

Technical Report

The carbon capacity nexus

**A framework for supply-side industrial
emission reduction pledges**



Disclaimer

This work is published under the responsibility of the Secretary-General of the OECD. The opinions expressed and arguments employed herein do not necessarily reflect the official views of the Member countries of the OECD.

This document, as well as any data and map included herein, are without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area. Extracts from publications may be subject to additional disclaimers, which are set out in the complete version of the publication, available at the link provided.

Photo credits: Shutterstock ID 153149813. Contributor: Jianqing Diao.



Attribution 4.0 International (CC BY 4.0)

This work is made available under the Creative Commons Attribution 4.0 International licence. By using this work, you accept to be bound by the terms of this licence (<https://creativecommons.org/licenses/by/4.0/>).

Attribution – you must cite the work.

Translations – you must cite the original work, identify changes to the original and add the following text: In the event of any discrepancy between the original work and the translation, only the text of original work should be considered valid.

Adaptations – you must cite the original work and add the following text: This is an adaptation of an original work by the OECD. The opinions expressed and arguments employed in this adaptation should not be reported as representing the official views of the OECD or of its Member countries.

Third-party material – the licence does not apply to third-party material in the work. If using such material, you are responsible for obtaining permission from the third party and for any claims of infringement.

You must not use the OECD logo, visual identity or cover image without express permission or suggest the OECD endorses your use of the work.

Any dispute arising under this licence shall be settled by arbitration in accordance with the Permanent Court of Arbitration (PCA) Arbitration Rules 2012. The seat of arbitration shall be Paris (France). The number of arbitrators shall be one.

Acknowledgements

The report was developed with support from the Co-Chairs of the Climate Club (Chile and Germany) and with funding from the German government.

The study was prepared by Jonas Algers (Lund University, Sweden), Luciano Giua and Adrien Corneille from the OECD Steel Secretariat, under the supervision of Stephan Raes, Head of the OECD Structural and Industry Policy Division. The study benefited from a peer review by several experts and from comments by the Climate Club Co-Chairs and members.

The report has been submitted for feedback from OECD Steel Committee members.

Table of contents

Disclaimer	1
Acknowledgements	2
Highlights	5
1 Introduction	6
2 Towards a framework for supply-side industrial emissions pledges	9
3 Interpreting the framework and levels	12
Overall objective (level 1)	12
Capacity adjustments to reduce emissions (level 2)	13
Decrease emission-intensive capacity (level 2 A)	14
Lower emissions in existing capacity (level 2 B)	16
Increase near-zero emission capacity (level 2 C)	19
4 From framework to pledge	23
5 Pledges and international collective action	26
6 Assessing potential pledges	28
7 Conclusion	32
References	33

FIGURES

Figure 1. Framework for supply-side pledges and possible implementation actions on industrial emissions reductions	10
Figure 2. Example of United Kingdom	16
Figure 3. Country's BF-BOF carbon intensity stemming from scopes 1 and 2 in 2024	19
Figure 4. Example of United States	22
Figure 5. Pledge structure inside the carbon-capacity nexus lens	24

TABLES

Table 1. Overview of potential pledges on the steel sector: benefits, implications and side effects

28

Highlights

This report aims to propose a new framework to gain deeper understanding on the complex interactions between emissions reductions and capacity adjustments, referred to as the carbon-capacity nexus, with a focus on steel.

To accelerate the industry transition and deliver on the Paris Agreement, countries can make emission reduction pledges linked to the interrelations between capacity, production, requirements and policies. The framework identifies three main supply-side capacity adjustments to lower industrial emissions: 1) decreasing emission-intensive capacity, 2) lowering emissions from existing capacity, and 3) increasing near-zero emission capacity.

Articulating these supply-side capacity adjustments is particularly important since they currently receive less attention than demand-side pledges. They are also important because they help clarify that in order to achieve the objectives of the Paris Agreement, a focus on increasing near-zero emissions capacity in itself is insufficient but needs to be combined with efforts to decrease emission-intensive capacity and the lowering of emissions from existing capacity.

Addressing the carbon-capacity nexus challenge may require strengthening international collaboration among a wide range of stakeholders. Collective supply-side pledges are likely to be more effective than pledges by individual countries or companies. As countries are in different positions to make changes in expanding, reducing, or changing capacity, policy coordination is needed to address potential imbalances, synergies and trade-offs resulting from the carbon-capacity nexus. Such issues could be further addressed with the Climate Club in the coming period.

1 Introduction

1. This paper is provided by the OECD Steel Secretariat as part of the Work Programme for 2024 of the Climate Club. The Climate Club Work Programme (2024) is organised along three pillars:

- Pillar 1: advancing ambitious and transparent climate change mitigation policies,
- Pillar 2: transforming industries,
- Pillar 3: boosting international climate cooperation and partnerships.

2. The paper is part of the second pillar, in particular its second module on promoting markets for near-zero GHG emissions materials to accelerate the industry transition, which builds on the Climate Club Terms of Reference indicating that “Members endeavour to deploy relevant policy measures and instruments, including considering comparable goals for a certain share of low and near zero GHG emission materials in a given year (Climate Club, 2022^[1])

3. This study focuses on how to navigate the complex and fast-changing industry decarbonisation landscape and aims to deep dive into supply-side issues in relation to the setting of such comparable goals, emphasising the pivotal role of production capacity.

4. The decarbonisation of industrial activities is a cornerstone to comply with near-zero emissions in mid-century. The industry sector accounts for more than a third of global carbon emissions, with significant potential for emission reduction. However, the complexity of business dynamics including the rapid expansion of industrial capacity, the diversity of production pathways, as well as the supply chain risks of raw materials and energy inputs, make industry decarbonisation a challenging objective. The setting of comparable goals – or pledges as the term this paper addresses them – can be important in such a context.

5. Public pledges (as have been made on reaching net-zero by 2050 or tripling renewable energy capacity by 2030 and nuclear energy capacity by 2050) are common tools for climate policy and help guide technology investments. A pledge can be defined as a statement made voluntarily by a government or company – or a group of governments at an international level, characterised by an ambitious shared goal – that is quantitative and timebound where possible – and recommends supporting actions, ideally backed by plans for implementation through adequate policies and enabling conditions.

6. Collective pledges by groups of countries, for instance in the context of the Climate Club, can enhance the effectiveness of such pledges. First, operating collectively can expand the scale of the reduction in carbon emissions envisaged. Second, it can also help reduce the risks of negative international spillovers from mitigation policies, as well as create positive spillovers and help the transition to advance more rapidly. This is particularly the case where markets for industrial products are interconnected across countries via trade and investment. For instance, limiting steel scrap exports, while aiming to enhance scrap availability in one country, may in fact create challenges in other countries and fragment scrap markets. Similarly, countries could benefit from co-operating in the trading of low-emissions intermediate goods, such as green iron, allowing for more efficient steel decarbonisation pathways across steel producing economies. Finally, collective pledges could relate to inclusiveness, a central asset of the Climate Club, where pledges are combined with collective efforts towards capacity building in emerging and developing economies. Crucially, collective pledge-making should recognise the heterogeneity of production pathways, the diversity of available technologies and resources of each country. This implies that effective policies and pledges must be flexible enough to accommodate varying national circumstances, such as differing levels of technological maturity, resource availability, infrastructure readiness, and economic contexts, thereby maximising the potential for successful implementation and sustained progress towards near-zero emissions.

7. As indicated in the net zero scenarios by the IEA, pledges by governments to date – even if fully achieved – fall well short of what is required to bring global energy-related carbon dioxide emissions to net zero by 2050 (IEA, 2023^[2]). Whereas there are various examples of demand-side pledges, there are currently few or no supply- or capacity-focused pledges on industrial decarbonisation. Several examples from various industry and country experiences suggest greater maturity of demand-driven pledges and policy targets in both public and private procurement initiatives (for instance from the Clean Energy Ministerial (CEM)/Industrial Deep Decarbonisation Initiative (IDDI), Steel Zero), albeit there are some recent supply-side developments in the power sector¹. At the same time, policy-oriented discussions are emerging on how supply-side and decarbonisation issues may be considered in conjunction.

8. Reducing emissions from the industrial sector is ultimately a supply-side phenomenon which is predicated upon changing production process and quantities. Therefore, the pathways to decarbonisation and the way this can be translated into pledges can be quantified in terms of production capacity relative to existing emission-intensive production capacity. The existing stock of emission-intensive production capacity must either be retrofitted/altered to lower emissions while keeping the existing facilities, be phased out or be replaced with new production capacity using new, near-zero technologies.

¹ The power sector is a notable exception where the industry and governments have undertaken the formulation of supply-side pledges, for example tripling renewable energy capacity by 2030 and nuclear energy capacity by 2050.

9. This study aims to support deeper understanding on the nexus between industrial emissions and capacity development and its relevance for pledge-making for industrial decarbonisation. Many studies focus on the carbon-resource nexus, energy-carbon nexus (Zhai et al., 2020^[2]), but only few highlight the interrelations between industry capacities and carbon emissions (GFSEC, 2022^[3]). This study builds a novel framework as a basis to pledge decarbonisation targets related to industrial capacity.

10. There are four main outcomes that policymakers and industry stakeholders may find in this framework, described as follows:

- **Actionability:** The framework starts with the steel industry, as an example of key hard-to-abate industries and identifies the main enabling conditions to ensure that capacity developments are on track with decarbonisation progresses. The qualitative assessment approach in the report includes key country's examples, empirical illustrations as well as insights on pros and cons to address capacity and decarbonisation challenges together
- **Flexibility and replicability:** The framework is centred on a common objective, to reduce industrial emissions, and analyses step-by-step the supply-side nexus among capacity adjustments, production pathways, key requirements, and policymaking. The framework takes stock of industry specificities and national circumstances. The application to the steel industry provides a practical example that could be transposed to another industry
- **Collective pledging:** Finally, the framework helps identify possible areas to deepen international collaboration on the nexus issues, underscoring i) the importance of an integrated approach, ii) the need for policy coordination and iii) examples of collective action. The Climate Club could play a key role in bringing countries together to explore the potential for developing capacity related emission reduction approaches and solutions in policymaking.

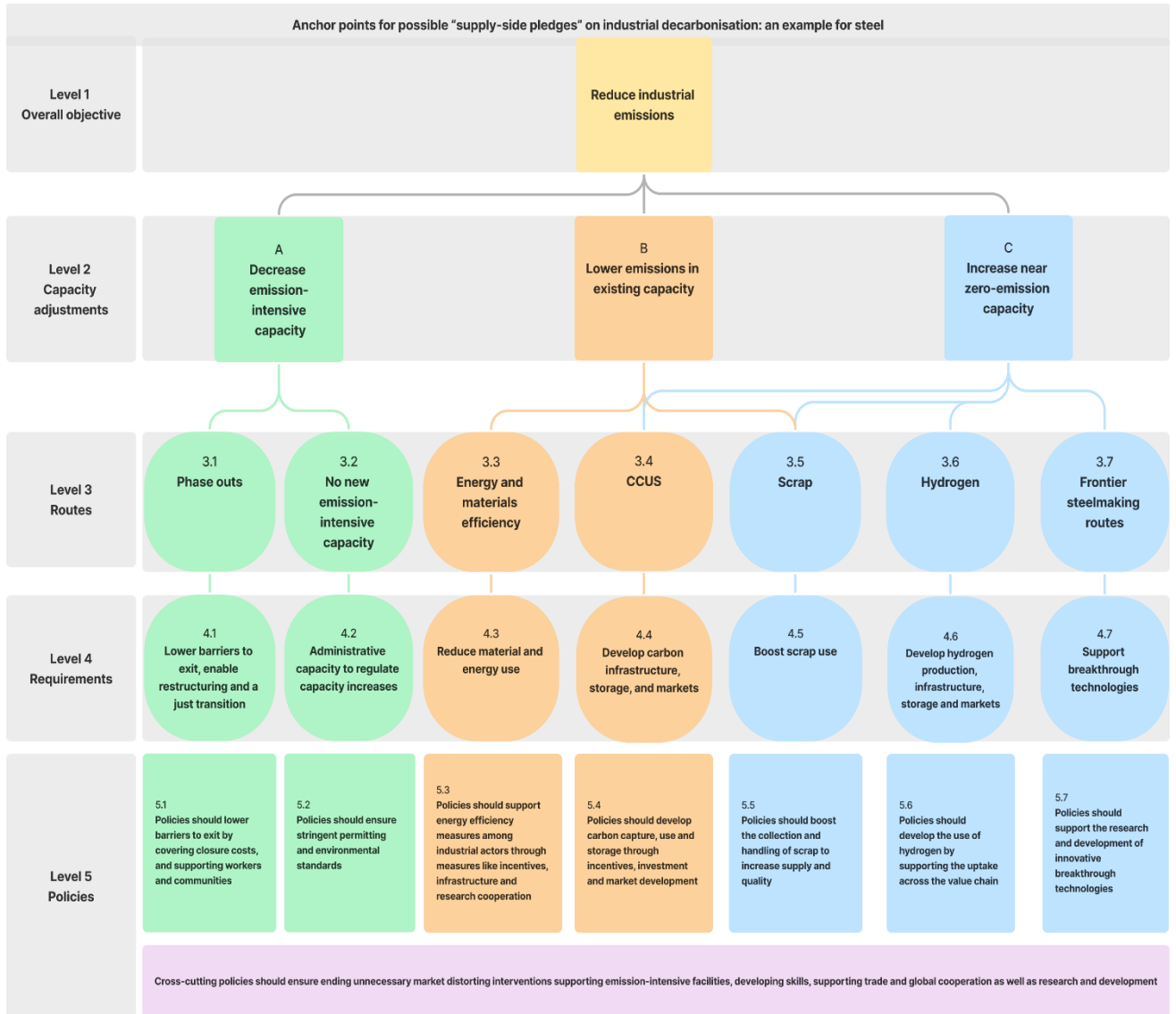
11. The proposed Nexus framework and empirical illustrations allow for informed discussions on the possible ways supply-side oriented emission reduction pledges could be formulated. It is developed in parallel to and complements work done by the International Energy Agency for the Climate Club on demand and supply-side measures.

2 Towards a framework for supply-side industrial emissions pledges

12. The section introduces a carbon-capacity nexus framework and key takeaways for policymakers to address capacity challenges in line with emissions reduction. The steel industry is taken as a basis for building the carbon-capacity nexus.

13. The intention of the carbon-capacity nexus framework is to support sectors and countries in formulating pledges to adjust their industry capacities in conjunction with climate goals. The conceptual framework identifies five core levels to address the carbon-capacity nexus: an overall objective of industry decarbonisation (level 1) followed by four further levels: capacity adjustments (level 2), different production routes (level 3), key requirements (level 4), as well as supportive policies (level 5). Each level in the framework is relevant for meeting the overall objective of industry decarbonisation and requires coordinated policymaking and action.

Figure 1. Framework for supply-side pledges and possible implementation actions on industrial emissions reductions



Note: The figure presents the carbon-capacity nexus in five levels. The top-level is the general objective (level 1), followed by underlying levels: capacity adjustments (level 2), production routes (level 3), requirements (level 4), and policies (level 5). As different capacity adjustments can imply various production routes, requirements, and policies, each node of the carbon-capacity nexus is numbered with letters (A, B, C for capacity level) and numbers (from 1-5 for down levels).

Source: Authors' elaboration.

14. The nexus framework provides a general overview of the diversity of capacity-production pathways to achieve decarbonisation in the steel industry. As an energy- and emission-intensive sector, the steel industry is typically characterized by various assets, processes, raw materials, and products involving diverse industry's stakeholders along the steel value chain (OECD, 2023^[5]). There are at present also a large set of conventional and innovative technologies at different technological readiness level. This results in a strong heterogeneity in the industry structure which is also common to many other industrial sectors such as for aluminium and cement.

15. Structural transformations associated with capacity development and the existing asset base have a large influence on industrial emissions through the choices of key production routes and their requirements but may also affect the implementation and effectiveness of decarbonisation strategies and policies in a sector and country. The nexus concept enables to identify and address trade-offs and to seek policy synergies in an industry among capacity, technology, resources, energy, and climate. It can be applied to one or more sectors as an integrated approach to policymaking, where considering these interactions helps make policy interventions more effective.²

16. In line with this study's scope, the analysis focuses on three types of capacity adjustments in the steel sector: 1) Decrease emission-intensive capacity, 2) Lower emissions from existing capacity, and 3) Increase near-zero emission capacity. The three capacity approaches were selected to help identify, in the steel industry, examples of key interactions between production routes (e.g., based on scrap, CCUS, hydrogen), requirements (energy saving or access to raw materials), and policy areas (energy efficiency measures, research and development).

17. Different or additional routes could be selected to broaden the scope areas for industry decarbonisation. While a specific route can require the implementation of more specialized policies (e.g., product-level policies on steel scrap), there are also horizontal policy approaches that could support multiple technology pathways and would not necessarily be tied to specific routes in an industry. However, the selection of these elements is intended to represent some of the key technological areas in which capacity adjustments could lead to the industry's emissions reduction.

18. The carbon-capacity nexus framework can help provide a basis on which to develop supply-side oriented pledges towards approaches and solutions in policymaking. It provides equal weight to each capacity adjustment and tries to identify the interactions among production, requirements and policies. In this way, policymakers can see opportunities to prioritise decarbonisation objectives in connection with capacity developments and transformations.

² When not considering carbon-capacity links, a country may risk addressing various supply-side problems in isolation, putting further risks on industry decarbonisation.

3

Interpreting the framework and levels

19. The following sections describes in detail each level within the framework and provides empirical illustrations of how the interrelations work for the steel industry. Sections in the text are numbered in accordance with the numbering in the framework in Figure 1, to facilitate understanding. Where appropriate, they suggest possible metrics of steelmaking capacity and decarbonisation for formulating supply-side pledges.

Overall objective (level 1)

20. This is the most general level, referring to level 1 in Figure 1, where the pledge regards the emissions from the sector as a whole and not on any specific measures or technologies. For example, a pledge could be to “reduce emissions from the steel sector by 20% by 2030” or “reduce the emission intensity of steelmaking by 20%” or similar. The benefit of making pledges on this level is that it focuses on the specific emission reductions while leaving open the varying approaches that could be used to reach the goal.

21. However, the limitation of this approach is that it may not be sufficiently transparent or actionable, due to carbon leakage, growth in near-zero production increasing domestic emissions, or near-zero emissions being impossible with existing facilities. For example, some countries with good renewable energy resources are well-suited for an expansion of near-zero emissions capacity. Such an expansion could contribute to a reduction of global emissions by replacing emission-intensive capacity abroad but may increase domestic emissions as it is difficult to reach zero emissions from any project. In addition, reducing emissions from existing facilities may lead to a dead-end, as maximum emission reduction potential is lower than potential emission reductions in transitioning to new near-zero emission facilities.

22. In addition, actions taken by an individual country to decarbonise its industrial sector may have unintended side effects such as carbon leakage, or a spike in demand for necessary resources, thus limiting decarbonisation in other countries. For example, if a country opts to decarbonise its steel industry by increasing its secondary capacity and halting scrap exports, it will make it more expensive for another country to follow the same capacity adjustments.

23. Pledges to reduce emissions from industry are therefore more credible if combined with pledges and implementation actions at more granular levels, such as the specific capacity adjustments by which a government aims to reduce emissions which we will explain in the following section.

Capacity adjustments to reduce emissions (level 2)

24. Measures to lower emissions from industry can be quantified by their effect on production capacity in three ways: decreasing emission-intensive capacity by closing facilities or restricting the growth of production capacity (level 2A), lowering emissions from existing capacity through retrofitting and adaptations (level 2B), and finally to invest in the expansion of near-zero emission capacity (level 2C). Each individual country will have its unique conditions requiring any combination of these measures, and governments could pledge to follow any or several of these capacity adjustments and quantify targets depending on the needs of its own industrial structure.

25. Making additional pledges to decarbonise industry quantified by capacity adjustments has the benefit of being more transparent in terms of how supply will change to meet emission targets. Quantified pledges at this level would also signal to stakeholders in each industry how the Paris Agreement should be realised, and actors can therefore align investments based on a long-term transition pledge.

26. At this level, potential side effects, such as effects on resource and product markets should be considered. Reducing emission-intensive excess capacity can both lower emissions and improve the financial health of a sector as capacity is adjusted to demand. However, recent research shows that new low-carbon steelmaking projects in aggregate increase steel capacity, risking a widening gap between steel demand and steel capacity (Algers and Åhman, 2024^[6]). Another pitfall would be expanding scrap-based steelmaking capacity by restricting scrap exports, as that would reduce other countries' access to scrap. Therefore, policymakers could consider how to formulate pledges to minimise negative side effects and maximise positive side effects.

Decrease emission-intensive capacity (level 2 A)

27. Decreasing emission-intensive capacity in the steel industry is vital for reducing overall emissions. World crude steelmaking capacity in 2023 was estimated at 2 432 million tonnes, exceeding global steel production by 543 million tonnes and steel demand in 2050 in the IEA Net-Zero Scenario by roughly 400 mmt (De Carvalho, 2024^[7]); (Karacan et al., 2011^[8]). A decrease in emission-intensive capacity directly reduces emissions, reduces excess steel capacity and incentivises material efficiency in downstream industries. By scaling back on traditional blast furnace operations, which are heavily reliant on coal and coke, the industry can achieve substantial reductions in carbon dioxide emissions. In 2023, BOF steel accounted for 71.1% of global production. On average, the BF-BOF process directly emitted 2.33 tonnes of CO₂ for every tonne of steel produced on average, i.e. more CO₂ than steel.

28. A pledge to reduce emission-intensive capacity could be a significant step in the decarbonisation of the steel industry. In 2040, Worldsteel Dynamics figures show that with a projected steel production of 2,135 million tonnes, a decrease of BF-BOF steel production by 58% (Worldsteel Dynamics, 2024^[9]), will save approximately 460 million tonnes of CO₂ compared to 2023 levels. To put this into perspective, this reduction is roughly equivalent to eliminating all the annual CO₂ emissions from Brazil³.

Phase outs, barriers to exit and a just transition (A3.1, A4.1)

29. Pledges can also be made at the more granular level of routes to realise changes in capacity. The primary route to decreasing emission-intensive capacity is through phase outs and a relevant pledge could therefore be to phase out emission-intensive capacity. However, phasing out capacity also comes with its challenges, as it may have detrimental effects on individual companies, workers, and local communities where facilities are located. It may also be costly, as closing a site incurs costs on a company, and may require costly environmental cleanups as well as pensions for workers. Such costs may function as barriers to exit (Rimini et al., 2020^[9]); lowering such barriers to exit is a necessary requirement for this route.

30. By easing the financial and logistical burdens associated with exiting carbon-intensive steel production, governments can accelerate the industry's transition to more sustainable practices. Therefore, careful phase out policies will be needed to lower barriers to exit and enable workers to shift to new sectors and communities to attract new investment. Historically, policies to support the phaseout of industries have included clear roadmaps allowing stakeholders to plan and adapt, labour market interventions, state aid for covering the closure cost of plants, as well as alternative industrialisation (Algers and Åhman, 2024^[6]). Countries could therefore pledge to phase out a given amount of capacity by a given year to give a clear indication of timelines for phase outs.

³ This is given the base emission of the UK in 2023. Which was approximately 384.2 million tonnes of CO₂.

Stronger regulations for no new emission-intensive capacity (A3.2, A4.2)

31. Stopping the expansion of new emission-intensive facilities is another route relevant for some countries, and a pledge could be to limit new emission-intensive facilities. As investment cycles in the industrial sector are long, new facilities will be in use for several decades and risk creating new groups of people dependent on the facility. Currently, almost 65 mmt of emission-intensive BF-BOF capacity is expected to be added in Asia alone, contributing to global steel excess capacity (OECD, 2024_[10]). As there are alternative near-zero emission technologies available, these can be used in new facilities.

32. Therefore, a potential pledge could be to not build any new emission-intensive facilities. Many emission-intensive facilities need reinvestment at shorter intervals. In the steel sector, a blast furnace can keep running for 40+ years, but it needs relining around every 15-25 years, which costs 80-100 % of the cost of a new blast furnace (Bashmakov et al., 2022_[11]). Due to the high cost, this is a point in time where a steelmaker can opt to rather invest in a new, low-carbon facility. A relevant pledge could therefore be to not reline emission-intensive blast furnaces.

Policies to support a decrease in emission-intensive capacity (A5.1, A5.2)

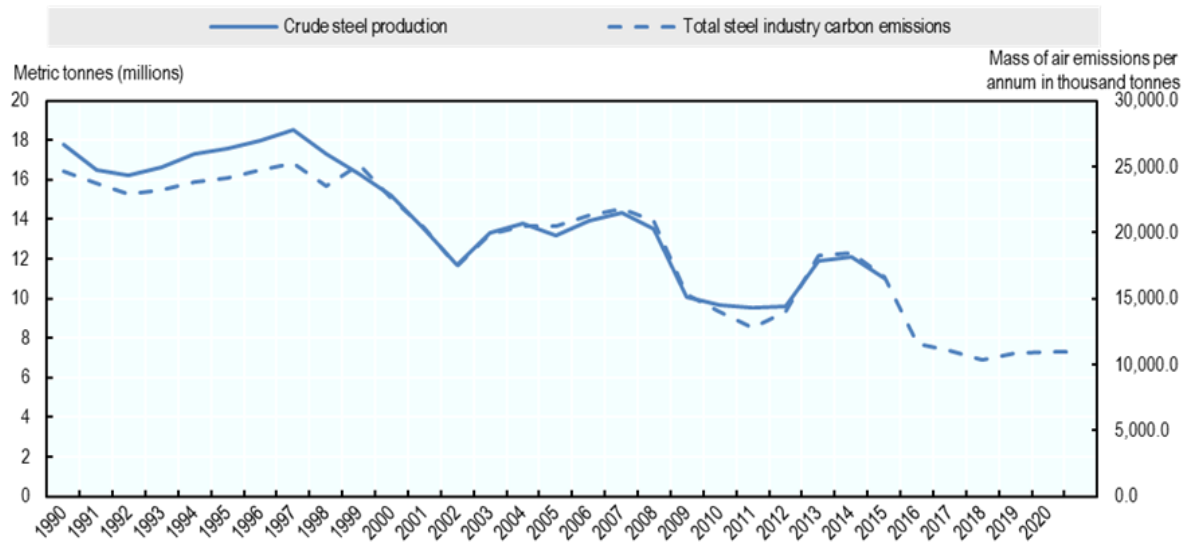
33. Stricter regulations on permitting and environmental regulations can support this route. These measures ensure that any new or expanded steelmaking facilities comply with the latest environmental standards, effectively limiting new emission-intensive operations.

34. The OECD Jobs Strategy underscores the necessity for comprehensive policy packages to assist workers amid labour market transformations, particularly relevant to the steel industry facing structural adjustment pressures (OECD, 2024_[12]). Workers in high-emission sectors tend to have a larger earning loss after displacement than workers in other sectors, as is discussed in the recent OECD Employment Outlook (OECD, 2024_[12]). Active labour market policies (ALMPs) such as re-training and up-skilling have shown success in reintegrating displaced workers into employment. If the large fleet of emission-intensive plants are to be replaced or phased-out at the required pace, similar interventions are highly likely to be needed at scale. Policies for assisting the phase out of coal-fired power generation could provide a model (IEA, 2021_[13]).

Empirical illustration

35. Figure 2 shows the decline in nominal crude steelmaking production and the associated fall in emissions in the United Kingdom. It shows that production fell by 61% and emissions by 48% from 1990 to 2015. Reducing emission-intensive capacity and related production unsurprisingly lowers emissions, creates market space for the expansion of near-zero emission capacity and helps reduce the overcapacity of emission-intensive products. Future reductions in emission-intensive capacity must be timed and well-planned and be part of a broader just-transition scheme for workers and communities dependent on emission-intensive plants. Without careful planning, there are risks of socioeconomic turbulence and backlash to climate policy.

Figure 2. Example of United Kingdom



Source: Ricardo Energy and Environment, Office for National Statistics (2022)

Lower emissions in existing capacity (level 2 B)

36. Reducing emissions in existing emission-intensive facilities could provide a key contribution to the global decarbonisation of industrial sectors. It may be challenging in the short run to phase out existing assets due to the effects on steel and labour markets. Therefore, a second path to reduce total industry emissions is to lower emissions in existing capacity making use of different technologies available or under development.

37. For the steel sector, there are three general routes: energy and material efficiency measures, carbon capture use and storage (CCUS) and increased use of scrap. While retrofitting existing BF-BOF facilities (constituting about 70% of total steelmaking capacity) will not take these facilities to near-zero emissions (Bashmakov et al., 2022^[11]; (Oda et al., 2012^[14])), reductions from existing emission levels can be reached through these routes. A relevant pledge could be to lower emissions by a given share in existing facilities.

38. Increasing energy and material efficiency is one of the key routes to lower emissions while retaining existing steelmaking capacity. Both efficiency measures⁴ contribute to reducing the amounts of waste and energy consumed, significantly decreasing carbon emissions and preserving raw materials (OECD, 2024^[15]).

⁴ They encompass measures acting on the design (design for reducing material intensity, design for improving circularity), manufacturing (improving yields, increasing process efficiency), use (increasing the intensity of use and lifetimes, shared and service-oriented consumption modes) and end of life (improving material recovery and recycling) phases.

Energy, material efficiency and scrap (B3.3, B4.3, C3.5, C4.5)

39. Tackling material efficiency could lower steel demand by at least 20% in 2050, compared to a business-as-usual approach (IEA, 2021^[16]), with a potential for carbon reduction estimated at around 20% in 2050 (E3G, 2021^[17]). Material efficiency targets, recycling targets or minimum standards of recycled material in a product are essential metrics to support steel circularity in the green transition. Governments could make pledges to increase the scrap recycling rate, increase the scrap share in production or to reduce the energy or emission intensity by given years. Beyond direct energy and material efficiency, it is also possible to lower emissions through other efficiency measures such as monitoring and minimising methane and carbon leakage from mines and supply chains for fossil-based industries (IEA, 2023^[18]).

40. Energy efficiency has also great potential for carbon reduction in steel production. Efficiency measures do not have negative side effects, as improved efficiency lowers the use of inputs per tonne of product, although it can also lead to increased costs through the required use of more expensive raw material types. Improving efficiency in one country can therefore reduce emissions without making it more difficult for other countries to realise the same improvements. At the same time, efficiency in industry varies substantially across countries. However, pledges to improve efficiencies must not lead to the lock-in of long-term emissions through the construction of more efficient emission-intensive production facilities. Efficiency pledges should therefore relate to existing fleets, meaning that measures could be retrofits or closures of inefficient facilities.

41. Steel is already one of the most recycled materials, with higher-end estimates suggesting an 84% recycling rate in 2017 (IRENA, 2020^[19]). In 2019, 32% of all inputs were scrap (S. Managi, 2020^[20]). Scrap recycling results in a 90% reduction of CO₂ emissions and 70% energy savings compared with virgin iron ore in a BF-BOF. However, scrap-based steelmaking will not be sufficient to meet all steel demand due to quality and availability limitations⁵

⁵ For instance, in some countries such as the US, existing BOF plants may have reached their maximum in scrap usage. Furthermore, there may be little room in flat-rolled EAF for increasing scrap use.

CCUS retrofits (B3.4, B4.4)

42. Carbon Capture and Storage (CCS) can be an important technology for decarbonizing heavy industries like steel and energy. There are currently 30 commercial CCUS projects worldwide (IISD, 2023_[21]). In the steel industry, CCUS use is currently still limited and is for instance used in the Al Reyadh facility in the UAE capturing emissions from a natural gas-based DRI facility with a capture rate of 26%. A study suggests that it will be “difficult to retrofit BF-BOFs beyond 50% capture” of emissions (Bashmakov et al., 2022_[11]) which is insufficient for reaching near-zero emissions and the Paris Agreement. However, retrofitting existing BF-BOFs with CCUS can play a role in relatively new and efficient facilities with available or affordable carbon transport and storage infrastructure, and alternative low-carbon steelmaking technologies are unviable. Countries could therefore pledge to support the use of CCUS at relevant sites.

43. As nations commit to stringent climate goals, the establishment of robust carbon infrastructure becomes essential to manage and sequester emissions effectively. This includes building facilities for the capture, transport, and safe storage of carbon dioxide, a process that requires extensive R&D to innovate and refine the technologies involved.

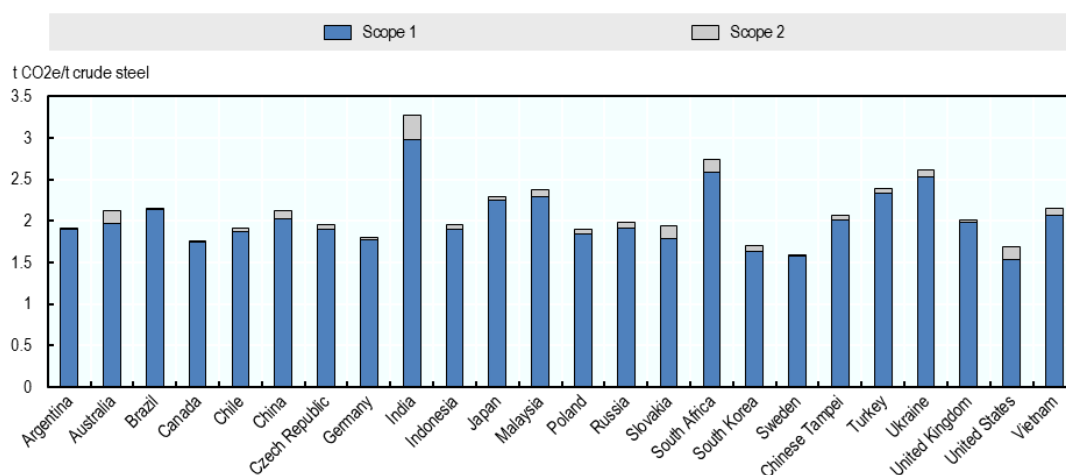
Policies for lowering emissions in existing capacity (B5.3, B5.4, C5.5)

44. Lowering emissions in existing capacity requires creating incentives for steelmaking firms to monitor and improve energy efficiency and to invest in carbon capture where relevant. This can be done for example through pricing schemes or taxes on energy use and carbon emissions, and by removing energy subsidies where relevant. Increasing material efficiency requires a value-chain perspective, where downstream actors are incentivised to cut material use and contribute to high-quality recycling back to steelmakers. Policies for material efficiency therefore tend to be broad in scope such as the EU eco-design regulation (OECD, 2024_[15]).

Empirical illustration

45. Figure 3 shows the CO₂ intensity in the BF-BOF steelmaking route across countries. The BF-BOF fleet of Canada has almost half the CO₂ emissions per tonne of steel as the BF-BOF fleet in India. In the hypothetical case where India had a BF-BOF fleet with the same emission levels per tonne of steel as the Canadian fleet, India's total annual emissions would have been almost 70 million tonnes or about 2.7% lower.

Figure 3. Country's BF-BOF carbon intensity stemming from scopes 1 and 2 in 2024



Source: CRU database

Increase near-zero emission capacity (level 2 C)

46. Sector-wide deployment of low-carbon technologies is central to reaching net-zero in industrial sectors rapidly and sustainably. Retrofitting existing sites with new technologies often only leads to limited emission reductions that are not sufficient for reaching net-zero emissions. Reaching net-zero will therefore require the construction of new, near-zero facilities, and thus an expansion of near-zero emission capacity. Examples for the steel industry are scrap-based secondary steelmaking, hydrogen-based steelmaking, as well as breakthrough innovative solutions at early innovation stages. Countries could therefore pledge to support or expand this type of capacity by a given amount or to a given share by a given year. For example, a pledge to increase the share of near-zero emission capacity by a given year or a pledge to increase the amount of hydrogen-based steelmaking capacity to a given level. While such commitments would not be technology agnostic, it could nevertheless be useful for countries with the relevant renewable energy potential.

Scrap-based steelmaking (C3.5, C4.5)

47. The most mature near-zero emission steelmaking technology is the scrap-based EAF route⁶. The share of the EAF scrap route varies widely across countries, where the United States has a share of over 70 %, the EU 44 %, Turkey 70 %, and China 10 % (BIR, 2022_[22]) (OECD, 2024_[15]).

⁶ According to the IEA definitions, EAF production is not inherently classified as near-zero emission. The classification depends on the carbon intensity of the electricity used and other relevant factors.

48. Due to the limitations of scrap availability, it is important that measures and potential pledges to increase the use of scrap are made considering the side effects of measures. Increasing the use of scrap by restricting exports will have negative side effects on other steelmaking countries as their cost of using scrap will increase. Therefore, increasing scrap collection rates as well as improving scrap handling for quality purposes are key measures for expanding the scrap share of steel production without negative externalities on other countries. Countries could therefore pledge to increase scrap collection rates, or scrap handling where relevant, or to refrain from export restrictions on scrap. In a similar vein, countries could also consider and develop pledges on developing trade partnerships and/or refraining from import restrictions on low-emissions intermediate goods such as green iron (OECD, 2024_[23]).

Hydrogen-based steelmaking (C3.6, C4.6)

49. Hydrogen-based steelmaking is another near-zero steelmaking route with a high level of technological maturity. This steelmaking route requires new DR-EAF facilities capable of using hydrogen, and several are currently being built, notably the HYBRIT-facility in Northern Sweden, where a new EAF and an H-DR facility are being constructed to replace the old BF-BOF facilities.

50. Less than 6% of steel in 2019 was produced via a direct reduction furnace and most of these furnaces used methane-based syngas of H₂ and CO as both reductant and fuel (some use coal), and it is unclear to what extent these furnaces can use hydrogen (Bashmakov et al., 2022_[11]). Therefore, for hydrogen-based steelmaking to take a significant market share of total steelmaking there will have to be an expansion of H-DR-EAF capacity. Countries could pledge to expand the amount of hydrogen-based steelmaking capacity by a given amount or share of total steelmaking by a given year, giving equipment suppliers credibility to expand production.

51. Hydrogen-based steelmaking requires a large amount of clean electricity - about 3.5 TWh per million tonne of steel (Vogl, Ahman and Nilsson, 2018_[24]). Expanding hydrogen-based steel production is therefore in many cases subject to a large expansion of clean power production. Combined with hydrogen storage, demand can be flexible, allowing for larger use of intermittent clean power. Countries could therefore pledge to increase the amount of clean power and hydrogen storage and infrastructure to support hydrogen-based steelmaking. Such a pledge could be to increase the amount of clean power available for energy-intensive industries by a given amount by a given year. Given the costly nature of such investments, this will be more challenging for some countries than others.

CCUS in new facilities (B3.4, B4.4)

52. CCUS in newly built facilities can reach higher capture rates than when retrofitted on existing facilities and this is therefore a potential third route to increasing near-zero emission capacity. New BF-BOF plants can be built to be more suitable for CCUS increasing the capture rate, but for instance DR-EAF plants using natural gas can lead to even deeper emission reductions. CCUS technologies could have the potential to decrease emissions by up to 90% compared to BF-BOF (IEA, 2023_[18]) but face significant implementation barriers that may undermine their overall efficacy in real-world applications.

53. High costs, technological complexity, and the necessity for extensive infrastructure development are major obstacles that can delay or even prevent the widespread adoption needed to achieve these emission reductions. Moreover, the effectiveness of CCUS is contingent upon the availability of suitable geological storage sites, which are not uniformly distributed globally, thus limiting the geographical applicability of this technology. In addition, if carbon is captured and then used and released into the atmosphere, the reduction potential is a maximum of 50 % – insufficient for net-zero emissions (Bashmakov et al., 2022_[11]). Relevant pledges could be to use CCUS in all new fossil-based steelmaking facilities with capture rates at above 90-95 % across the entire value chain which would be compliant with the Paris Agreement (Bataille et al., 2023_[25]). This would require strong monitoring to ensure sufficient capture rates to avoid lock-in of carbon-intensive production.

Frontier steelmaking routes (C3.7, C4.7)

54. Finally, there are a number of near-zero emission steelmaking technologies in the early development stages. These include molten oxide electrolysis and electrowinning which have been piloted at a small scale, and these technologies have the benefit of not needing to first produce hydrogen to reduce iron. However, they are in the early development stage and there could be significant global spillovers from developing the technology. Relevant pledges could be to cooperate and support the development of these new innovative routes.

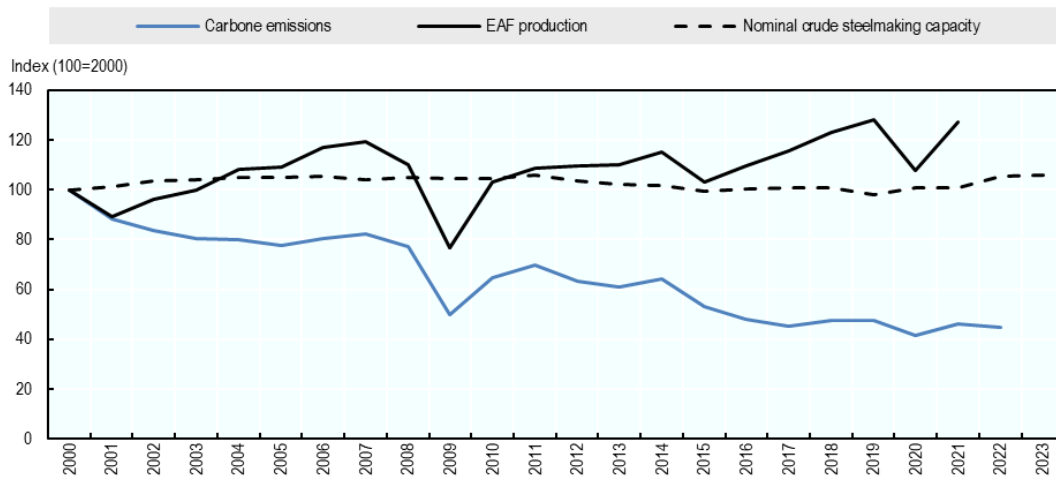
Policies for increasing near-zero emission steelmaking capacity (B5.4, C5.5, C5.6, C5.7)

55. Strong policy frameworks are necessary to support the development of near-zero emission steelmaking capacity on both the supply and demand-side. On the supply-side, risk-sharing through subsidies, grants and credit guarantees can be a key intervention to trigger investment in first-of-a-kind plants to manage risk in the early development stage of the sector and to demonstrate low-carbon steelmaking technology at scale (Bataille et al., 2024_[26]). For technologies that are at lower levels of technological readiness, supply-side policies to research and develop key technologies are vital to speed up technological development. On the demand-side, policymakers can help support the development of niche markets for low-carbon steel through public procurement and standard-setting. For example, the Swedish initiative The Industrial Leap has been pivotal for piloting and demonstrating hydrogen-based steelmaking in Sweden (Swedish Energy Agency, 2024_[28]).

Empirical illustration

56. Figure 4 shows the growth in the use of scrap-based EAF steelmaking in the United States and the associated fall in carbon emissions from the steel sector from 2000 to 2021. Scrap-based steelmaking grew by 27 % in the period, maintaining nearly constant total steelmaking capacity, and emissions from the steel sector fell by 54 %. This is a case where the expansion of near-zero steelmaking contributed to the fall of emissions in the US, while production was retained, albeit at a slower pace than necessary to reach net-zero emissions from industry by mid-century. Not all countries can go down the same route, as there is not the same amount of scrap available relative to demand and therefore other countries may have to follow alternative capacity adjustments to lower emissions.

Figure 4. Example of United States



Note All indicators are transformed into an index for comparison purpose starting at the baseline year 2000. Direct carbon emissions trends are measured for the steel industry production (under scope 1), while the indirect effects of carbon emissions due to production is not reported. Emissions associated with the use of conventional fuels for electricity generation are reported under the Energy chapter of the inventory of Greenhouse Gas Emissions and Sinks (EPA, 2024).
 Source: Greenhouse Gas Inventory Data Explorer (US EPA, 2024); Iron and Steel - Historical Statistics, Data Series 140 (USGS, 2024).

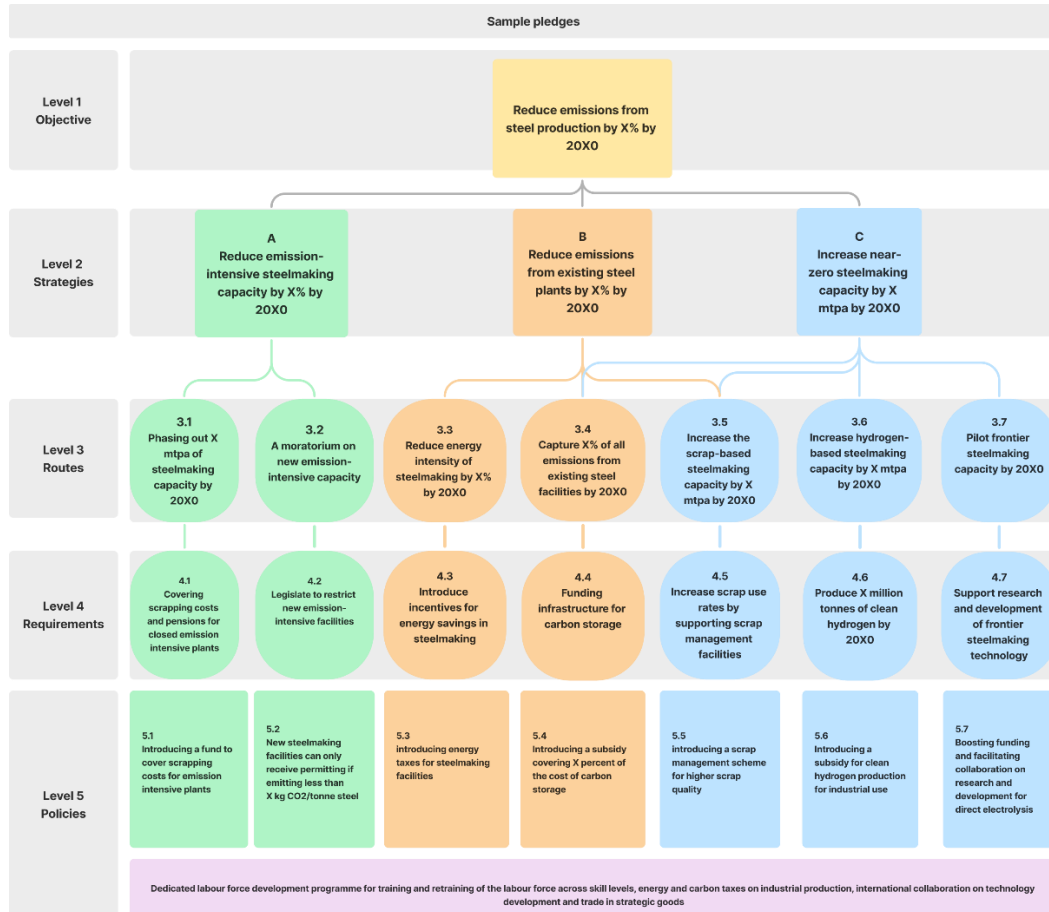
4 From framework to pledge

57. This section further develops examples of supply-side pledges and corresponding targets on the carbon-capacity nexus to allow for discussions on the ways a country or a sector may address trade-offs and strengthen co-operation across countries and between industries.

58. A key motivation for using the nexus framework is to help countries and industries to address the carbon and capacity challenges in their respective jurisdictions. Building on the key findings of the framework, this study examines how a policymaker could shape emission reduction pledges rooted in the carbon-capacity nexus⁷. Figure 5 proposes a collection of sample pledges, applied to the steel sector, which are intended to illustrate key actions, quantitative targets and timing that could contribute to achieving climate goals.

⁷ In line with what was stated in the introduction of this paper on technological neutrality, the framework recognizes no “one-fit-all” policy approach for industry decarbonisation is possible and in no way intends to suggest specific policies that ‘pick winners’ in this respect.

Figure 5. Pledge structure inside the carbon-capacity nexus lens



Note: The figure provides a list of indicative sample pledges, taking a nexus framework of the steel sector as a reference base Figure 1. These are not intended to be exhaustive, universal, and complete and might vary between industries and across countries.

Source: Authors' elaboration

59. The nexus approach also suggests that policymakers need to pay greater attention to the implications of decarbonisation pledges on the restructuring of an industry. Furthermore, there is a need to explore the potential of emission reduction beyond a specific production route or geographical characteristic considerations. Overlaps can occur within this framework because of the many interconnections and complexities between production routes, technologies, energy and materials. For example, hydrogen consumption can relate to the use of scrap to produce steel in the DRI-EAF route, while a CCUS can be compatible with most areas of steel production. Pledges should be formulated in such a way that all the different solutions are not treated separately, but rather as a collective response of the industry to decarbonisation challenges.

60. The timing of capacity adjustments is also an essential condition for the successful industry decarbonisation pledges. Committing to reducing emissions-intensive steelmaking capacity by phasing out existing older assets can be difficult in the short term, for a variety of reasons such as the immediate and unintended consequences on steel markets and employment. Similarly, adapting existing facilities to improvements in energy efficiency and resource use can often lead to a reduction in emissions in the short and medium term, with scrap use and the EAF route being a particularly important pathway. However, gains in emission reductions through for instance energy efficiency would still be at a lower level than the net-zero target requires. Finally, the net-zero objective would be supported by the construction of new low-emission facilities and therefore depends on the long-term reconfiguration of emission-intensive capacity to comply with net-zero emission targets.

61. Coordinated policymaking plays a key role in supporting supply-oriented pledges. Specific targets on production, materials use, and energy consumption can be applied in conjunction with market-based and non-market-based instruments. Key examples taken from the nexus framework are applied to CCUS, scrap, and hydrogen-based production routes, to illustrate different combinations and integration from a general pledge to specific targets, to coordinated policies that decarbonise a steel industry.

62. to address complex interactions within the carbon-capacity nexus. System thinking can help policymakers identify potential imbalances, synergies, and trade-offs (Hynes, Lees and Müller, 2020^[26]) between different ways of restructuring an industry to comply with climate goals. In the steel sector, the application and management of one type of capacity adjustment can not only directly impact the others, but also determine the intensity of potential trade-offs between resource-energy systems issues generally treated separately.

5 Pledges and international collective action

63. Assessing possibilities for international cooperation and collective action with regards to industrial decarbonisation pledges is a key objective of this paper, which is relevant at all levels of the framework, with some of the levels at which pledges are distinguished being more relevant for (certain types of) collective action than others. At level 1 (overall objectives) and 2 (capacity adjustments), the benefit of international co-operation lies primarily on scale: if more countries join such pledges, the amount of emissions covered would increase which would help enhance the impact of such pledges. However, effective collective action must also recognise the heterogeneity of production pathways and the diversity of available technologies and resources of each country. Policies and pledges should therefore remain sufficiently flexible to accommodate national differences, ensuring practical feasibility and broader participation.

64. There is a strong case for collective pledges in areas where there is a risk for negative international spillovers or vice versa the possibility for positive international spillovers, which is particularly the case for level 4 (requirements) and level 5 (policies) of the framework proposed. Resources such as scrap, renewable energy, carbon storage sites, and fiscal and engineering capacity are unevenly distributed across the globe. As steel and inputs such as iron ore are tradable, cooperation on trade and development will also be crucial for realising the decarbonisation of industries. As some resources are essential for near-zero emission capacity expansions, but unevenly distributed around the globe (see for example (Watari, Giurco and Cullen, 2023^[27])) and there is significant heterogeneity across countries' steel industries, countries could also pledge to coordinate changes in capacity with access to resources, such as one country pledging to expand scrap-based rather than emission-intensive steelmaking capacity in exchange for access to scrap markets in another country. This could be done at a bi-lateral level, facilitated by the Climate Club, or at a multi-lateral level across the Club. Similarly, pledges on the greening of iron production could go hand in hand with partnerships between potential exporters and importers of green iron to allow for a smooth and mutually beneficial approach.

65. Finally, in some cases the relevance of collective action in pledging relates to inclusiveness. Countries could make pledges on the level of international cooperation for realising the various capacity adjustments. For example, countries could pledge to support an international fund covering a share of the closure costs of emission-intensive plants. Such a fund has previously been suggested by the OECD Steel Committee in 2002 to manage global overcapacity challenges (Algers and Åhman, 2024^[6]). Countries could also pledge to cooperate on expanding and sharing engineering capacity or technological transfers, to facilitate growth in near-zero emission facilities. For such a pledge to be meaningful, it would have to be concrete as to what form such cooperation would take. As direct reduction furnaces today constitute a small share of total ironmaking capacity but are expected to grow, the capacity to build and install such furnaces is a potential major bottleneck for the growth of the industry (Agora industry, 2023^[28]). Collective pledges could also combine joint pledges on decarbonisation efforts with support for capacity development in emerging and developing economies. Pledges on international cooperation in this perspective would be supportive of national pledges.

6 Assessing potential pledges

66. Figure 1 assesses the emission reduction potential and outlines potential market implications and side effects associated with each sample pledge formulated in figure 5. The assessment uses a colouring system to indicate the emission reduction potential of various pledges, where dark green means a strong emission reduction potential, lighter green means moderate emission reduction potential and lightest green is used where there is a marginal or indirect effect on emissions.

67. Table 1 illustrates how the environmental benefits of these pledges may be weighed against market implications, including increased demand pressures, rising production costs, and substantial shifts in capacity. Additional side effects may arise from implementing a given pledge, such as increased risks of job market disruptions, uneven distribution of benefits, and challenges in gaining social acceptance. The prioritisation of various pledges will largely depend on the domestic context of the steel industry and relevant market factors.

68. The colour coding applied in this emission reduction analysis is based on a logical and systematic approach considering each pledge's effect on emissions. For instance, historically, the phase out of emission-intensive steelmaking has demonstrated a strong emission reduction effect, which justifies its dark green categorisation. However, there are notable limitations to this approach, including the fact that it does not account for the significant heterogeneities across countries. The impact of such pledges can vary widely depending on domestic steel industry structures, energy availability, technological readiness, and socio-economic factors, which means that a one-size-fits-all categorisation may not fully capture these national variations. Additionally, while the colouring system provides a useful framework for categorisation, it may oversimplify the nuances of the potential risks and benefits, particularly where multiple factors interact.

Table 1. Overview of potential pledges on the steel sector: benefits, implications and side effects

Type of pledges	Emission reduction potential	Market implications	Side effects
A. Reduce emission-intensive steelmaking capacity	Emission reduction potential depends on country's industry profile	<ul style="list-style-type: none"> • Reduced excess capacity • Reduced demand for fossil fuels 	<ul style="list-style-type: none"> • Risks for labour market disruptions, detrimental economic effects on local communities and companies • Risk of carbon leakage

A3.1 Phase outs	Strong emission reduction effect	<ul style="list-style-type: none"> • Reduced excess capacity • Reduced demand for fossil fuels • Increased demand for steel from clean sources 	<ul style="list-style-type: none"> • Risks of job losses and unjust transition • Risk of carbon leakage
A4.1, A5.1 Covering scrapping costs and pensions for closed emission intensive plants	Accelerated reduction in emission-intensive capacity	<ul style="list-style-type: none"> • Mitigation of financial risks • Exit from the market of less financially robust firms 	Unclear, but potentially high costs
A3.2, A4.2 No new emission-intensive capacity	No emission growth	No growth in emission-intensive excess capacity	Little-to-no side effects
B. Reduce emissions from existing steel plants	Moderate carbon reduction potential depending on country's industry profile	<ul style="list-style-type: none"> • No direct effect on capacity • Ambiguous effects on steel production, price 	Ineffective with additions of emission-intensive capacity
B3.3 Reduce energy intensity of steelmaking capacity (Energy and materials efficiency)	Marginal emission reduction effect	<ul style="list-style-type: none"> • Small effect on steel markets • Technological cost 	No major side effects
B4.3, B5.3 Introduce incentives for energy savings in steelmaking	Marginal emission reduction effect	Moderate reduction in energy costs	Moderately reduced energy demand
B3.4 Capture carbon emissions from all existing facilities (CCUS)	<ul style="list-style-type: none"> • In existing capacity: Medium emission reduction effect • In new capacity: Potential for strong emission reduction effect 	<ul style="list-style-type: none"> • Higher steelmaking costs 	<ul style="list-style-type: none"> • Growing demand for carbon storage • Not technology neutral
B4.4, B5.4 Funding infrastructures for carbon storage	Indirect emission reduction potential depending on country's industry profile	<ul style="list-style-type: none"> • Competitive advantage for early adopters • Lowering the cost of using CCUS-based technologies 	<ul style="list-style-type: none"> • Risk of lock-in to high-carbon technologies • Uneven distribution of benefits • Not technology neutral
C. Increase near-zero steelmaking capacity	Moderate emission reduction potential according to industry profile	Market frictions on resources	Large amounts of investment needed
C3.5 Increase scrap-based steelmaking capacity	Marginal emission reduction potential	<ul style="list-style-type: none"> • Growing demand for scrap • Capacity addition 	<ul style="list-style-type: none"> • Increased scrap prices • Limited scrap stock (end-of-life steel products)
C4.5 Increase scrap use rates by supporting scrap management facilities	Marginal emission reduction potential	Lower production costs More stable scrap markets	Scrap availability limited by the stock of scrap
C5.5 Introducing scrap management scheme for	Marginal emission reduction potential	Strengthening scrap-based steelmaking	<ul style="list-style-type: none"> • Few side effects

higher scrap availability and quality		quality	
C3.6 Increase hydrogen-based steelmaking capacity	Strong emission reduction potential if replacing emission-intensive capacity	<ul style="list-style-type: none"> Higher steelmaking costs Growing demand for clean hydrogen Capacity addition 	<ul style="list-style-type: none"> Demand for renewable energy Potential reconfigurations of steel supply chain Large investment cost Not technology neutral
C4.6 Production targets of clean hydrogen	Indirect emission reduction Potential	Support hydrogen markets growth	<ul style="list-style-type: none"> Risk of high initial costs Not technology neutral
C5.6 Support clean hydrogen production for steel end use	Indirect emission reduction potential	Creation of new market opportunities	<ul style="list-style-type: none"> Risk of clean energy shortage for other sectors Not technology neutral
C3.7 Pilot frontier steelmaking capacities	Indirect, long-term emission reduction potential	Small or no capacity effects in the short run	<ul style="list-style-type: none"> Low deployment at commercial scale before technology's maturity Risk of technology lock-in
C4.7 Support research and development of frontier steelmaking technology	Indirect, long-term emission reduction potential	Creation of new industries and jobs	<ul style="list-style-type: none"> Long path to commercial development
C5.7 Boosting funding and facilitating collaboration on research and development for direct electrolysis	Indirect, long-term emission reduction potential	Creation of new market opportunities	<ul style="list-style-type: none"> High initial costs Positive spillover on other hydrogen-using sectors Not technology neutral
Cross-cutting pledges: green employment, technology transfer, international/regional cooperation	Potential for indirect emission reductions	Expansion of green job markets and available skilled labour	Few negative side effects

Source: Authors' elaboration

69. The preliminary findings suggest key examples of trade-offs facing policymakers in the formulation of supply-side pledges in the steel sector.

- A first trade-off example arises from addressing the interplay between emissions, production, and replacement cost. The reduction of emission-intensive capacity decreases industrial pollution but can also open space for a green steel market and improve the financial health of the industry by reducing excess capacity. While these key advantages will be likely to generate significant environmental benefits, an integrated approach is needed to anticipate potential socioeconomic risks and avoid counterproductive policies. Phasing out old capacity can be costly in the short and medium term due to the negative effects on the employment and local community. Capacity adjustments require timely policy responses to address economic challenges including for example clear roadmaps for planning and adaptation, coordinated labour market interventions, state aid schema for covering the facility's closure cost, as well as the robust long-term plan for re-industrialisation (Algers and Åhman, 2024_[6])

- A second key example of trade-offs relates to the interactions between different energy-materials systems and market dynamics. Pledging efficiency improvements can lead to material saving and adaptation outcomes, while expected emissions reduction will depend on balanced market conditions. For example, scrap recycling targets can help increase steel circularity, avoid additional emissions from primary production, and reduce product costs (Morseletto, 2020_[29]). The success of this type of pledge to achieve emissions savings depends on the domestic scrap market balance, global availability of steel scrap, scrap trade flows, requirements for high-quality scraps and electricity consumption. Furthermore, applying efficiency improvement measures can contribute to extending the life of the steel asset base, at a disadvantage to slow down the positive impacts of capacity reduction measures, especially for high-emission emitting capacities.
- Finally, there is another example of a trade-off between the cost-effectiveness issue of new technological solutions and the need to accelerate deep decarbonisation. The growth of low-emission steelmaking capacity will depend on the emergence of new technology, energy and materials markets to meet decarbonisation challenges. Compared to conventional technologies, most low-carbon technologies are capital-intensive and at a low scale of commercialisation (OECD, 2023_[30]), but their competitiveness is also heavily impacted by high operating costs, particularly due to the price of hydrogen in both current and projected markets. Future low-emission capacities imply important trade-offs of different technology choices, energy costs and materials needed. Green hydrogen-based steelmaking illustrates new challenges and opportunities for steel producers to achieve substantial emissions reduction. On the one hand, expanding hydrogen-based DRI capacity would require substantial production of low-emission hydrogen and key materials for both electrolyzers (e.g., platinum, iridium, nickel) and renewable energy infrastructure to meet steel demand. There are still inherent risks of fossil fuel lock-in as most low-carbon investments are currently directed to natural gas-based DRI capacities. On the other hand, new trade-offs can emerge with green hydrogen production for different end-uses (e.g., steelmaking, refining, chemical production), via domestic electrolyzers or import from outside.

70. Several key insights can be drawn from this preliminary analysis and applied to industries at large. First, emission reduction pledges can have effects that go beyond positive environmental outcomes and bring additional economic risks and benefits. Second, concerted policies between the various stakeholders involved can help identify solutions that capitalise on potential synergies and minimise environmental, social and economic trade-offs. Policymakers need to coordinate strategies and policies to address emission reduction and industry capacity adjustments in conjunction. Under specific national circumstances, some trade-offs may be more achievable than others in current and future terms and could possibly have economic benefits and side effects that should be considered across borders.

7 Conclusion

71. This paper provides a conceptualisation of a carbon-capacity nexus for assisting in the development of quantifiable and actionable pledges for the decarbonisation of industry. A change in emissions from industry is intimately tied to changes in production capacity and therefore the steps to decarbonise industries can be quantified based on changes in capacity. Such supply-side perspective on industrial decarbonisation and the way this can be supported by pledges is currently lacking.

72. As industrial products are highly traded and industries depend on cross-border supply chains, there may be unintended negative side effects of routes to decarbonisation that should be avoided for long-term success. It is therefore crucial that pledges on industrial decarbonisation are based on considerations of both decarbonisation technologies and market effects of each route.

73. This paper provides anchor points and discusses pitfalls of potential pledges by governments to decarbonise the industry, using the steel industry as a case. Capacity adjustments can be classified into three categories based on their effect on production capacity and pledges and could be made depending on countries' industrial structure. These capacity adjustments are to reduce emission-intensive capacity, lower emissions in existing emission-intensive capacity, and increase near-zero emission capacity. Pledges that solely focus on increasing near-zero capacity without addressing existing emission-intensive a capacity will not be sufficient to achieve climate objectives.

74. Each of these categories can be realised through several routes, and countries could also make more pledges on this level of granularity for higher transparency and clarity on the pathway for their own industry. These routes require changes in technology, regulations and infrastructure, and depending on the requirements, there are clusters of policies that can support each route.

75. Pledges on several capacity adjustments or levels of granularity can be combined in a coherent approach for industrial decarbonisation. A combination of pledges that are both expansionary and reducing capacity is likely to be more politically feasible than simply reductive pledges. Such combinations can be made either within a sector like the steel industry or across sectors.

76. Finally, the effectiveness of pledges could significantly increase when undertaken collectively by countries, for instance in the context of the Climate Club. Such collective pledging could enhance the scale of impact and efforts, would help address negative spillovers and could enhance inclusiveness.

References

- Agora industry (2023), *15 insights on the global steel transformation*, <https://www.agora-industry.org/publications/15-insights-on-the-global-steel-transformation> (accessed on 17 March 2025). [31]
- Algers, J. and M. Åhman (2024), “Phase-in and phase-out policies in the global steel transition”, *Climate Policy*, <https://doi.org/10.1080/14693062.2024.2353127>. [6]
- Bashmakov, I. et al. (2022), “Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P]”, <https://doi.org/10.1017/9781009157926.013>. [12]
- Bashmakov, I. et al. (2022), “SPM 11 Industry Coordinating Lead Authors: Lead Authors: Contributing Authors: Chapter Scientist: Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P]”, <https://doi.org/10.1017/9781009157926.013>. [36]
- Bataille, C. et al. (2023), “A Paris Agreement Compliant Definition for “Abated Fossil Fuels””, *SSRN Electronic Journal*, <https://doi.org/10.2139/SSRN.4574502>. [26]
- Bataille, C. et al. (2024), “Triggering Investment in First-of-a-Kind and Early Near-Zero Emissions Industrial Facilities”, <http://www.sipa.columbia.edu> (accessed on 17 March 2025). [27]
- BIR (2022), “WORLD STEEL RECYCLING IN FIGURES 2017-2021 13 TH EDITION Steel Scrap-a Raw Material for Green Steelmaking”. [23]
- Climate Club (2022), *Terms of Reference for the Climate Club*, <https://climate-club.org/wp-content/uploads/2023/11/TOR-CC-logo.pdf> (accessed on 17 March 2025). [1]
- De Carvalho, A. (2024), “DIRECTORATE FOR SCIENCE, TECHNOLOGY AND INNOVATION STEEL COMMITTEE Latest developments in steelmaking capacity and outlook until 2026”, <http://www.oecd.org/termsandconditions>. (accessed on 17 March 2025). [7]
- E3G (2021), *1.5C Steel: decarbonising the steel sector in Paris-compatible pathways - E3G*, <https://www.e3g.org/publications/1-5c-steel-decarbonising-the-steel-sector-in-paris-compatible-pathways/> (accessed on 17 March 2025). [18]
- GFSEC (2022), *Assessing Steel Decarbonisation Progress in the context of Excess Capacity A Steel Indicator Decarbonisation Dashboard*, <https://www.steelforum.org/steel-indicator-decarbonisation-dashboard.pdf> (accessed on 17 March 2025). [4]
- GFSEC/OECD (2022), *Assessing Steel Decarbonisation Progress in the context of Excess Capacity: A Steel Indicator Decarbonisation Dashboard*, <https://www.steelforum.org/steel-indicator-decarbonisation-dashboard.pdf>. [35]
- Hynes, W., M. Lees and J. Müller (2020), “Systemic Thinking for Policy Making THE POTENTIAL OF SYSTEMS ANALYSIS FOR ADDRESSING GLOBAL POLICY CHALLENGES IN THE 21 ST CENTURY”. [29]
- Hynes, W., M. Lees and J. Müller (2020), *Systemic Thinking for Policy Making: The Potential of Systems Analysis for Addressing Global Policy Challenges in the 21st Century*, New [39]

- Approaches to Economic Challenges*, OECD Publishing, <https://doi.org/10.1787/879c4f7a-en>.
- IEA (2023), *Energy Technology Perspectives 2023 – Analysis - IEA*, [19]
<https://www.iea.org/reports/energy-technology-perspectives-2023> (accessed on 17 March 2025).
- IEA (2023), *Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach – Analysis - IEA*, [2]
<https://www.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach> (accessed on 17 March 2025).
- IEA (2021), “Iron and Steel Technology Roadmap Towards more sustainable steelmaking Part of the Energy Technology Perspectives series”, <http://www.iea.org/t&c/> (accessed on 17 March 2025). [14]
- IEA (2021), “Net Zero by 2050 - A Roadmap for the Global Energy Sector”, [17]
<http://www.iea.org/t&c/> (accessed on 17 March 2025).
- IISD (2023), *Unpacking Carbon Capture and Storage: The technology behind the promise | International Institute for Sustainable Development*, [22]
<https://www.iisd.org/articles/insight/unpacking-carbon-capture-storage-technology> (accessed on 17 March 2025).
- IRENA (2020), “Reaching zero with renewables: Eliminating CO2 emissions from industry and transport in line with the 1.5°C climate goal”, <http://www.irena.org/publications> (accessed on 17 March 2025). [20]
- Karacan, C. et al. (2011), “Coal mine methane: A review of capture and utilization practices with benefits to mining safety and to greenhouse gas reduction”, *International Journal of Coal Geology*, Vol. 86/2-3, pp. 121-156, <https://doi.org/10.1016/j.coal.2011.02.009>. [8]
- Morseletto, P. (2020), “Targets for a circular economy”, Vol. 153, p. 104553, [40]
<https://doi.org/10.1016/j.resconrec.2019.104553>.
- Morseletto, P. (2020), “Targets for a circular economy”, *Resources, Conservation and Recycling*, Vol. 153, p. 104553, <https://doi.org/10.1016/J.RESCONREC.2019.104553>. [32]
- Oda, J. et al. (2012), “International comparisons of energy efficiency in power, steel, and cement industries”, *Energy Policy*, Vol. 44, pp. 118-129, [15]
<https://doi.org/10.1016/J.ENPOL.2012.01.024>.
- OECD (2024), “CIRCULAR ECONOMY POLICIES FOR STEEL DECARBONISATION”. [16]
- OECD (2024), *OECD Employment Outlook 2024: The Net-Zero Transition and the Labour Market*, OECD Publishing, Paris, <https://doi.org/10.1787/ac8b3538-en>. [13]
- OECD (2024), *Steel | OECD*, <https://www.oecd.org/en/topics/sub-issues/steel.html> (accessed on 17 March 2025). [11]
- OECD (2024), “UNLOCKING POTENTIAL IN THE GLOBAL SCRAP STEEL MARKET: OPPORTUNITIES AND CHALLENGES”. [24]
- OECD (2023), *OECD work in support of industrial decarbonisation*, OECD Publishing, [41]
<https://doi.org/10.1787/cd589e4f-en>.

- OECD (2023), "OECD work in support of industrial decarbonisation", <http://www.oecd.org> (accessed on 17 March 2025). [33]
- OECD (2023), "THE HETEROGENEITY OF STEEL DECARBONISATION PATHWAYS REPORT PREPARED FOR THE 2023 JAPANESE PRESIDENCY OF THE G7", <http://www.oecd.org/termsandcondition> (accessed on 17 March 2025). [5]
- OECD (2024-e), *Unlocking Potential in the Global Scrap Steel Market: Opportunities and Challenges*. [38]
- Rimini, M. et al. (2020), *Barriers to exit in the steel sector*, OECD unclassified document DSTI/SC(2019)16/FINAL, Paris, <https://www.oecd.org/industry/ind/steel-data-and-resources.htm>. [10]
- S. Managi, S. (2020), "Iron and Steel Industry, Dialogue on European Decarbonisation Strategies". [21]
- Sekera, J. and A. Lichtenberger (2023), "Assessing Carbon Capture: Public Policy, Science, and Societal Need", *Biophysical Economics and Sustainability*, Vol. 5/3, <https://doi.org/10.1007/S41247-020-00080-5>. [37]
- Swedish Energy Agency (2024), *The Industrial Leap*, <https://www.energimyndigheten.se/en/innovations-r--d/energyintensive-industry/the-industrial-leap/> (accessed on 17 March 2025). [28]
- Vogl, V., M. Åhman and L. Nilsson (2018), "Assessment of hydrogen direct reduction for fossil-free steelmaking", *Journal of Cleaner Production*, Vol. 203, pp. 736-745, <https://doi.org/10.1016/J.JCLEPRO.2018.08.279>. [25]
- Watari, T., D. Giurco and J. Cullen (2023), "Scrap endowment and inequalities in global steel decarbonization", *Journal of Cleaner Production*, Vol. 425, p. 139041, <https://doi.org/10.1016/J.JCLEPRO.2023.139041>. [30]
- Worldsteel Dynamics (2024), "Glass half full or half empty?". [9]
- Zhai, M. et al. (2020), "Inter-regional carbon flows embodied in electricity transmission: network simulation for energy-carbon nexus", *Renewable and Sustainable Energy Reviews*, Vol. 109511, p. 118, <https://doi.org/10.1016/j.rser.2019.109511>. [34]
- Zhai, M. et al. (2020), "Inter-regional carbon flows embodied in electricity transmission: network simulation for energy-carbon nexus", *Renewable and Sustainable Energy Reviews*, Vol. 118, p. 109511, <https://doi.org/10.1016/J.RSER.2019.109511>. [3]