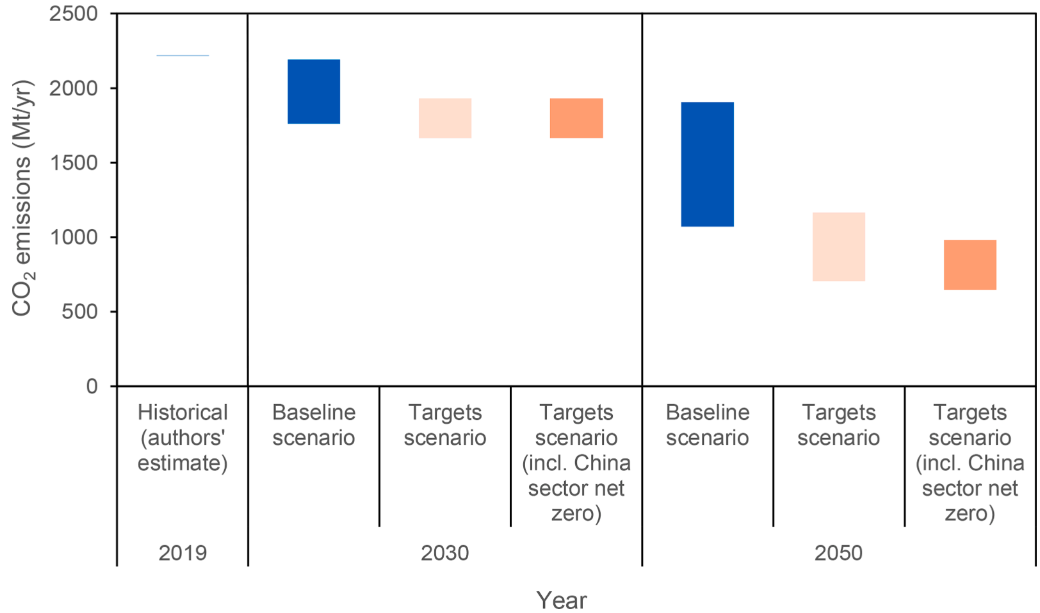

Fig. 3. CO_2 emission projection ranges for the 60 largest steel companies in 2030 and 2050 under the baseline scenario and the full implementation of all company-level emission reduction targets (Targets scenario), with and without the consideration of Chinese state-owned companies under the national 2060 net zero emissions target. The upper bound projections reflect a high BF-BOF emission intensity convergence level in 2050 and high total steel production from the 60 companies, whereas the lower bound projections reflect a low BF-BOF emission intensity convergence level in 2050 and low steel production from the 60 companies.

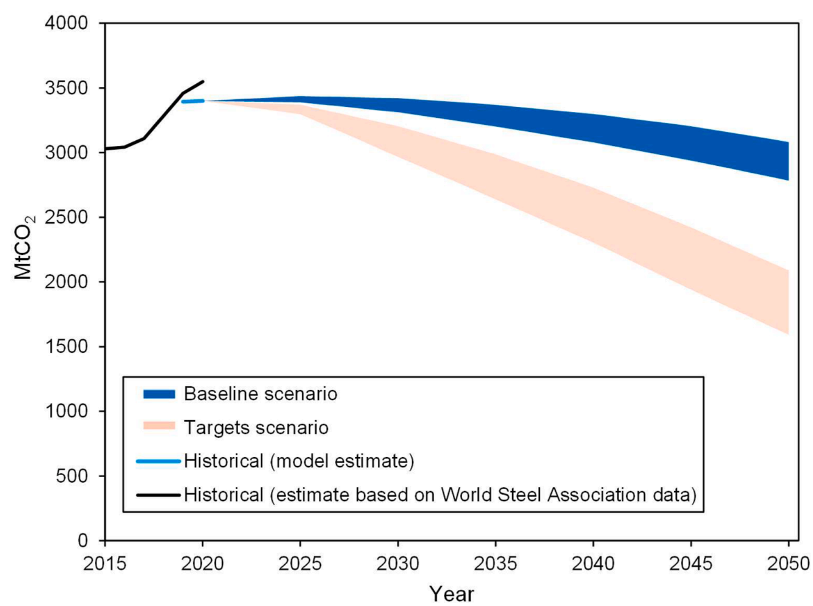

Fig. 4. CO_2 emissions trajectories from global steel production and potential CO_2 emissions mitigation from achieving all GHG reduction targets in the 60 largest steel producers and the rest of the world.

the extrapolated Targets scenario projects a 6–10 % reduction in 2030 and a 32–43 % reduction in 2050. Here, the upper bound projections reflect a high BF-BOF emission intensity convergence level in 2050 and low total steel production from the 60 companies, whereas the lower bound projections reflect a low BF-BOF emission intensity convergence level in 2050 and high steel production for the 60 companies.

GHG emission reduction targets until 2030 drive the carbon intensity of steel production at a level almost in line with the upper end of the benchmarks consistent with the 2050 net zero CO_2 emissions or limiting warming to 1.5 °C with no or limited overshoot (Fig. 5). However, the reduction rate thereafter is not fast enough and leads to carbon intensity levels in 2050 of around half of what is needed to achieve full decarbonisation.

Measures considered in emission reduction plans

Existing work on steel decarbonisation suggests that the emissions intensity of steel production should decrease between 25 % and 44 % in 2030 compared to 2020 and further decrease between 93 % and 100 % in 2050 [37,52]. While the ranges indicate uncertainty around technological development and commercialisation of near-zero technologies and different assumptions on carbon pricing, these studies agree that by 2050 all steel must be produced with technologies with deep emission reduction potential e.g. green hydrogen-based DRI, scrap-based EAF

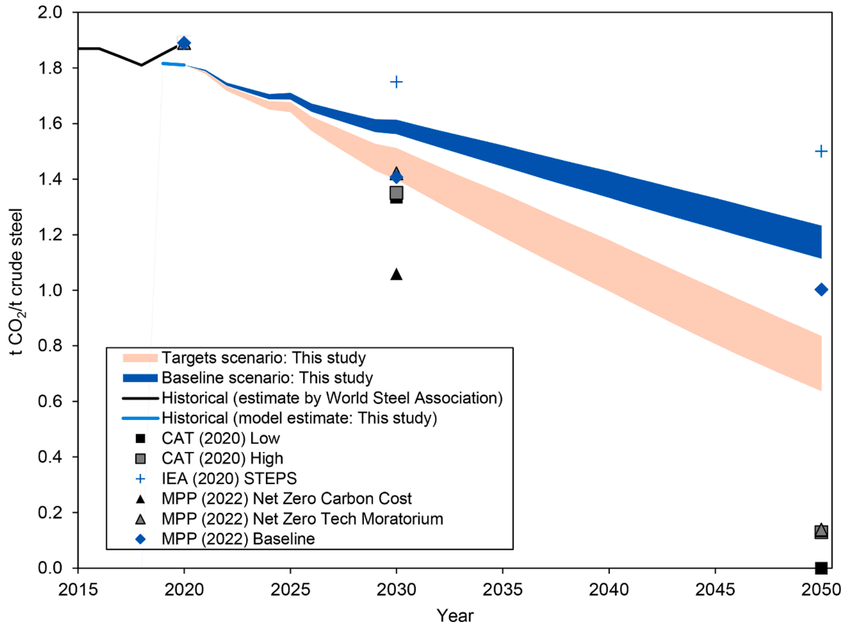

Fig. 5. Comparison of projected, global average carbon intensity per tonne of crude steel against the 1.5 °C-consistent benchmarks in the literature [4,37,52].

steel, fossil fuel-based DRI coupled with CCU/S.

We found that 16 companies have communicated at least one emission reduction measure they are considering in their publicly available emission reduction plans (Table 1). Fourteen companies with emission reduction targets have not clarified any emission reduction measure publicly. We include two companies acquired in 2021 by companies with targets under this category (Benxi Steel acquired by Ansteel Group, and Shandong Steel Group acquired by China Baowu Group). Moreover, four of the 14 steelmakers without a public emission reduction plan only have set a short-term target, suggesting that they completely lack any vision for future GHG emission reductions.

Almost every company for which a public emission reduction plan was available considered more than one measure. Including more than one measure is a positive sign, especially for primary steel production as the existing decarbonisation measures have varying levels of development and mitigation potential (see Table 1). While some measures with limited and moderate mitigation potential are readily available and can be implemented in the short term, others with deeper emission reduction potential are still under development and will only be available at a later stage. Amongst the companies that reported emission reduction measures in consideration, hydrogen-based DRI ($n = 14$), enhanced use of renewable electricity ($n = 13$) and CCU/S ($n = 9$) were the three most popular measures.

When also including the use in conventional BOFs, 17 of the 30 steelmakers with a GHG emission reduction target states their intention to pursue hydrogen-based primary steelmaking. Fourteen companies stated their intention to use hydrogen-based DRI, equivalent to more than a third of crude steel production by the 60 largest producers or 24 % of the global steel production in 2019. Another 9 % of the global crude steel production is covered by companies that want to use hydrogen in their BF-BOF installations. Even though the emission intensity of these steelmaking options depends largely on how the hydrogen is produced, companies generally did not provide details on this in their emission reduction plans.

It is also important to note for CCU/S in BF-BOFs, deep reduction of emission intensity is only possible if carbon capture and storage is combined with substantial replacement of coke and coal with biomass, and possibly with other unconventional options such as using carbon monoxide and hydrogen from the blast furnace for methanol and ethanol production [43]. Without these measures, the emission avoidance rate would only reach about 50–60 % [47,53].

Six companies responsible for a third of the total production by the 30 companies with emission reduction plans explicitly mentioned the use of offsetting. This may be considered a contentious strategy since offsetting comes with various uncertainties regarding, for example, permanence, additionality, and high environmental costs [17,22].

The cost and viability of emission reduction measures depend largely on the geographies [47]. However, emission reduction plans reviewed in our analysis did not provide details on differentiated emission reduction strategies across different countries they are operating in other than a few examples of pilot and demonstration projects.

Discussion and conclusion

Significance and implications

Our research is one of the first in the academic literature that conducted a comprehensive assessment of the current collective ambition of company-level GHG emission reduction targets and plans set by major steel companies. It also provides early insights into the likelihood of the achievement of steelmakers' long-term targets. In addition to its findings, this research proposes a set of indicators to assess the integrity of GHG emission reduction target-setting and planning, and how the indicators can be developed. The methodology can be applied in future research not only to track the progress of target-setting and planning integrity in the iron and steel sector companies but also to assess the integrity of targets and plans in other sectors.

We have shown that as of mid-2022, the emission reduction ambitions of the 60 largest steel companies up to 2050 are collectively far from sufficient to be consistent with the global 2050 net zero CO_2 emissions required to keep warming below 1.5 °C with no or limited overshoot. Moreover, we found that nearly half of the companies with targets have not published emission reduction plans and existing plans often did not provide sufficient details about how their targets would be achieved. These findings are, unfortunately, consistent with other studies on corporate climate action that exposed the lack of ambition to reduce their own value chain emissions consistent with 1.5 °C warming and the lack of well-designed planning towards long-term deep decarbonisation [17,22].

This study provides a current snapshot of the emission reduction

Table 1
The emission reduction measures that are considered by the 26 companies with climate targets, showing the number of times measures were mentioned and the sum of crude steel production in 2019. The indicative emission reduction rates are in comparison with a conventional BF-BOF and are based on the literature estimates [4,34,54–57].

Indicative emission reduction rate	Emission reduction measure	% emission reduction in comparison to traditional BF-BOF	Companies considering the listed measures	
			No. companies	Total crude steel production in 2019 in Mt crude steel
Limited mitigation potential 10% to 30%	Increased deployment of BATs and energy efficiency	15–25 %	7	310
	Use of hydrogen in BF-BOF	10–20 %	3	160
	Increased use of scrap in BF-BOF	N/A	5	230
	Increased share of renewable electricity	N/A	11	360
	Smelting reduction (e.g. HIsarna, vs. BF-BOF)	20 % (without CCU/S)	1	30
	Enhanced use of biomass	25–30 %	7	280
Moderate to deep emission reduction potential: 50% to 100%	Carbon Capture, Utilisation and Storage (CCU/S) in BF-BOF	50–90%	9	360
	Hydrogen-based DRI (vs. BF-BOF)	95–100 %	12	440
Production route switch	Increased share of scrap-EAF in total crude steel production	N/A	8	260
Other	Planned use of offsets	N/A	5	210
	Unspecified or unclear[a]	N/A	12	270
Total of the 30 companies with their own emission reduction targets		N/A	N/A	750
Total of the 60 companies assessed		N/A	N/A	1150

[a] Companies with no own emission reduction targets but that have been acquired by a parent company (Benxi Steel and Shandong Steel Group) with targets (Ansteel Group and China Baowu Group, respectively) were placed under this category.

target-setting landscape in the iron and steel sector. Both the climate actions by individual companies and the discussions around corporate climate action integrity are evolving fast [58] and we may already be seeing new developments amongst the 60 major steel companies since the literature cut-off date. Nonetheless, the current collective status of target-setting and planning toward decarbonisation amongst steel companies raises major concerns about the feasibility of a rapid transition of the industry consistent with 1.5 °C warming because the development of a new infrastructure for decarbonised steel production requires long lead times [59]. Moreover, considering that nearly half of the existing global blast furnace capacity has exceeded the typical lifetime of 40 years, further delays in action may also result in missing the timing for new investment cycles (See Fig. S-1 in Supplementary Data; [32,57]).

As financial institutions have started to consider, or are under pressure to, align their investment with the goals of the Paris Agreement [60,61], steel companies without long-term decarbonisation pledges or robust transition plans may also be risking themselves by keeping investors away. This may prove to be critical for the survival of steel companies in the next decades because of the magnitude of the investment required to remain competitive in the global market while minimising their emissions.

Methodological limitations

We identify several limitations related to the research methods applied and the data used for the analysis. On the research scope, we analysed companies that are responsible for only 60 % of global steel production today. While the geographic distribution and the coverage of primary steel production by these companies suggest that our findings are representative of the entire global iron and steel sector, further research on companies outside the top 60 could provide more insights into how smaller steel producers envision (or not) their transition toward decarbonisation. Production and emission data for small producers are currently not readily available in a centralised manner as is the case for major producers.

Another related limitation is the company-specific emissions data for the base year, the use of which we prioritised whenever they were available. The emissions reporting of many companies is supposedly consistent with the system boundary recommended by the Worldsteel Association [31] and thus consistent with the boundary applied in this study. However, it was not possible to ensure full consistency for all companies.

Our research did not review documents published in languages other than English. This may have led to an underrepresentation of the 60 largest companies headquartered outside Europe, India and North America, in particular Chinese companies, especially on the details of the emission reduction targets and measures.

We identified several limitations related to the methods applied in the emission scenario analysis. First, we did not consider the future development of individual steel companies nor the geographical distribution of companies' steel production capacities for most companies (exceptions being companies operating globally where we used global factors instead of the country where they are headquartered e.g. ArcelorMittal). Several of our technical assumptions per company applied to develop emission projections were based on where the companies are headquartered. While many large steel companies, especially those headquartered in China, Japan and South Korea, have the vast majority of their production capacity in their headquartered countries today [62], there are also companies such as ArcelorMittal that have production sites in different countries within and outside the countries where their companies are headquartered. In the future, companies may also relocate their steel production capacity or start operating new plants in countries where they currently do not operate. We consider the assumptions applied in our analysis to be sufficiently granular for analysing global-level emission trajectories but perhaps less so for company- or country-level emission trajectories.

Second, we did not examine the companies' targets and actions against the national net zero implementation plans in detail, except for Chinese state-owned steel companies. As of June 2022, more than 80 % of the global GHG emissions were covered by national net zero emission targets, including both the current and prospective major steel producer countries [17]. Future research could focus on the alignment and complementarity between national and corporate-level decarbonisation strategies. Such research would require a detailed assessment of, e.g., sector-level net zero strategies and roadmaps published by national governments and broader long-term corporate strategies in the global market.

Third, the feasibility of the quantified emission reduction potential could be examined further. While we collected information on emission reduction measures considered by companies to achieve their respective targets, further research on the comprehensiveness of the companies' emission reduction plans, possibly going beyond publicly available information, would be needed to provide additional insights into the credibility and feasibility of their long-term emission reduction ambition.

Fourth, our research only considered scope 1 and 2 CO_2 emissions from steelmaking processes. Further analysis could complement this study by expanding the emissions coverage to include scope 3 emissions (from upstream and downstream activities) and include all remaining GHGs. Methane emissions resulting from coal mining are considered to be significant. Based on a value reported by the Responsible Steel initiative [63], we estimate that the upstream methane emissions resulting from steel production amount to about 260 $MtCO_2e$ (expressed in 100-year global warming potential (GWP)) or about 7 % of direct and indirect CO_2 emissions.

Fifth, this article investigated the emission reduction targets of steel producers, but it did not investigate the demand-side corporate actions to reduce their steel consumption-related GHG emission footprint. In recent years a number of international private-public partnerships have been launched to boost demand for low-carbon steel, such as the SteelZero and the Industrial Deep Decarbonisation Initiatives by UNIDO [64]. The IEA estimated that the reduction potential of direct emissions through enhanced material efficiency could be as large as 0.5 $GtCO_2$ in 2050 compared to the baseline STEPS scenario [4]. Increased demand for net-zero steel from end-use sectors could not only increase the number of steel companies setting GHG emission reduction targets but also encourage companies with existing targets to set more ambitious ones and/or to define clearer plans and strategies to achieve them. Future research on the corporate actions to reduce emissions from the steel global iron sector could shed light on the demand-supply (mis) match of low-carbon steel products.

Policy recommendations

Despite the need for urgent action by all actors to achieve global net zero CO_2 emissions around mid-century to keep global warming to 1.5 °C, the findings of our analysis based on publicly available information strongly indicate that the steel companies are overall not acting fast enough. Based on these findings, we provide four policy-relevant recommendations. First, national governments need to exert pressure on the steel companies to set their own emission reduction targets consistent with the long-term net zero emission targets of the countries they are operating in, or with the global net zero CO_2 emissions by 2050 to keep warming below 1.5 °C. Comprehensive policies with clear strategies by national governments, supported by international coordination and cooperation to create an international level-playing field, will also be essential to facilitate companies making investment decisions [59]. It is also crucial that the companies set both long-term deep decarbonisation targets and interim targets that are consistent with each other. Second, companies need to develop a long-term transition plan that provides sufficient details about the technological options they are considering for achieving their emission reduction targets and their deployment roadmaps. Third, since the iron and steel sector has an important and strategic role in the economy of many countries, national governments also need to strengthen their support to the iron and steel sector in various aspects, including creation of demand for low-carbon steel through public procurement, to ensure that the necessary transition to deep decarbonisation takes place [4,10]. International cooperation and public-private partnerships are also crucial to enhance RD&D, including finance, of low-carbon steel while ensuring fair global market competition [64,65]. Fourth, acknowledging that there will likely be some residual emissions after exhausting all the feasible emission reduction measures in the long term, companies need to transparently communicate how they intend to neutralise the residual emissions.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.egycc.2023.100120.

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