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Ironing Out the Transformation of EU Steelmaking: Actionable Pathways for Climate Neutrality

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Ironing Out the Transformation of EU Steelmaking: Actionable Pathways for Climate Neutrality

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FOREWORD

As one of the most emission-intensive sectors in the EU, the iron and steel industry is a significant contributor to overall emissions, with efforts for emissions reduction in the sector playing a crucial role in achieving Europe's climate goals. The challenge of decarbonising this sector is immense, but as recent developments have highlighted, the sector faces several hurdles such as high electricity prices, stark competition from cheaper imports, and a slower-than-expected pace for operationalising hydrogen-based ironmaking.

In this critical context, EPICO is contributing to the debate with 15 targeted policy recommendations for the EU level, offering a roadmap for a realistic transformation of the EU steel industry. These are guided by a commitment to reducing emissions, leveraging Europe's competitive advantages, and ensuring financial responsibility while strengthening social support and cohesion.

The policy recommendations are structured around the following pillars:

1. Ensuring access to affordable, low-carbon electricity
2. Accelerating hydrogen adoption for the ironmaking process
3. Enhancing steel circularity: reduce, reuse, recycle
4. Developing lead markets for low-emission steel through public procurement and standardisation
5. Engaging with the global dimensions of steel decarbonisation

EPICO hosted two stakeholder consultation workshops on steel decarbonisation in Brussels (19-20 March 2024) and Berlin (25 April 2024), involving participants from EU institutions, business associations, industry, NGOs, think tanks and academia. At these workshops, extensive discussions were held between a broad spectrum of over 50 stakeholders to help provide a blueprint for a financially, socially, and environmentally sustainable steel industry agenda in Europe. Some of these inputs have also been referenced in this policy report.

EPICO'S 15 POLICY RECOMMENDATIONS FOR THE CLIMATE-NEUTRAL TRANSFORMATION OF THE EU STEEL INDUSTRY

SECURING ACCESS TO CLEAN ELECTRICITY

1. Accelerate the Decarbonisation of the Electricity Mix

Streamline and accelerate permitting processes by investing in capacity building, fully utilising the Renewable Energy Directive's provisions, such as acceleration areas and predictable permitting processes, as well as expanding and upgrading the energy grid infrastructure.

2. Reduce the Cost of Renewable Energy

Encourage Member States to fully utilise and strengthen the tools provided by the latest Electricity Market Design, including Contracts for Difference, Power Purchase Agreements, and innovative financing models, to accelerate the production and consumption of renewable energy.

3. Explore Industrial Demand Side Response

Promote flexible energy consumption by revising network charges and adjusting indirect cost compensation to reflect sector-specific flexibility, compensating for demand response and supporting strategies like energy storage and improved inventory management.

SECURING ACCESS TO FOSSIL-FREE HYDROGEN

4. Adopt A European Hydrogen Roadmap

Formulate a detailed and integrated pan-European hydrogen infrastructure roadmap mapping future hydrogen demand and supply points and identify critical areas to ensure hydrogen delivery to key industrial hubs.

5. Improve the Design of Auctions for Hydrogen Production to Favour Emissions Abatement

Include CO_2 abatement potential in EU-wide renewable hydrogen auctions, increase their budget, promote Auctions-as-a-Service, and offer default guarantees to mitigate risks beyond hydrogen producers' control.

6. **Enhance Social Acceptance of Hydrogen and Address Hydrogen Leakage More Systematically**

Utilise hydrogen more strategically for cost-effective emissions reductions in a limited number of sectors, while avoiding misallocation and requiring risk-based programmes as a permit condition, to mitigate hydrogen leakage and its effects.

MAKING STEEL MORE CIRCULAR: REDUCE, REUSE, RECYCLE

7. **Enhance Support for Recycling Technologies and Infrastructure**

Advance steel recycling by supporting technologies for alloy sorting and tracking material flows. Establishing quality standards, robust material tracking systems, and assessing the environmental and economic impacts of recycling technologies are also essential.

8. **Strengthen Integration and Knowledge Sharing in the Recycling Sector**

Integrate recycling into EU steel, environmental, and trade policies by setting quality standards, fostering collaboration, and supporting advanced technologies. Promote partnerships with downstream industries, expand design-for-recycling standards, and mainstream the cradle-to-cradle approach across EU policymaking.

9. **Improve Circular Economy Policy Frameworks to Promote Demand-side Measures, Material Efficiency, and the Reuse of Steel**

Elevate measures such as material efficiency, demand substitution and reuse of steel products, as these areas remain underutilised despite their significant potential for emissions reduction.

CREATING LEAD MARKETS FOR LOW-EMISSION STEEL

10. **Adopt a Common European Labelling System for Low-Emission Steel to Provide Clarity and Avoid Greenwashing**

Adopt a holistic standard for low-emission steel that considers emissions across the entire value chain, promotes circularity, integrates reliable EPDs and PCFs, and includes strong safeguards against greenwashing.

11. **Reform the Public Procurement Directive to Reduce Emissions in Steelmaking**

Align the EU Public Procurement Directive (2014/24) with climate and sustainability goals, shifting from price-only criteria. Mandate pre-demolition audits, improve data-sharing, and implement an EU Skills Plan to train officials in lifecycle costing and Green Public Procurement.

12. **Adopt Ambitious Product-Specific Standards Coupled with Evolving Lifecycle Carbon Limits**

The EU should further encourage Whole Lifecycle Carbon caps and Life Cycle Assessment approaches to decarbonising steel for sectors such as construction and automotive, with strong product-specific standards.

ENGAGE WITH THE GLOBAL DIMENSIONS OF STEEL DECARBONISATION

13. **Engage in Focused Climate Diplomacy**

Include concerted international climate diplomacy efforts in future EU policy to address the potential for international partnerships and cooperation, including through the strengthening of the Climate Club.

14. **Ensure the Effectiveness of the CBAM**

Retain the CBAM's focus on its core goal of preventing carbon leakage, make and efforts to strengthen it and increase its acceptability for trade partners.

15. **Take the Evolving Supply Chain Into Account in Policy Discussions on Resilience and Competitiveness**

Address the reality of shifting supply chains in future-oriented discussions on EU steel decarbonisation policy, while assessing the future competitiveness of European steel, and the most efficient utilisation of public funds to support decarbonisation.

I.

OVERVIEW OF THE STEEL INDUSTRY IN THE EU

In 2021, the EU adopted the European Climate Law, which mandates a 55% reduction of greenhouse gas emissions generated in the EU by 2030 and net-zero emissions by 2050 (relative to 1990 levels). These legally binding targets require significant changes in various energy-intensive industries such as the iron and steel sector, which emits around 221 million tonnes (Mt) of CO_2 annually, representing an estimated 5.7% of the EU's annual greenhouse gas emissions (European Commission, 2021a). The third-largest industrial sector, iron and steel generated a gross value added of EUR 152 billion in 2023, more than the annual EU budget (EUROFER, 2024b). Its 500 production sites spread across 22 Member States directly support over 300,000 jobs, and 1.57 million indirectly. In 2023, it produced 126 Mt of steel – primarily from Germany (28%), Italy (17%), and Spain (9%) – down from 150 Mt in 2019 (EUROFER, 2024b). Since 2008, this decreased production led to a loss of almost 100,000 workers (EUROFER, 2024a).

In 2023, a record 27% of EU steel consumption came from imports, driven by export-focused production in Asia-MENA as well as Chinese overcapacities, artificially lowering global steel prices and putting the transformation of the European steel industry at risk. This pressure on EU steelmakers is strengthened by faltering demand, high domestic energy costs, and the planned phaseout of free EU Emissions Trading System (EU-ETS) allowances (EUROFER, 2024e ; Hasanbeigi, et al., 2024). While the sector has long struggled with profitability, as can be seen in Figure 1, the current downturn signals an unprecedented crisis. In November 2024, ThyssenKrupp Steel, Europe's second-biggest steelmaker after ArcelorMittal, announced plans to reduce employment by a staggering 11,000, out of 27,000 employees of the German company in Europe, after reporting a EUR 1.5 billion loss for 2023/2024 (Euronews, 2024; ThyssenKrupp AG, 2024). ArcelorMittal has delayed its European decarbonisation plans, planning to revise its 2030 target of a 35% emissions reduction (L'Echo, 2024). Salzgitter reported a loss of between 275–325 million EUR in 2024, and ArcelorMittal Europe's EBITDA[1] dropped 28% year-on-year in the first three quarters of 2024 (ArcelorMittal, 2024; Salzgitter AG, 2024). Numerous steel mills and production lines have been mothballed since the pandemic and the energy crisis, and thousands of workers are temporarily unemployed. Besides these issues, the trend has created a negative spiral consisting of eroding innovation, with metallurgy disappearing from curricula, teacher shortages, fewer young engineers and researchers, falling wages, and declining job opportunities – all while demand for these skills is rising significantly (EESC, 2024).

National governments and the EU need to urgently address the situation. Reactions so far include a debate in the European Parliament, the European Commission's announcement

[1] Earnings Before Interest, Taxes, Depreciation, and Amortisation.

of a new Steel and Metals Action Plan, and a call for a Steel Pact, supported by 70 MEPs, the European Steel Federation and European Metalworkers Unions (EUROFER, 2024a), and a separate call for a Steel Pact from German federal states, the German metalworkers' union and the German Steel Association (Nationaler Aktionsplan Stahl, 2024).

The EU reformed its EU-ETS, in place since 2005, to phase out free allowances between 2026 and 2034, but only for sectors covered by the Carbon Border Adjustment Mechanism (CBAM). The CBAM, which will apply in its definitive regime starting 1 January 2026 (after a transitional reporting-only phase between 2023 and 2025), is a first-of-its-kind[2] border carbon adjustment (BCA) requiring EU importers of carbon-intensive goods to pay a carbon price, in order to prevent carbon leakage[3] and drive global decarbonisation goals. Between 2008 and 2019, 95% of EU-ETS allowances were free, with some companies even making a profit from the system, effectively disincentivising emissions reductions (Carbon Market Watch, 2022).[4] The low profitability of Europe's only DRI plant, in Hamburg, is a prime example of the negative effect of free allowances on the incentive to decarbonise.

Steel is indispensable to the functioning of all industrialised and industrialising economies, playing a vital role in everything from buildings to transportation systems and energy infrastructure. Producing low-emission steel will also be essential for defence technologies, building zero-carbon housing, wind turbines, and trains.

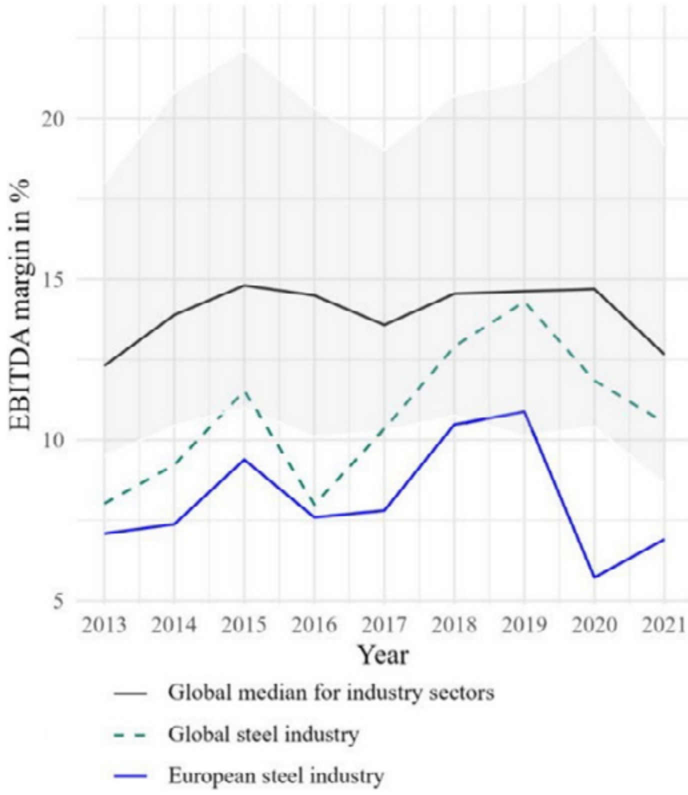

Figure 1 : EBITDA of global industry sectors, the global and the European steel industry between 2013 and 2021 (Hüttel & Lehner, 2024)

[2] California introduced the first BCA in 2013, requiring electricity importers to pay for emissions from power generated in other US states.

[3] Carbon leakage is defined as the imported production of carbon-intensive steel made in regions with less stringent environmental regulation (Carbon Market Watch, 2022).

[4] Since the EU decided to integrate Clean Development Mechanism credits, established under the Kyoto Protocol, into the ETS, the iron and steel sector also benefited from approximately EUR 850 million between 2008 and 2019, as the price of international credits was lower than EU allowances (de Bruyn, Juijn, & Schep, 2021).

LONG AND FLAT PRODUCTS

The distinction between the two main steel production routes, and types of intermediary steel products, namely long and flat products, is crucial for understanding the structure and dynamics of the steel industry.

Long products are produced by extruding steel into long shapes, such as rebars, beams, rods, bars, wire, and rails. Steel products like rebar ensure that concrete structures can bear loads without cracking or collapsing, and structural steel (beams, columns, and girders) is used in frameworks that provide strength and durability for large buildings, bridges, and industrial plants.

Flat products are produced by rolling steel into flat sheets, which are then wound into coils, which can in turn be processed into sheets, strips, or plates. Steel sheets are thinner and flexible, used in automotive and appliance industries, while steel plates are thicker and stronger, used for more heavy-duty applications like shipbuilding and wind towers.

THE TWO STEELMAKING ROUTES

The Blast Furnace (BF)-Basic Oxygen Furnace (BOF) route creates steel from iron ore through a continuous sequence of operations at a single facility, which is why it is labelled "integrated". Iron ore is reduced with coke coal in a BF, after which pure oxygen is blown into the molten iron in a BOF. This method is more important for flat steel, used in products such as automobiles, home appliances, and industrial equipment, but can also produce long steel. Most flat products require precise dimensions and high surface quality, which are currently difficult to obtain from lower-grade recycled steel (Sandbag, 2022; Systemiq Earth and ThyssenKrupp Steel Europe, 2024). Steel scrap or recycled steel[1] can constitute up to 15-20% of the metallic charge of a BOF helping to regulate the temperature during the oxygen-blowing process while contributing to resource efficiency and cost reduction (International Iron Metallics Association, 2017; Sandbag, 2022).

The alternative to using BOFs is electric arc furnaces (EAF). As an alternative to BOFs, EAFs offer several advantages. EAFs are widely used to produce long products, such as billets and rebar for construction and energy infrastructure,[5] as well as flat steel products. In the market for long products, competition exists between the two routes, with producers vying over factors like scale, quality, and material consistency. With an average annual production capacity of 1 Mt compared to over 3 Mt for integrated BF-BOF steelmaking mills, EAFs also require significantly lower upfront capital, making them a cost-effective option (EUROFER, 2024b). EAFs are capable of melting various metallic feedstocks, such as steel scrap (up to 98% of the charge), sponge iron (up to 100% of the charge), and pig iron (typically 5–10% of the charge, and limited to 60% of the charge due to its higher carbon content and impurities) (International Iron Metallics Association; Nucor, 2023). Since these need to be melted at very high temperatures (up to 1600°C), the energy needs are high: Georgsmarienhütte, producing over 17 Mt of steel each year, necessitates 1 tWh of electricity for its EAFs (Kallmeier, 2023). Due to their flexibility with raw materials, EAFs are especially suited for producing alloyed steels, including stainless steel, which require additional elements like nickel, chromium, and manganese. When powered by renewable electricity, EAFs can achieve near-zero emissions, offering a cleaner pathway to decarbonising steelmaking,[6] as can be seen in Figure 2 (European Commission, 2022; Kurrer, 2020).

[5] Since scrap, or "Schrott" in German, has negative connotations, the Bureau of International Recycling has suggested and adopted "recycled steel" as a new term (Bureau of International Recycling, 2023, p. 4).

[6] Between 1 and 7 kilogrammes CO_2 per tonne of steel are still generated from electrode consumption, which will represent the EAF's only residual emissions in a net-zero scenario (Echterhof, 2021, p. 3).

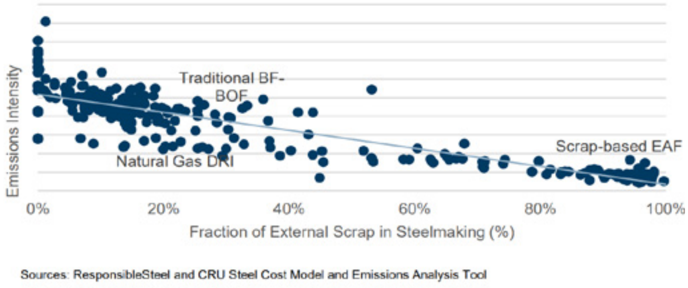

Figure 2: Global emissions intensity of steelmaking by technology and input mix (Rocky Mountain Institute, 2022)

The traditional distinction between primary and secondary steelmaking overlooks the flexibility of EAFs, which, while historically reliant on scrap, can also use DRI. This binary classification does not reflect the complexities of the changing landscape of steelmaking, as can be seen in *Figure 2*. To address this, the report uses "ore-based steelmaking" for processes reliant on iron ore and "scrap-based steelmaking" for those using little to no virgin iron ore. Accordingly, it avoids terms like "primary" and "secondary" steelmaking, opting instead for more precise terminology such as BF-BOF, EAF, ore-based, and scrap-based steelmaking.

In the EU, 56% of steel is produced through the integrated BF-BOF route, which contributes to between 87% and 97% of the sector's emissions (European Commisson, 2022; Koolen & Vidovic, 2022; Sandbag, 2022). The remaining 43% is produced through the scrap-EAF route. Hybrid setups, such as using pig iron in EAFs or incorporating scrap in BOFs, complicating strict classification, but these figures depend on the proportion and origin of the input materials. As a comparison, the share for the latter is 68-70% in the United States and 71-75% in Turkey, the EU's two major steel trading partners (SEFiA, 2022, p. 12; Steel Manucturers Association Website; World Steel Association, 2024).[7]

For the 2016/2017 period (the last data made available by the European Commission), the direct greenhouse gas emissions intensity of steel production by EAFs was 0.1 tonnes of carbon dioxide (CO_2) per tonne of steel, compared with 2.06 tonnes for BF-BOF steelmaking (European Commission, 2021b). The reliance on BF-BOF steelmaking also increases the EU's external dependency: in 2023, the EU imported over 70 Mt of iron ore and 40 Mt of coke coal - a dependency that is growing due to Czechia and Germany respectively scaling down and ceasing domestic coal mining.[8] In 2023, the top iron ore producers were Australia (960 Mt), Brazil (440 Mt), China (280 Mt), and India (270 Mt). By contrast, European producers such as Ukraine (36 Mt) and Sweden (38 Mt) are far behind, illustrating the dependency created by ore-based steelmaking) (GMK Center, 2022; Liljenstolpe, Hamberg, Hedström, Larsson, & Kjellson, 2024).

The low global steel prices and the high price of natural gas in Europe since February 2022 raise important challenges of profitability for low-emission ironmaking in Europe.[9] Additionally, the iron ore must be pelletised before reduction into so-called sponge iron, as the pellets allow for consistent reduction and efficient gas flow within the furnace. Given

[7] Worldwide, Indonesia has the highest carbon emission factor for ferrous metal production per unit mass of ferrous metal (kilogramme-equivalent carbon dioxide per kilogramme) at 2.2, followed by India at 2.1 and China at 2.0. In contrast, the United States (1.1) and Italy (1.2) have the lowest values (World Steel Association, 2024). France, Germany, and Turkey fall within the middle range, with 1.4 kilogramme-equivalent CO2 per kilogramme of ferrous metal (Ministère de la Transition Energétique, 2023).

[8] The coke coal imports primarily originated from China (48%), Colombia (21%), and Turkey (16%) (European Commission Raw Materials Information System).

[9] Hamburg's DRI furnace, which has used Midrex® technology since 1971, is still the only one producing DRI in Europe at industrial scale, but is not running at full capacity given the high price of natural gas and LNG. In 2019, a new furnace using 60% hydrogen and 40% natural gas was built, with waste heat repurposed for district heating (Schmidt, 2019), but the shift to fossil-free hydrogen has stalled (Busch, 2024).

the high cost of pelletisation, these processes have been attractive only in markets where natural gas is substantially cheaper than coal, such as in the US, Russia, or the MENA region (Kurrer, 2020). Other leaders in DRI production are India and Iran (Financial Tribune, 2021). The requirement for low impurities and high iron content in DR-grade ores poses a challenge due to their limited availability. Tow iron content ores can be upgraded through the iron ore beneficiation process. Fluidised beds provide another solution, as they can directly process ores with higher impurity levels, reducing the need for ultra-pure DR-grade ore (IEEFA, 2022).[10] However, these two options are expensive. Ukraine and Sweden have high-quality DR-grade iron, but these will not suffice for the projected DRI production (IEEFA, 2022).

Gradually shifting from BF-BOF steelmaking to DRI and scrap with EAFs is therefore paramount for reducing carbon emissions. Some degree of ore-based steel production will remain necessary due to the quality requirements (high tensile strength, ductility, smoothness, uniformity), such as flat products for automotive body panels and high-strength structural components. Recycled ferroalloys also might not be fully able to replace the need for virgin inputs because they often contain trace impurities, such as copper and tin, that are difficult to remove and can compromise the steel's mechanical properties, corrosion resistance, and surface quality. Moreover, vanadium for instance is particularly difficult to recycle due to its tendency to form stable compounds. An important debate revolves around the extent to which ore-based steel is needed, addressed in Chapter IV (M., Silveira, & Duerinck, 2017; Sandbag, 2022; Hundt & Pothen, 2024; Steel Manufacturers Association, 2023).

DIRECT REDUCED IRON

The DRI process originated in the United States, with Midrex® (now owned by Japanese steelmaker Kobe Steel) launching its first plant in Portland in 1969. In 1998, Mexican steelmaker Hylsa introduced the Energiron Zero Reformer® process in Monterrey. The Energiron ZR process eliminates the need for external reformers by generating reducing gases directly within the shaft furnace, reducing both capital and operating costs while simplifying Carbon Capture integration. By contrast, the Midrex process offers more precise control over gas composition, enabling hydrogen integration of up to 30% without modifications to process equipment, while delivering higher efficiency and product purity (Astoria, Hughes, & Mizutani, 2022). Midrex controls around two-thirds of worldwide DRI capacity, followed by Energiron with 15% and Indian rotary kilns (internal sources). Unlike BFs, DRI uses natural gas (NG-DRI) and/or hydrogen (H2-DRI) as the reducing agent to remove oxygen in a so-called shaft furnace. The fact that natural gas can be used for DRI, and can be gradually replaced with fossil-free hydrogen without great infrastructural changes is crucial for the steel industry's decarbonisation path, as sponge iron made from natural gas is around 60% to 70% less carbon-intensive than pig iron made from coal (Agora Industry, Wuppertal Institute and Lund University, 2021; IEA, 2020; Kurrer, 2020; Somers, 2021)

[10] Poor-quality ore contains less iron and more gangue, which remains in the product after direct reduction, unlike in BFs where it is removed as slag. This leads to excessive slag in EAFs, capturing iron and necessitating high-quality ore (66-67% Fe), which is scarce and costly (Agora Energiewende and Agora Industry, 2024). Namibia highlights the challenge of sourcing DR-grade pellets, as its iron ore, with less than 66% Fe, requires crushing, separation, and silica removal via magnetic methods. The Electric Smelting Furnace (ESF) addresses this issue by processing lower-grade ore (e.g., 62% Fe), expanding the usable global supply to 50% and increasing raw material flexibility. However, the molten iron from the ESF must still be refined in a BOF, resulting in significant CO_2 emissions. Alternatives include beneficiation or sourcing high-grade ore, such as Guinea's Simandou mine, that could produce 200 Mt annually of 65-66% Fe ore by decade's end (IEEFA, 2023).

The adoption of disruptive, clean technologies by European steelmakers has been sluggish, making the transition path steeper (Stede, Pauliuk, Hardadi, & Neuhoff, 2021). DRI technology offers a promising way to cut emissions – up to 95% with fossil-free hydrogen (Somers, 2021; Agora Industry, Wuppertal Institute and Lund University, 2021; Kurrer, 2020; IEA, 2020).[11] But discussions on fossil-free hydrogen as a technology to replace natural gas in steelmaking did not start before 2015, with the surprising outlier of Outokumpu running a pilot in Trinidad and Tobago, using DRI technology with grey hydrogen in 2001[12] (Vogl, Åhman, & Nilsson, 2018). This is due to technological, economic, and infrastructural barriers, including high costs, limited renewable energy capacity, and a lack of large-scale hydrogen production and storage, but most importantly because of free EU-ETS allowances (Hölling & Sebastian, 2018; Somers, 2021). In the reduction process, hydrogen gas behaves differently than methane gas, leading to technical uncertainties about its large-scale application in DRI.

Thirteen companies in the EU have announced H_2-DRI-EAF industrial-scale projects (Leadit). These include incumbents (Voestalpine, ArcelorMittal, Tata Steel, ThyssenKrupp, Liberty (Romania) SSAB/LKAB, Salzgitter and Stahlholding Saar) and startups (HyIron, FerroSilva, Hydnum Steel, Blastr and GravitHy). SSAB, LKAB and Vattenfall's pioneering HYBRIT project plans to produce 1.3 Mt of fossil-free sponge iron annually starting in 2026 in Gällivare, with plans to increase this to 5.4 Mt

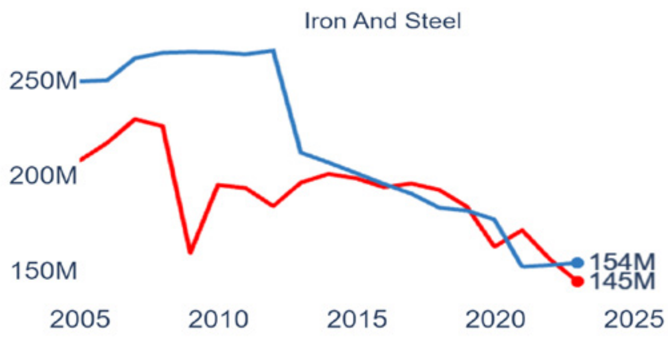

Figure 3: Emissions and free allowances for iron and steel. Blue: free ETS allowances, red: CO2-e emissions (Sandbag, EU ETS Dashboard)

in 2030 (SSAB, 2024). It aims to replace its four current BFs in the Nordic countries with fossil-free hydrogen DRI.[13]

The EU-ETS has historically favoured incremental carbon emissions reductions over technological shifts, as can be seen in *Figure 3*. **Only in January 2024 did the European Commission grant low-emission steel and hydrogen producers the same free allowance eligibility as traditional coal-based producers,** effectively putting both technologies on a level playing field in the EU-ETS.[14] Timing is now critical, as steel plants usually undergo relining approximately every 15 years and require major reinvestment every 20-25 years (Sandbag, 2022; Agora Industry, Wuppertal Institute and Lund University, 2021). Combined with long investment cycles and a general reluctance to invest, **this has resulted in a coal lock-in within the European steel industry**, as opposed to the US, which had available cheap natural gas, and Turkey, which was able to leapfrog as it installed its furnaces around 2000 (Material Economics,

11 Coal-based DRI technologies like SL/RN and Krupp-Codir, widely adopted in India due to its thermal coal abundance, can be highly polluting, emitting 3.2 tonnes of CO_2 per tonne of liquid steel—more than the BF-BOF route (Institute for Industrial Productivity, 2024).

12 Back in 2000, Outokumpu's Circored® process in Trinidad and Tobago offered lower emissions, high-purity HBI, and green hydrogen readiness but was forced to shut down in 2001 due to low global HBI prices (Nuber, Eichberger, & Rollinger, 2006).

13 As some operations will still require gas, SSAB will use LNG and perhaps later biofuels or biogas. LKAB will also use biofuels. It remains to be seen if the DRI furnace run by LKAB will be able to run on 100% fossil-free hydrogen. (HYBRIT Development, 2021)

14 This removes the fuel exchangeability ratio, allowing low-emission hydrogen and steel producers to claim and sell EU-ETS credits from 2025.

2019; Stede, Pauliuk, Hardadi, & Neuhoff, 2021; Material Economics, 2019). According to the Federation of German Industries, the iron and steel sector is now the most at risk following coking plants, the mineral oil industry, and basic chemicals, primarily due to high energy costs and shrinking markets (BDI, 2024).[15]

The capital-intensive nature of replacing high-emission BFs with cleaner alternatives poses a substantial financial burden, while the currently non-existent production of fossil-free hydrogen, a critical enabler of low-emission ironmaking, at the industrial scale, faces a tough chicken-and-egg problem that Europe has not yet resolved (Hydrogen Europe, 2023; Marcu, et al., 2024). The green premium for low-emission steel is not absorbed by the market, requiring investment support and lead market mechanisms. Unlike organic produce or EVs, low-emission and conventional steel look identical to end-users (Hasanbeigi, et al., 2024; France Stratégie, 2024, p. 79; Hydrogen Europe, 2022; France Stratégie, 2024, p. 79; Hydrogen Europe, 2022).

[15] The EU's ULCOS (Ultra Low CO2 Steelmaking) initiative, started in 2004, exemplifies European shortcomings (Quader, Ahmed, Dawal, & Nukman, 2016). The consortium, which included all major steelmakers, focused on Top Gas Recycling Blast Furnace (TGR-BF), a technology that recycles BF gas but can only reduce emissions by a maximum of 30% (European Commission, 2018, p. 314). Tata Steel adopted the HIsarna process, developed by ULCOS, at its IJmuiden site in the Netherlands, directly smelting iron ore into liquid iron without requiring coke ovens (to make coke) or sintering plants (to prepare iron ore), with the potential to cut emissions by up to 80% (Somers, 2021, p. 28). ULCOS also promoted some electricity-based solutions, such as iron ore electrolysis, which work by directly reducing iron ore using electricity, similar to how metals like copper, zinc, and aluminium are extracted. However, these processes currently require significantly more electricity than hydrogen-based DRI. While biochar offers a carbon-neutral alternative by producing biochar, its use is constrained by high costs, scalability challenges, and the fact that it can currently only replace up to 50% of the coke coal charge in steelmaking (Somers, 2021). Like fossil-free hydrogen, biochar could replace natural gas for ladle heating and reheating furnaces.

II.

SECURING ACCESS TO CLEAN ELECTRICITY

A. DECARBONISATION PATHS

Replacing the BF-BOF route with fossil-free H_2-DRI-EAF while increasing scrap recycling and usage and using fossil-free electricity in EAFs can bring the EU steel industry close to zero emissions. However, natural gas, as a bridge feedstock for DRI-making, is no longer available at a relatively low price and there is currently close to no production of low-emission hydrogen (Marcu, et al., 2024; European Court of Auditors, 2024). Furthermore, given the size of the industry, **the amount of fossil-free electricity required for steel decarbonisation is immense, regardless of the production route**. This is what makes the decarbonisation of this energy-intensive industry so challenging (IRENA, 2024).

Carbon capture, utilisation (CCU) and storage (CCS) are not generally regarded as a viable option for decarbonising the BF-BOF steelmaking route due to significant costs and technical challenges (Agora Industry, Wuppertal Institute and Lund University, 2021; IEEFA, 2024; Amand, Tahmisoğlu, & Woods, 2024; Lot & Frida, 2024). Co-product gases, such as those from coke production and furnace operations, include CO_2, mixed with nitrogen and carbon monoxide. They provide low energy per unit, have a higher global warming potential than coal and make effective capture complicated. The Oxford Institute for Energy Studies therefore concludes that "***even if most emissions from the blast furnace are captured, the emissions intensity of the overall steelmaking process would only be reduced by around half***" (Muslemani, 2023). For EAFs, reheating furnaces do not reach the necessary carbon concentration levels (15-20%) for CCU and CCS to be cost-effective. **CCS at a large scale should be considered solely for NG-DRI, while steelmakers await the large-scale availability of fossil-free hydrogen,** which will initially have to be blended with fossil gas during a limited, transitional period (Vangenechten, 2023). EnergIron, a leading DRI technology provider, has already implemented partial CO_2 capture and recycling in its production process in Abu Dhabi (Global CCS Institute, 2023). While it showcases high emissions reductions compared with the BF-BOF route, natural gas is still a fossil fuel, and increased demand for Norwegian gas, the EU's largest gas supplier, could motivate more exploration activities in the Arctic, a fragile ecosystem already under pressure (Lot & Frida, 2024). Blending natural gas with hydrogen incurs significant costs, so it is essential to precisely determine which infrastructure should be retrofitted for hydrogen readiness and assess its cost-benefit carefully (Bard, et al., 2022).

B. THE GEOGRAPHIC CHALLENGE

European steelmakers' decarbonisation plans currently only cover half of the bloc's integrated steelmaking, mainly in Northern and Western Europe and Iberia (Leadit ; Packroff, 2024). Coke coal, abundant in regions such as Germany's Ruhr Valley, Poland's Upper Silesian Basin, and Ukraine's Donetsk Basin, once made these areas major steel producers. In France, steel production shifted from the Saar-Warndt Basin to Fos-sur-Mer, on the Mediterranean, for easier shipping of Brazilian iron ore and South African coke. Today, the energy transition is reshaping industrial locations again, with coal's role as a location factor giving way to renewable electricity, fossil-free hydrogen access, and state support. This is discussed in greater detail in Chapter VII.

The high cost of hydrogen is significantly reshaping the Levelised Cost of Low-emission Steel (LCOS), with electricity accounting for 28–43% of total LCOS, compared to 20–25% for conventional steel using BF-BOFs (Devlin & Yang, 2022). Similarly, it is estimated that hydrogen will account for 36-38% of production costs at Liberty Galați between 2030 and 2050 (Miu, Bălașa, Cătuți, Strîmbovschi, & Lazăr, 2024). This trend, combined with lower demand and higher costs caused by the pandemic, inflation and the energy crisis, caused multiple sites to slow production, mainly in Central and Eastern Europe, but also at ArcelorMittal sites in Belgium, France and Germany (GMK Center, 2023).[1] This stands in stark contrast to Europe's comparative advantages around scrap availability and recycling infrastructure and knowledge, the opportunities from which are dealt with in Chapter IV.

Interestingly, other locations such as the planned H2-DRI plant in Boden, Sweden, Puertollano, Spain, or in Ingå, Finland, respectively by Stegra (formerly H2 Green Steel), Hydnum Steel and Blastr will host steelmaking facilities for the first time (Yermolenko, Hydnum Steel will build the first green steel plant in Spain, 2024). This is part of a broader trend, that places access to renewable energy as a growing factor determining industrial production (EPICO KlimaInnovation, IW Koeln & Stiftung KlimaWirtschaft, 2023; Samadi, Fischer, & Lechtenböhmer, 2023). **In Spain, the median LCOH of the 46 projects that applied for the first auction of the European Hydrogen Bank was EUR 5.8/kg, compared with EUR 11.6 for the 20 German bids, more than double** (European Commission, 2024b).

C. THE FINANCING CHALLENGE

The estimated cumulative capital investment required to transition the existing BF-BOF route to carbon-neutral production in the EU by 2050 is projected to be between EUR 70 billion and EUR 100 billion (Somers, 2021, p. 35). Financing steel decarbonisation projects is a significant consideration, and national governments have been involved in compensating for costs. Germany, for example, has invested vast amounts of public money, mainly in so-called Carbon Contracts for Difference (CCfDs), long-term state aid that bridges the price gap of low-emission technology, integrating carbon

[1] ArcelorMittal announced the temporary shutdown of a blast furnace in Ghent, Belgium and the permanent closure of a blast furnace in Fos-sur-Mer in France in 2023 (GMK Center, 2023). It also announced maintenance shutdowns at its Bremen and Hamburg plants in Germany and in Krakow, Poland (Ibid). The British Liberty Steel temporarily ceased operations at its Galati, Romania, and Ostrava, Czechia plants, and permanently closed its Dunaferr plant in Hungary (where it is building two EAFs) (Liberty Steel, 2024). In Ghent, ArcelorMittal planned to convert waste wood into bio-coal for use in its blast furnace, while the resultant biogas will be sold as a co-product and transformed into ethanol. However, the plan is currently stalled, along with the switch to DRI (L'Echo, 2024). In 2023, ArcelorMittal announced the temporary shutdown of blast furnace A at its Ghent plant in Belgium for maintenance, along with the permanent closure of blast furnace No. 1 at its Fos-sur-Mer plant in France (Figaro, 2023). Similar maintenance shutdowns occurred at ArcelorMittal's Bremen and Hamburg plants in Germany and at Krakow in Poland, officially due to a weak steel market and low demand, but with the additional aim of influencing market prices (GMK-cannot link). Concurrently, Czech steelmaker Liberty Ostrava, a subsidiary of UK-based Liberty Steel, temporarily ceased operations in Galati in Romania and Ostrava in Czechia, affecting nearly 5,000 people and 6,000 workers in Czechia (GMK Center, 2024).

pricing projections. Germany also plans to use Contracts for Difference (CfDs), another state aid mechanism, invented in the UK in 2014, for gas plants converting to low-emission hydrogen (BMWK, 2024 ; Bundesregierung, 2024). As of January 2024, steelmakers in Germany had received over EUR 7 billion in state support for decarbonisation processes (Handelsblatt, 2024). ArcelorMittal received a further EUR 1.59 billion for its sites at Dunkirk (France), Ghent (Belgium) and Gijón (Spain) (European Commission, 2023a; European Commission, 2023b; European Commission, 2023c).

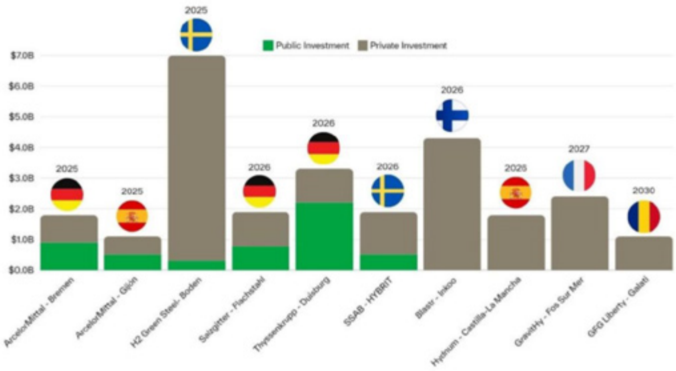

Figure 4: OPEX investments of selected low-emission steel projects as of March 2024 (Industrious Labs & Public Citizen, 2024)

Startups like Hydnum, HyIron, Stegra, and Blastr can adopt distinct strategies, being less reliant on state subsidies due to fewer employment-related constraints. Their focus on low-emission innovations attracts ESG-driven investments, supported by simpler permitting processes and clearer cost estimations. This has enabled them to successfully secure private funding: Stegra raised EUR 6.5 billion for its Swedish plant and EUR 2.7 billion for its Iberian project (location unspecified), Blastr secured EUR 4.2 billion in Norway, and Hydnum in Spain raised over EUR 1 billion (H2 Green Steel, 2024; Blastr, 2024). A substantial portion of Stegra's funding was provided by private equity, as can be seen in *Figure 4*, complemented by support from the Swedish National Debt Office in the form of green credit guarantees, and by Euler Hermes through export credit cover (H2 Green Steel, 2024).[2] In September 2024, Voestalpine issued its first EUR 500 million green bond, reviewed by Moody's, with a 3.75% coupon over five years (Voestalpine, 2024). Similarly, Salzgitter secured EUR 500 million in loans backed by Export Credit Agencies OeKB (Austria) and SACE (Italy) (Salzgitter, 2024). These could serve as an encouraging example for other steelmakers to issue similar green bonds or pursue the support of Export Credit Agencies, relying less on state aid.

The EU requires significant private and public investment for its economic transition, but state deficits from the financial crisis and pandemic have left public resources scarce.[3] CCfDs, inaugurated by Germany, present an innovative temporary financial mechanism designed to support the transition to low-emission technologies by covering both capital expenditures (CAPEX) and operational expenditures (OPEX) over 15 years (BMWK, 2024).[4] Countries such as France, Spain, Austria, Sweden, and Denmark are exploring the potential of this scheme.[5] In contrast, Italy and countries in CEE rely more heavily on EU funds, illustrating a risk of economic divergence within the EU.

2 H2 Low-emission steel has also been awarded a EUR 250 million grant from the EU Innovation Fund.

3 With current fiscal rules, only four EU countries can afford the spending increase needed for high emissions reduction in line with net zero targets, making strategic use of every public euro crucial (New Economics Foundation, 2023).

4 This system operates on an auction-based model where the economic viability of conventional energy use is compared to low-emission alternatives. The process involves establishing a strike price for the decarbonisation project and then adjusting this price by subtracting the costs associated with CO_2 emissions that are no longer incurred due to the adoption of cleaner technologies.

5 It is to be noted that CCfDs do not allow for cross-funding (such as from the EHB auctions) and payment is not made to the companies before the new facility is in operation, creating big upfront investment needs.

D. THE RENEWABLE ENERGY CHALLENGE

During EPICO's workshop, stakeholders emphasised that while the new attention on industrial demand for energy is welcomed, the decarbonisation of energy production must remain high on the political agenda. **The Clean Industrial Deal is needed to accelerate the European Green Deal, not to supplement it.** Stakeholders particularly emphasised the need to reduce the cost of fossil-free energy, noting its strong linkage to fossil fuel prices, particularly natural gas, which often determines electricity market prices. This recommendation was later echoed by former ECB President Mario Draghi, who called to "*decouple the price of renewable and nuclear energy from higher and more volatile fossil fuel prices*" in his September 2024 report (Draghi, 2024). The main reason for the increase in energy prices since February 2022 is the influence of gas prices on overall electricity prices, due to the merit order system.

Eurometaux, representing non-ferrous metals producers, and several other energy-intensive industries have suggested algorithmically splitting the market into two tiers and applying a pay-as-bid model to the upper 10% with the highest production costs (Eurometaux, 2023).[6] Still, this dual system might complicate market operations and regulatory oversight, and the electricity market design (EMD) file will not be reopened for a while at the EU level.

Inframarginal revenue caps, which tax or limit profits from variable renewable energy sources (VRES) operators due to their low operational costs and higher rents driven by marginal pricing, can be justified.[7] **Contracts for Differences (CfDs) are the most effective tool to decouple renewable energy prices from the spot price** with the current marginal pricing system (Heussaff & Zachmann, 2024). By offering long-term price stability with a fixed strike price, CfDs provide producers with predictable returns through government support, boosting investor confidence and accelerating renewable energy deployment. (SolarPowerEurope, WindEurope, Eurelectric, EFET, & Europex, 2023). In addition to CfDs, Power Purchase Agreements (PPAs) have been strengthened by the recent reform of the electricity market design to support the

THE MERIT ORDER SYSTEM

The system dispatches power plants in ascending order of their marginal costs, with the market price set by the cost of the last, most expensive plant needed to meet demand. Introduced in 1996 through the first European energy directives aimed at harmonising and liberalising the EU internal energy market, this system supports renewable energy deployment by prioritising the cheapest sources, such as renewables, while incentivising investments in flexible energy solutions like demand-side response. As a result of Gazprom and EU importers halting natural gas provision from the Russian Federation, prices increased, doubling for the German steel industry between 2019 and 2024 (Wirtschaftsvereinigung Stahl, 2024). The Commission's Joint Research Centre predicts that with current rules, in 2030, fossil fuel-based plants will set the electricity price 86% of the time while generating only 16% of the electricity (Gasparella, Koolen, & Zucker, 2023).

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6 This approach would calculate the final price by averaging the equilibrium price for the initial 90% of demand with the pay-as-bid prices for the last 10%. This system would have the advantage of mitigating the impact of fossil fuel prices on the final price, and reduce the price of electricity.

7 Two examples for revenue caps are the French Contribution sur la rente inframarginale which generated revenue for the government—albeit only EUR 600 million—by taxing excess profits from electricity producers, and the UK's Cost-Plus-Revenue Limit, which directly limits the amount generators can earn.

green transition. PPAs are long-term contracts between companies and renewable energy producers to purchase electricity at an agreed price for a set period of time. The PPA helps both parties mitigate risks by locking in prices and volumes. However, accessing PPAs has been difficult for energy-intensive industries due to high prices, expensive counter-party risk guarantees and the costs of matching intermittent supply with continuous demand (i.e., shaping/firming costs), compounded by the entry of less energy-intensive firms and complexities in securing them. Many steel manufacturers have difficulties demonstrating the long-term viability of their products, given strong market volatility. The German energy agency confirms that PPAs are more relevant for the chemical, automotive and ICT sectors, with the latter representing over 50% of the corporate offtakers (dena, 2024). Iberdrola Deutschland signed 15-year PPAs with Salzgitter and Stahlholding Saar (SHS) for 60 and 200 GWh of renewable electricity annually, respectively, but experts note this covers at most 25% of an EAF steelmaker's electricity needs due to limited flexibility and long commitment (Iberdrola, 2023; Iberdrola, 2024).

"Redispatch costs for the German electricity system, stemming from the need to balance supply and demand to resolve grid bottlenecks, reached EUR 4.2 billion in 2022 and EUR 3.1 billion in 2023."

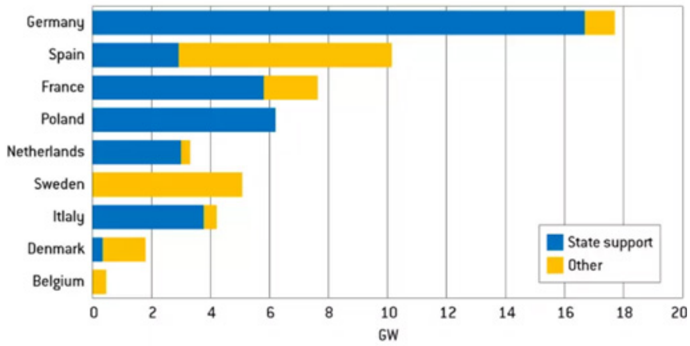

Figure 5: Source of funding for installed renewable capacity 2023-2024 (Heussaff & Zachmann, 2024)

As the push for decarbonisation intensifies, competition for green electricity among industrial, public, and private consumers is likely to increase. To ensure sustainable energy supplies, steelmakers should be incentivised to increase their investments in VRES, and be supported by mechanisms like CfDs, PPAs, hybrid measures, and investments in flexibility and storage infrastructure. Currently, most investment in VRES, particularly in Germany, is driven by the state, as can be seen in *Figure 5*. Grid infrastructure is another issue that urgently needs more political attention. Currently, fossil-free electricity from sparsely populated regions remains underutilised due to insufficient connections to industrial clusters. Redispatch costs for the German electricity system, stemming from the need to balance supply and demand to resolve grid bottlenecks, reached EUR 4.2 billion in 2022 and EUR 3.1 billion in 2023 (iwd, 2024; Bundesnetzagentur, 2024). To further advance energy infrastructure development, Member States should also expand their support for Public-Private Partnerships, which has been untapped by EU Member States, especially compared with the UK.[8] Draghi has proposed that VRES suppliers allocate a small, publicly subsidised share to energy-intensive industries exposed to international trade, such as steel (Draghi, 2024). This would enable these

[8] The total quantum of public-private partnership investments in the EU is significantly smaller than that of the UK, where EUR 166 billion was invested in delegated management between 1990 and 2022. This exceeds the combined total amounts of public-private partnership investment in France (EUR 56.5 billion), Spain (EUR 35 billion), Germany (EUR 22 billion), and Italy (EUR 18 billion) over the same period (Auriol & Saussier, 2025).

sectors to procure electricity at lower costs, reducing exposure to volatile, fossil-fuel-dominated spot market pricing.

E. POLICY RECOMMENDATIONS FOR THE EU

Accelerating the decarbonisation of the electricity mix

The slow pace of the clean energy transition puts a burden on both ore-based and EAF steelmakers' decarbonisation goals, given the importance of fossil-free electricity and hydrogen for emissions reductions. Tackling lengthy permitting times for renewable energy projects is crucial. In Greece and Ireland, onshore wind permits take an average of eight and nine years (Draghi, 2024). This needs to change. Denmark streamlined offshore wind permits in 2020 by introducing a one-stop-shop – one system centralising the application, review, and approval processes, streamlining all necessary permits through a single administrative entity - while Germany's 2022 permitting reform is credited with boosting permitting (Bloomberg, 2024). The reform designated renewables as being "of overriding public interest," enabling them to take precedence over species protection and landscape considerations. Maintaining thermal energy production poses greater risks to biodiversity and impacts are often more severe than those associated with wind turbines or solar panels, and this should be reflected in permitting processes. "Positive silence", inaugurated by the Net Zero Industry Act for intermediary steps of the permitting process, can also reduce delays. Digital tools like Geographic Information Systems (GIS) and EasyPermits can further accelerate procedures. The Commission should accompany Member States in strengthening public authorities' capacity, fostering community buy-in, and adopting tools provided by the revised Renewable Energy Directive (2023/2413) such as renewables acceleration areas and predictable permitting (Becker Büttner Held, et. al, 2024).

Expanding grid infrastructure is vital for managing VRES load and stability, as bottlenecks and redispatch limit their full integration. Strategically locating EAFs in regions with low-emission, resilient grids could optimise energy use and reduce the sector's carbon footprint. Yet even in model countries like Sweden, grid limitations present significant challenges. For instance, Hybrit's production plans in Kiruna have been delayed by about a decade due to inadequate grid capacity (Lindberg, 2024). Here, the Commission's consideration of dedicated funding for distribution grid upgrades in the next Multiannual Financial Framework is a promising step (Contexte, 2024). Additionally, adopting continuous casting and hot rolling, as Arvedi did with In-line Strip Production (Arvedi), would further reduce energy consumption, waste, and spatial requirements by eliminating intermediate cooling and reheating.

Reducing the cost of renewable energy

Member States should further adopt the use of the tools provided by the latest EMD reform, such as two-sided CfDs, PPAs, and innovative financing models. For PPAs, mandates could require electricity utilities to allocate a predefined share of subsidised generation through PPAs with energy-intensive industries (Articles 19b and 19a(5) of the EMD). Non-energy cost components of industrial electricity bills can be minimised by reforming regulatory charges while introducing tariff structures that reward RES consumption by energy-intensive industries. Transparent allocation of charges, harmonisation across Member States, and targeted exemptions are additional tools. The Commission must ensure that indirect cost compensation for industries exposed to international competition remains WTO-compatible as the CBAM is phased in. While the WTO's role in enforcement has waned and will likely continue to do so under Donald Trump's second presidency, maintaining compliance is important to minimise the risk of trade disputes or retaliatory measures from other members, which could undermine trust and cooperation in international trade relations.

An alternative solution could be a hybrid approach combining government underwriting of PPAs with CfDs, reflecting both long-term financial viability with a preferential price (PPAs) and the market price (through CfDs). Governments should embrace public guarantees and act as the buyer of last resort, ensuring the financial viability of PPAs for renewable energy providers, even if steel companies face operational changes. Aggregating multiple PPAs, including from different industries, into a single pool could address intermittency by balancing supply and demand across various contracts, as suggested by Draghi (Draghi, 2024).[9] The CfD component would stabilise the remainder of the steel industry's power needs by compensating for the difference between the market price and a pre-agreed strike price, which could include costs for backup and balancing services required by VRES (EUROFER, 2024d).

The EU should ensure that every euro it allocates – whether from ETS revenues, CBAM revenues, or spending from Horizon projects – advances climate mitigation goals and accelerates the scaling up of low-emission production processes (in accordance with EU state aid rules). EU-wide auctioning of funds specifically destined for state aid could also be considered, as advocated by Draghi (Draghi, 2024; Cornillie, Delbeke, Egenhofer, Pandera, & Tagliapietra, 2024). The EU should prioritise the establishment of more and stronger cross-border interconnections, as formally suggested by Greece, Bulgaria and Romania, Draghi and Letta (Draghi, 2024; Letta, 2024; Euractiv, 2024). Changes need to be made to energy trading rules to limit financial speculation in energy trading, by increasing supervision and rules as advocated by Draghi.[10]

Addressing Industrial Demand Side Response

EPICO has recently highlighted the need for a technology-neutral flexibility strategy, given the increase of VRES in Member States' power mix (EPICO KlimaInnovation, 2024) while other reports argued for strategies such as oversizing machinery, storing excess production, energy storage, and improved inventory management to minimise disruption. Indirect cost compensation needs to be revised in a way that is tailored to the flexibility potential of each sector (Hirth, Koenig, & Weber, 2024).

Pressure Swing Adsorption (PSA) enables on-site oxygen production and storage, offering a flexible solution for steelmaking. Similarly, Proton Exchange Membrane (PEM) electrolysis generates oxygen as a byproduct for refining steel, while surplus hydrogen in H2-DRI can be stored in hot briquetted iron, albeit with minor energy losses due to cooling (Hölling & Sebastian, 2018).

EAFs already contribute to grid services like frequency control by reducing loads, the steel

[9] This had been suggested for gas in the Hydrogen and Gas Package for gas, but concrete conditions have not been detailed by the Commission yet.

[10] Strengthening regulatory oversight by enhancing monitoring, imposing position limits, and increasing reporting requirements could help curb speculative behaviour, without reopening the REMIT ((Regulation on Wholesale Energy Market Integrity and Transparency) framework. Additionally, amending MiFID II/MiFIR (Markets in Financial Instruments Directive) rules to tighten energy derivatives trading regulations and adjust exemptions for energy firms would further limit financial speculation in energy markets.

sector faces challenges in reorganising work shifts and production schedules to align with renewable energy availability due to limited automation, potential disruptions to base load operations, and the risk of losing off-peak consumption rebates, which makes such flexibility less attractive compared to other industries or households (EUROFER, 2024d).

III.

SECURING ACCESS TO FOSSIL-FREE HYDROGEN

A. STATE OF PLAY

The switch from all EU ironmaking (99% from BFs) to H2-DRI using fossil-free hydrogen would require between 8.5 and 9 Mt of hydrogen (MtH2), which in turn would require between 288 and 296 TWh of renewable electricity (Laguna, Duerinck, Meinke-Hubeny, & Valee, 2021 ; Hübner, Guminski, Pichlmaier, Höchtl, & von Roon, 2020).[1] This represents more than 62% of Germany's final electricity consumption in 2023, which was 466 TWh (BDEW, 2024, p. 27; Kurrer, 2020). For 2050, the European Steel Association (EUROFER) forecasts a demand of only 230 TWh of electricity to produce 5.5 MtH2, along with 170 TWh for other processes.[2] This brings **the total anticipated electricity needs for European steelmaking in 2050 to 400 TWh** (EUROFER, 2019, p. 7; EUROFER, 2024d). This difference reflects formalised and anticipated site closures, as well as acknowledgements by BF-BOF steelmakers that they do not plan to fully replace ironmaking with DRI furnaces. Nevertheless, this forecast represents a fivefold increase from the current 75 TWh. If existing EAFs experience difficulties maintaining competitiveness with VRES, transitioning from BF-BOFs to more EAFs paired with hydrogen-producing electrolysers could encounter even greater challenges without significant policy adjustments.

"Transitioning from BF-BOFs to more EAFs paired with hydrogen-producing electrolysers could encounter even greater challenges without significant policy adjustments."

However, **the current production of RFNBOs[3] in the EU is falling short of all targets** (European Court of Auditors, 2024). This includes the ones set out in the EU Hydrogen Strategy (2020), both the 2024 and the 2030 targets, with the Commission now projecting only 3 Mt of hydrogen (MtH_2) (Hydrogen Council, McKinsey & Company, 2024) of low-emission hydrogen use by 2030,

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[1] The electricity is used to split water molecules (H2O) into hydrogen (H2) and oxygen (O2). This is done in electrolysers, which use either liquid alkaline or solid polymer membrane ("PEM electrolysis") to conduct ions between the anodes and cathodes to separate water (H2O) into hydrogen (H2) and oxygen (O).

[2] Green steel projects for 2030 require 165 TWh alone already (EUROFER, 2024c).

[3] RFNBO (Renewable Fuels of Non-Biological Origin) refers to fuels such as hydrogen, synthetic methane, methanol, or ammonia, produced from renewable electricity and water, as defined under EU Directive (EU) 2018/2001 on the promotion of renewable energy and clarified by the Additionality Delegated Act on renewable hydrogen production. The European Commission is currently defining criteria for low-carbon hydrogen, including production via non RFNBO-compliant electrolysis, nuclear energy or steam methane reforming (SMR) with CCS.

compared to the 10 MtH$_2$ (Hydrogen Council, McKinsey & Company, 2024) envisioned in the EU Hydrogen Strategy, and the 20 MtH$_2$ (Hydrogen Council, McKinsey & Company, 2024) in the 2022 RePowerEU Plan. The ECA report projects 2.72 MtH$_2$ (Hydrogen Council, McKinsey & Company, 2024) produced in the EU by 2030 based on electrolyser projects in the construction phase. As of 2024, only 3.6% of hydrogen production projects for 2030 in the EU have reached the Final Investment Decision, resulting in only 0.6 MtH2, with a meagre 0.2 MtH2 being renewable (Marcu, et al., 2024). In 2024, the United States and Canada together have a low-emission hydrogen pipeline of 2.4 MtH$_2$ post-final investment decision (FID), while China has reached a capacity of 1.4 MtH$_2$ (Hydrogen Council, McKinsey & Company, 2024). Fossil-free hydrogen will play a primordial role in decarbonising ironmaking, but will also contribute to steelmaking processes, such as substituting natural gas in ladle heating and reheating furnaces. Heat pumps, while effective in other industrial applications, are currently not relevant in this context due to the high temperatures required for these processes. Supplementing hydrogen, FerroSilva – a process developed at KTH's Department of Materials Science and Engineering -produces fossil-free sponge iron from biocarbon (forestry and agricultural residues), using less than one-tenth of the electricity required for hydrogen-based electrolysis methods (KTH, 2023).

Due to uncertainties in future low-emission steel demand, continuously high costs of renewable hydrogen, and the absence of FIDs for both low-emission steel and hydrogen projects, deals between renewable hydrogen producers and steel consumers have been rare so far (Marcu, et al., 2024; Hydrogen Europe, 2023; Leadit; Financial Times, 2024). According to the most recent data, offtake discussions only cover 0.4 MtH2 for the EU steel sector by 2030 (Marcu, et al., 2024). One of the reasons is the lack of lead markets, an issue dealt with in Chapter IV of this paper.

"Fossil-free hydrogen will play a primordial role in decarbonising ironmaking, but will also contribute to steelmaking processes, such as substituting natural gas in ladle heating and reheating furnaces."

The European Hydrogen Bank's auctions for domestic hydrogen production, with the first supply auction in November 2023, are seen as a promising way to kickstart renewable hydrogen production in the EU (for now, hydrogen from nuclear energy is excluded). The funding of EUR 694 million from the EU Innovation Fund, for a total of 1.515 MtH2 over ten years will be awarded to six winning projects (European Commission, 2024b). These auctions are a prime example of how Member States and the EU can reduce investment risks, support European innovation and match suppliers with consumers. Still, most consumers are in the transport industry, as bid-offers are only ranked on price instead of CO_2 emissions reduced in end-use. According to sources, none of the six winning projects have steelmakers as contractors.

A base case electrolysis project today could achieve a levelised cost of RFNBO-compliant hydrogen (LCOH) in the EU ranging from EUR 6.6 to EUR 7.1 per kilogramme (Hydrogen Europe, 2022; European Hydrogen Observatory). However, for the hydrogen-based steel production route to be more cost-effective than the traditional method in the EU, it is estimated that the price of hydrogen would need to fall below USD 3.5 per kilogramme, assuming a carbon price of USD 50 per tonne of CO_2 (Hasanbeigi, et al., 2024, p. 21; Hydrogen Europe, 2024, p. 24). According to unpublished sources from EUROFER, this should be around EUR 1.5 per kilogramme, because of current low steel prices.[4]

DRI using fossil-free hydrogen offers significant abatement potential compared to coal-based ironmaking, with emissions ranging between 16kgCO2/kgH2 and 23kgCO2/kgH2 (EUROFER & Guidehouse, 2024). This has led to growing political and business pressure to relax additionality principles – requiring hydrogen to come from newly built fossil-free power plants – along with delaying the enforcement of time matching and geographic correlation requirements (Hydrogen Insight, 2024).[5] Electrolysis using nuclear power (so-called pink hydrogen) also offers viable fossil-free hydrogen options without relying on RES. **The hydrogen produced for the ironmaking should only come from electrolysis (off or on-grid)**, as NG-DRI (with or without CCS) is more economically and environmentally sound than blue hydrogen (steam methane reforming (SMR) or autothermal reforming (ATR) with CCS). The latter should be for ammonia production and refining, where blue hydrogen integrates easily into existing natural gas and grey hydrogen infrastructure (Resources for the Future, 2021).[6] Natural hydrogen, naturally produced through reactions between water and iron minerals, offers the potential of a quasi-unlimited source of hydrogen. However, due to high extraction costs, environmental concerns, and the need for advanced technology and expertise, it is unlikely to play a significant role in the immediate future, with its relevance more likely emerging in the context of 2040-2050 decarbonisation targets (Blay-Roger, et al., 2024).

> *"DRI using fossil-free hydrogen offers significant abatement potential compared to coal-based ironmaking, with emissions ranging between 16kgCO2 per kgH2 and 23kgCO2 per kgH2."*

Infrastructure poses a main challenge as the electrolysers, pipelines and storage facilities still need to be built. Given the risky business case and fragmented policymaking, projects

[4] The Daily steel hot-rolled coil index stands at EUR 560 in November 2024, compared with EUR 700 in March 2024 (Eurometal, 2024).

[5] Given Germany's fossil-dominated electricity mix (the sixth most polluting in the EU), Robert Habeck, the Federal Minister for the Economy and Climate Protection, proposed in September 2024 that additionality should only apply to power plants built after 2035 – instead of 2028 (BMWK, 2024). Currently, only Sweden and France meet the 70% CO_2 reduction requirement for on-grid electricity under the RED RFNBO DA, while in 15 out of 27 EU Member States, emissions from hydrogen production would exceed those of unabated fossil hydrogen (Agora Energiewende and Agora Industry, 2024, p. 22).

[6] Adding CCS to a DRI furnace offers a simpler, cost-effective way to decarbonise steel production by capturing CO_2 without overhauling natural gas infrastructure. In contrast, transitioning to blue hydrogen demands substantial investments in hydrogen production, storage, and transport facilities. Both approaches face methane leakage issues in the natural gas supply chain, limiting their emissions-cutting potential, particularly for blue hydrogen. Hydrogen production with CCS costs USD1.7–2.6/kg, while NG-CCS costs approximately USD16.1/tonne CO_2 making NG-CCS more economical than SMR-CCS or ATR-CCS, given that natural gas prices make up 25-35% of blue hydrogen costs (National Energy Technology Laboratory, 2022; Oni, Anaya, Giwa, Di Lullo, & Kumar, 2022).

are being delayed and costs have risen, causing steelmakers to delay their transformation plans.[7] Hydrogen production must initially be off-grid in most EU Member States, powered directly by renewable sources, ensuring the production of genuinely fossil-free hydrogen while avoiding grid-related issues. This can be justified considering the high abatement potential of steel.

Since the reduction shaft in a steel plant must operate at a constant baseload, a steady hydrogen supply is essential to buffer renewable energy fluctuations (Hydrogen Europe, 2022). Storage of hydrogen is therefore needed, but Europe is lagging both in technology, investment and deployment.[8] The use of pipelines to transport hydrogen to steel plants supports the development of the European Hydrogen Backbone, positioning steel as a first mover in the hydrogen economy, as Thyssenkrupp was meant to do in North Rhine-Westphalia (Guidehouse, 2022). This approach drives the need for dedicated infrastructure and storage while promoting a pan-European hydrogen network to ensure a stable, integrated hydrogen supply. If this fails, it risks jeopardising both the transition and the EU's leadership and credibility.[9]

B. POLICY RECOMMENDATIONS FOR THE EU

Adopt a European Hydrogen Roadmap

The European Court of Auditors has made several key recommendations for advancing the Hydrogen Economy in the EU. These include updating the EU Hydrogen Strategy to reflect market incentives, funding priorities, and geopolitical considerations, introducing a scoreboard to monitor progress; reviewing EU funding arrangements for hydrogen development, and defining the future scope, structure, and mandate of the Clean Hydrogen Alliance (European Court of Auditors, 2024). The Commission's decision to embrace these recommendations is a positive step for the hydrogen economy. However, it is regrettable that the recommendation to establish a more detailed and concrete roadmap was not accepted (European Court of Auditors, 2024). A detailed pan-European integrated hydrogen infrastructure plan should map future hydrogen demand and supply points, identifying critical areas to ensure efficient hydrogen delivery to key industrial hubs, particularly steel plants. It should have realistic intermediary targets, for both onshore and offshore hydrogen, as well as renewable and low-emission hydrogen.

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[7] In recent developments, the estimated cost for Belgium's 3 GW "Princess Elisabeth Island" energy project off the coast has escalated from EUR 2 billion to over EUR 7 billion (L'Echo, 2024). Denmark's energy island project also encountered delays and increased costs after Belgium and Germany refused additional funding (Reuters, 2024). Furthermore, Bloomberg New Economy Forum notes that unclear subsidy policies and inflation are leading to rising costs for electrolysers rather than the expected declines (Parkes, 2024).

[8] The EU has only 9 TWh of underground hydrogen storage (UHS) capacity in the pipeline for 2030, short of the 45 TWh needed, risking major bottlenecks (Frontier Economics, 2024).

[9] In 2016, GrInHy (Salzgitter) and H2FUTURE (Voestalpine), two pilot projects, started looking at hydrogen for steel, focusing on electrolyser development (Vogl, Åhman, & Nilsson, 2018). In June 2023, the Chinese company HBIS announced the successful production of sponge iron using hydrogen-enriched gas (60% hydrogen and 40% gas) with the Mexican-Italian Energiron, a result of the collaboration between the Mexican HYLSA group and the Italian companies Tenova and Danieli (Danieli, 2024; GMK Center, 2023). HYBRIT also announced it would use Energiron technology in Gällivare and Luleå, using an electric process gas heater (Tenova, 2024). The US Department of Energy announced support for H2-DRI plants in Ohio and Mississippi in March 2024, with the latter being built by SSAB, already present in Iowa and Alabama (DOE, 2024).

Engaging BF-BOF steelmakers in the planning and development stages of hydrogen infrastructure projects is imperative. This includes strategically positioning electrolysers and hydrogen pipelines. **The North Sea is a crucial potential additional hydrogen-producing location**, which can benefit the steel sector's transformation given that hydrogen pipelines can transport large amounts of energy over longer distances, more efficiently and cost-effectively than high-voltage direct current (HVDC) electricity cables (Mjahed, 2023 ; NSEC, 2022 ; Patonia, Lenivova, & Poudineh, 2023; Williams, Barnes, & Borchardt, 2024 ; van Wingerden, Geerdink, Taylor, & Hülsen, 2023).

Improve the design of auctions for hydrogen production to favour emissions abatement

As mentioned above, the offtake price for mobility in the EU's first auction was 33% higher than that of industry (European Commission, 2024b).[10] If hydrogen producers favour the higher prices offered by the mobility sector, it could lead to reduced availability and higher costs for industrial sectors like iron and steel, although the sector offers high abatement potential (EUROFER & Guidehouse, 2024).[11] Future auctions should incorporate criteria prioritising CO_2 abatement potential and impose maximum allocations per selected project to ensure equitable distribution. Support should more strongly prioritise sectors targeted by the RED to drive decarbonisation and meet binding consumption targets (Hydrogen Europe, 2023, p. 3; EPICO KlimaInnovation, KAS, & Guidehouse, 2023, p. 20). **To ensure that hydrogen is directed towards sectors with the highest abatement costs and no alternative decarbonisation options, such as DRI production, future auctions could require a share of RFNBO production to be supplied to industry including steel**, as suggested by stakeholders during EPICO's workshop, and by the Federation of German Industries (BDI, 2024). The European Commission should also further encourage and support Member States in establishing matching mechanisms for hydrogen funding,[12] such as Austria, Spain, Lithuania and Germany, or with the STEP seal projects to foster fossil-free hydrogen production across Europe (Parkes, Austria earmarks €400m to subsidise domestic green hydrogen projects, using EU auctions-as-a-service, 2024).[13]

Derisking investment is crucial to accelerate business transition plans. Default guarantees should mitigate risks beyond the hydrogen producer's control in take-or-pay contracts, including infrastructure delays, transportation issues, or offtaker defaults, such as bankruptcy (EPICO KlimaInnovation, KAS and Guidehouse, 2023). These guarantees compensate producers for losses if they cannot sell hydrogen or must sell at a lower price, but they do not

[10] The offtake price for green hydrogen is higher in the mobility sector than in industry due to the earlier stage of market development, greater consumer willingness to pay a premium for sustainable alternatives, less developed infrastructure, and smaller production scale, all of which contribute to higher costs in the mobility market compared to industrial applications.

[11] At the time of bidding into the auction, projects were not required to provide signed offtake contracts. However, they had to provide pre-contractual agreements such as memoranda of understanding or letters of intent with expected offtakers for at least 60% of their production volumes. As of October 2024, no offtaker had been revealed and one of the seven renewable hydrogen projects (Benbros Energy) withdrew.

[12] These Member States intend to leverage the results of the EHB's auction-as-a-service programme by supplementing EU-level auctions with additional national funding to support domestic projects, regardless of whether they were successful in the initial auction (European Commission, 2024c).

[13] The STEP Seal (so-called "Sovereignty Seal" under the STEP Regulation) is the EU quality label awarded to high-quality projects contributing to the STEP objectives. It is intended to give these projects visibility and help attract additional public investment.

cover production losses or price fluctuations. Public authorities, such as the European Investment Bank (EIB) Group, could provide these guarantees, as did the European Fund for Strategic Investments (EFSI), to mitigate credit risks, and governments can enhance First Loss Default Guarantee (FLDG) mechanisms by assuming the role of guarantor in strategic sectors, facilitating lender training and capacity-building initiatives, and developing standardised contracts to ensure legal clarity and uniformity (EPICO KlimaInnovation, KAS, & Guidehouse, 2023). Furthermore, as recommended by Mario Draghi in his report, there should be concerted action at the EU and the Member State level to materialise the Capital Markets Union and tap into the potential of pension funds to finance investment in industry decarbonisation (Draghi, 2024).

Enhance social acceptance of hydrogen and address hydrogen leakage more systematically

Hydrogen, the smallest molecule, can leak through small imperfections in infrastructure, including pipes, valves, joints, and seals. At present, no EU-wide guidelines exist on mitigating hydrogen leakage or its effects, even though operators have an interest in limiting leakage given the high economic value of renewable hydrogen. The EU could take inspiration from the UK, where all hydrogen operators are required to propose a risk-based Leak Detection and Repair (LDAR) programme using Best Available Techniques (BAT) as a condition for obtaining a permit. Innovative detectors, for instance using plasmonic hydrogen detection based on palladium nanoparticles could be supported and their deployment mandated (Arrigoni & Bravo Diaz, 2022). Given the economic, environmental, and social costs of hydrogen production and transportation, its use should be carefully prioritised. During the early stages of limited supply, hydrogen should be directed toward sectors where it achieves the most cost-effective emissions reductions. These include ammonia production, steelmaking, aviation, and shipping, as highlighted by the International Renewable Energy Agency (International Renewable Energy Agency, 2024). Clear communication is needed to explain how hydrogen resources will be allocated, their potential benefits, and how costs will be shared, as these issues are largely unfamiliar to the general public. The question of how much production for these key applications should occur in Europe remains to be addressed.[14] Extending hydrogen use to short-haul mobility and heating can currently be a misallocation of a scarce resource crucial for industrial decarbonisation (FCA, 2024).

[14] Chapter VII explores this further, highlighting the potential cost savings of offshoring parts of the iron and steelmaking value chain to regions with iron ore resources and cheaper renewable energy or green hydrogen.

IV.

ENSURING SOCIAL COHESION BY SUPPORTING A JUST TRANSITION FOR EUROPEAN STEELMAKING

The transition from BF-BOF steelmaking to DRI-EAF raises concerns about employment trends, affected communities, and local realities, as reflected in recent decisions by steel companies in the EU to cut jobs or postpone announced projects. With evolving trends in the iron and steel industry to potentially off-shore the emission-intensive iron-making part of steelmaking to countries with iron ore reserves and cheaper renewable energy, the workforce engaged in coal-based steelmaking in the EU is likely to be affected, as discussed in greater detail in Chapter VII. The massive transformation in the steel industry required to move away from fossil fuel-based steel-making will result in significant job losses, particularly in coal mining and coal-fired power plants, as well as in BFs, as EAFs require a smaller workforce, and because some parts of production, particularly in ironmaking, may move outside the EU.[1] While some of these losses may be offset by job creation in construction, renewable energy, and hydrogen production, challenges within these sectors suggest that employment losses could be even greater (Basirat & Nicholas, 2023; Bilici et al., 2024; Devlin & Markkanen, 2023; Flesch et al., 2024; Gielen, Saygin, Taibi, & Birat, 2020; Rystad Energy, 2024; Trollip, Berghmans, & Khandekar, 2024; Verpoort, Gast, Hofmann, & Ueckerdt, 2024). Additionally, some labour unions resist viewing the twin transition as a holistic process requiring cross-sectoral workforce mobility. One example is unions opposing the adoption of tandem and continuous rolling technologies due to concerns over job reductions linked to increased automation (Parker, 2022). The JRC reports that approximately 159,000 individuals are employed in coal mining and 49,000 in coal-fired power plants within the EU (Kapetaki, et al., 2021). By 2030, it forecasts employment in these sectors to decrease by 112,000, a decline of over 53%.[2]

European steelmakers are frequently in the spotlight for financial struggles, delays in decarbonisation and workforce reductions, often leaving employees in precarious situations with limited transparency or consultation.[3] These trends highlight the importance of an

1 This is due to the BF-BOF's more complex, labour-intensive processes, extensive material handling, and greater maintenance needs (Maldonado-Mariscal, Cuypers, Götting, & Kohlgrüber, 2023)

2 This projection is based on the ten-year network development plans (TYNDP) of the EU Transmission System Operators (TSOs) (Kapetaki, et al., 2021).

3 Liberty Steel, founded by the Indian Sanjeev Gupta, is facing severe financial and operational challenges across its European facilities. In Ostrava (Czechia), 2,600 workers are at risk following layoffs and the closure of coke ovens. In Poland and Hungary, the company has struggled to meet wage commitments, with wage cuts of 30% affecting over 1,000 workers in Dunaújváros (IndustriAll, 2024). ArcelorMittal, owned by the Indian Mittal family, has faced criticism for delaying decarbonisation plans and pressuring governments for subsidies through relocation threats (Mérieux, 2016; Steelwatch, 2024). These practices have left workers in precarious positions, often facing temporary unemployment and insufficient information. Addressing these challenges requires improved transparency on employment impacts and ensuring meaningful consultation with affected workers before mothballing steel sites (GMK Center, 2023).

inclusive approach to economic transformation. **Supporting retraining programmes and fostering job creation, especially in renewable energy and emerging industries, is essential to securing public support for the transition**. Experiences from regions like the Ruhr (Essen, Dortmund, Gelsenkirchen) and Limburg (Kerkrade, Heerlen) showcase how targeted investments in social infrastructure and research and the promotion of social enterprises can stimulate innovation and economic growth (Arora & Schroeder, 2022; Dudău, Ghinea, & Krynytskyi, 2019; Brauers, et al., 2018; Wuppertal Institute, 2022). Given the persistently high rates of poverty and unemployment, these regions simultaneously serve as stark reminders of the profound social upheaval that accompanies industrial transitions, where the decline of coal mining left deep economic scars, shaping the fabric of these territories in the long term.

Strengthening social dialogue and collective bargaining, along with developing just transition plans at all levels – national, regional, sectoral, and company-wide – can benefit from the approaches seen in Germany, Canada, and Scotland's Just Transition Commissions (EESC Opinion, 2023).

BEST PRACTICES FOR THE JUST TRANSITION

The Austrian Environmental Foundation's green upskilling initiative, with a EUR 10 million budget (2022–2025), aims to train 1,000 people in climate-related fields within 3–12 months, offering support through training subsidies and a mobility package for recipients travelling over 50 km (Aufleb GmbH, 2024). Zero unemployment zones, piloted in France and Wallonia, focus on tailored job creation by designing roles to match the skills and aspirations of the long-term unemployed, addressing local social needs without competing with existing industries (European Social Fund, 2024). France has invested €15 billion into a national skills plan (2018-2022) aimed at boosting access to training for job seekers. This investment has led to a significant increase in participation, with 1.64 million beneficiaries in 2021 compared to 801,000 in 2017, reflecting a marked improvement in training access for the unemployed.

V.

MAKING STEEL MORE CIRCULAR: REDUCE, REUSE, RECYCLE

A. CONTEXT

The Circular Economy framework prioritises reducing the resource footprint through the so-called 3 Rs: reduce, reuse, and recycle. With iron ore making up 93% of mined metals globally, making the iron and steel sector more circular is crucial to limit the environmental impact of European economies (Bhutada, 2023). The EU industry alone, representing around 8% of worldwide production, imports 40 Mt of coke coal and 81 Mt of iron ore to produce 136 Mt of crude steel (2022). The global steel demand is expected to exceed the availability of scrap in a business-as-usual scenario (Kanyilmaz, Birhane, Fishwick, & del Castillo, 2023). The imbalance between scrap availability and projected steel demand is a contentious issue, particularly in the EU, Canada and the US, the two main exporters of scrap (Sandbag, 2022; Hundt & Pothen, 2024; Steel Manufacturers Association, 2023). Some experts argue that the global reliance on pig iron is artificially inflated by surplus production capacity in China. However, the reduction of reliance on virgin materials is a complex and multi-faceted topic that requires a more comprehensive and holistic understanding.

The Circular Economy Action Plan (CEAP), presented by the European Commission in 2020, emphasises the need to decouple economic growth not only from carbon emissions but also from resource use, to keep the EU's resource consumption within planetary boundaries, and to double the circular material use rate in this decade. Some of the overarching priorities set out by the CEAP include improved product durability, reusability, upgradability, and reparability, and increased recycled content in products. The CEAP stresses the importance of "*high impact intermediary products such as steel, cement and chemicals*" (European Commission, 2020), without specific recommendations for steel. More recently, the newly appointed Commissioner-designate for Environment, Water Resilience and a Competitive Circular Economy has been tasked with crafting a new Circular Economy Act "*with measures to create demand for secondary materials and establish a single market for waste, notably in relation to critical raw materials*" (von der Leyen, 2024). Importantly, new legislation aimed at promoting circularity in steel production should also prioritise simplifying reporting requirements for manufacturers.

B. REDUCE

The production of steel using virgin iron ore leads to significant emissions and comes at significant environmental costs; therefore, it is important to consider solutions to use a lower proportion of primary resources such as iron ore to create steel products**. Innovative solutions to reduce the demand, in particular for ore-based steel products, should be explored to reduce carbon emissions from steelmaking.** The IEA considers the reduction in global steel demand including through material efficiency strategies to be an important measure to achieve emissions reductions in the steel sector in its ambitious Sustainable Development Scenario (IEA, 2020). This objective also found recognition in a report by France Stratégie – (a department under the French Prime Minister, tasked with preparing for reform on a variety of topics) which highlights the role of decreasing the use of ore-based steel as a measure for decarbonising the industry in France (France Stratégie, 2024). In particular, it emphasises that the construction sector, which accounts for 52% of global steel demand, presents significant opportunities for intervention, highlighting material efficiency measures through improved designs and standards (France Stratégie, 2024). As steel expert Milan Elkerbout stated in relation to increased circularity and material demand reduction: "*without it, the volumes of renewables, clean hydrogen, CCS and biomass will simply be too high*" (Elkerbout, 2023).

In 2023, apparent steel consumption in the EU fell by 9% (EUROFER, 2024e). However, this decline in EU steel consumption is not a result of policies or business strategies aimed at demand reduction but was driven by reduced activity in the construction sector and a slow-down in the automotive sector, not associated with a long-term trend (GMK Center, 2023).

Some of the discussions at EPICO's stakeholder workshop emphasised the circularity hierarchy, where the reduction, reuse, and repair of resources (e.g. through extending lifetime, decreasing demand, substituting materials, and ecodesign) need to be prioritised over recycling, and should be given adequate attention by policymakers, who have neglected the potential of circularity for industrial decarbonisation. It was suggested that public procurement, which is addressed in Chapter V, should be made greener and more circular, including emissions across the lifecycle and the use of natural resources.

Substitution with other materials

To optimise resource allocation, further integrated research is needed to assess the feasibility of substituting steel with alternative materials. A zero-sum outcome or worse, increased production of carbon-intensive materials like primary aluminium, or hard-to-recycle options like thermosetting plastics, must be avoided. Aluminium, which has one-third of steel's density, could replace steel in several applications where weight matters more than strength, such as car bodies, particularly given the need for electric vehicles to be lightweight (European Aluminium Association, 2022). Aluminium can also serve as an alternative to steel core conductors in power transmission lines and aircraft fuselage construction (Shuang–Shuang, et al., 2023). However, given aluminium's higher carbon emissions, due to the use of carbon anodes, alumina refining and direct emissions, its use as a replacement for steel should be limited to secondary (recycled) aluminium (Zhu, et al., 2021). The material's advantage in lightweighting is also diminishing, as advanced high-strength steels (AHSS) and thin-walled ductile cast iron (TWDCI) now offer similar weight reductions to aluminium with lower environmental impact (Sandbag, 2022; Ricardo, 2024).

In the construction industry, beams and light frame structures could be substituted with sustainable materials like wood, including wood framing, cross-laminated timber (CLT), and glued laminated timber ("glulam") (Hurmekoski, 2017; D'Amico, Pomponi, & Hart, 2021; Cherhat, 2024). Fibre resin composites, made from materials such as glass, carbon, or aramid, have a smaller environmental footprint, a longer lifespan, and lower maintenance requirements (France Stratégie, 2024). In particular, sand-coated glass fibre rebars could replace steel rebars.[1] Low-carbon concrete, which combines binders such as cement with reinforced steel, achieves its final strength through the complementary contributions of both materials, allowing for partial substitution of steel in specific applications. However, the widespread adoption of these alternatives faces challenges such as entrenched industry practices, insufficient research and development, price-only considerations, unsupportive policy frameworks and outdated rules (Xue, Zhang, Yang, & Dai, 2014).

Lightweighting

Lightweighting, which involves reducing product weight through lighter materials and optimised designs, offers emissions reductions potential in the steel sector (German Federal Ministry for Economic Affairs and Climate Action). In EV manufacturing, lightweighting can lower steel demand by using high-strength steel, contributing up to 11% of cumulative steel demand reductions in the IEA's Sustainable Development Scenario (IEA, 2020). However, materials like cold-rolled coil and stainless steel, while reducing weight, remain carbon-intensive unless produced via DRI-EAF processes using natural gas or hydrogen. Maximising the benefits of lightweighting also requires improved scrap treatment and prioritising recycling over virgin iron for products like Advanced High-Strength Steel (AHSS) and Thin-Walled Ductile Cast Iron (TWDCI). To fully realise the potential of lightweighting, future policies should integrate emissions reductions with circularity goals. [2]

WHOLE LIFE CYCLE LEGISLATION

WLC legislation sets limit values, provides a comprehensive approach to assessing and reducing emissions throughout a building's entire life cycle - from construction to demolition (Buildings Performance Institute Europe, 2024, p. 16).[2] WLC legislation creates a level playing field, as steel enters fair competition with other materials such as aluminium (for lightweight structural applications), cement (for large-scale construction and foundational work), biomass (for large-span construction, beams, and headers), and fibre-reinforced composites (for reinforcement and structural applications). They offer a direction where economic costs and environmental costs are considered together, but this is currently far from being mandatory (Grafström & Aasma, 2021; Cherhat, 2024; Domínguez Pérez, Eustermann, & Siimso, 2024). The recently adopted European Building Performance Directive (EPBD) (Article 7) already mandates disclosure of WLC. WLCs are compatible with CPR regulation (LCA for construction products) and the Acquis CPR process, which prepares the implementation of the Construction Products Regulation (CPR) . The Commission has also endorsed Level(s), an LCA method for construction. Several countries, including Denmark, Finland, Sweden, the Netherlands, and France, have pioneered or are planning to implement Whole-life Carbon (WLC) legislation for buildings (Steinmann, Röck, Lützkendorf, Allacker, & Le Den, 2022) (Buildings Performance Institute Europe, 2024, p. 16). Still, WLC legislation does not provide targeted incentives or risk mitigation measures for investments in BF-BOF steel decarbonisation, advanced lightweighting techniques, or the enhanced use of lower-grade steel scrap.

1 However, similar to aluminium, glass fibre production is energy-intensive as polymers are derived from fossil fuels, and are more difficult to recycle than steel (Lu, Afefy, Azimi, Sennah, & Sayed-Ahmed, 2021).

2 The RE2020 regulation in France aligns with this broader trend, setting ambitious standards for new buildings to limit energy consumption and CO_2 emissions. Implemented in January 2022, it applies to single-family homes of 100 m_2 or more, as well as multi-family dwellings, offices, and schools over 50 m_2 Its key goal is to encourage the construction of buildings that produce more energy than they consume, moving towards a net-positive energy model. While the French Ministry predicts an increase in construction costs—3.4% initially, and up to 10% by 2030, when stricter limits come into force—this is expected to be balanced out by reduced energy consumption, resulting in long-term savings. The regulations are expected to lead to a 52% fall in carbon emissions thresholds by 2031 (Steelzero, 2024).

C. REUSE

Reuse models in the steel sector include the re-utilisation of finished steel products as well as the use of by-products created in the process of producing steel. In the case of finished products, the term “reuse” refers to their recovery and direct re-utilisation without remelting, which avoids the human and energy costs of recycling and preserves the original microstructure and geometry of the components (IEA, 2020; Cooper & Allwood, 2012; Kanyilmaz, Birhane, Fishwick, & del Castillo, 2023).[3] In the IEA Sustainable Development Scenario, direct reuse contributes to 15% of the reduction in crude steel demand (IEA, 2020). Depending on the condition and performance of the component in question and the service it provides, reuse can take different forms.[4] Since reuse involves extending the lifecycle of a product with minimal physical transformation, it is often a more sustainable option than recycling, which requires energy to process materials and can sometimes lead to a loss of quality, depending on the material and recycling method (Kanyilmaz, Birhane, Fishwick, & del Castillo, 2023).

Similar to reducing steel demand through lightweighting, the construction industry demonstrates practical examples of reusing steel elements, with projects in North-West Europe aiming to increase reclaimed building elements in circulation (Interreg North-West Europe, 2021). Recent efforts to develop industry standards for reusing of structural steel, focusing on factors such as quality assessment and testing protocols, reflect a promising development in the field (GENORMA, 2024). However, widespread demolition as the default practice limits the availability of structural components for reuse (Kanyilmaz, Birhane, Fishwick, & del Castillo, 2023), and this remains a challenge for the further proliferation of reuse practices.

D. RECYCLE

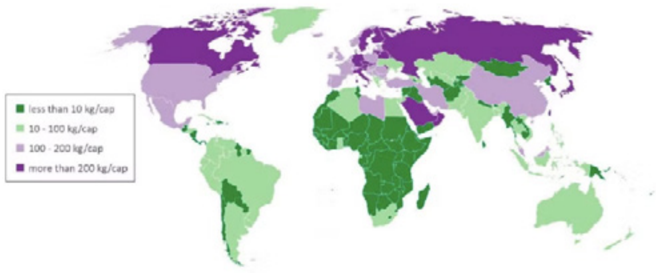

Figure 6: Estimated apparent domestic scrap supply per capita in 2022 (Hundt & Pothen, 2024)

Scrap and the debate around the scrap shortage

Political discussions on steel decarbonisation often centre on hydrogen as a solution for emissions reductions. However, increasing collection and recycling should be given equal importance in the decarbonisation process (Aydemir, Warnke, Lehmann, & Arens, 2024). This is guided by several factors, such as the environmental benefits associated with recycling, the limited availability of iron ore and affordable renewable energy in the EU, and the compatibility of recycling with EAF plants, which can utilise higher proportions of scrap.

> “Increasing collection and recycling should be given equal importance in the decarbonisation process.”

[3] Depending on the performance of the component in question and the service it provides, reuse can take different forms, such as relocation (when a large single component in good condition is repositioned into another product with minimal refurbishment), cascading (where the component is put to a less demanding use, particularly when the demand is low and the condition is poor), reforming (where the component is reshaped to create a new geometry), or remanufacturing (when the component has degraded considerably and may require disassembly or processing to recover its worn surfaces) (Cooper & Allwood, 2012).

There are notable differences in perspective among NGOs and industry players about where the gap lies and to what extent scrap's qualities limit its use. Within NGOs, some advocate for stronger incentives to boost scrap collection, while others point to limited scrap availability in the Global South and the risks of displacing recycling chains in Turkey or India (Berlepsch, 2024). Meanwhile, within the industry, concerns range from fears of rising scrap prices to a desire for fair competition between the two routes. **Ferrous scrap covers more than half of all exported waste outside of the EU, and exports have almost doubled between 2016 and 2023** (Yermolenko, 2024; Joint Paper, 2022). Some actors, including EUROFER and Members of the European Parliament, are openly asking for limits on scrap exports (Aunger & Ourakova, 2024). Other actors, such as the European Recycling Industries' Confederation (EuRIC) and its members oppose restrictions on steel scrap exports, which occur due to insufficient domestic demand rather than higher prices from third-country buyers, with increased local demand naturally reducing exports. The EU's new Waste Shipments Regulation also marks a significant step in combating so-called waste colonialism. It allows waste exports to non-OECD countries only if these nations notify the European Commission of their willingness to import and demonstrate their capacity to manage the waste sustainably (European Commission, 2024d).

Compared with virgin steel, recycling a tonne of steel scrap saves 1.67 tonnes of CO_2, 1.4 tonnes of iron ore, 0.8 tonnes of coal, and 0.3 tonnes of limestone and additives, surpassing the reductions achieved by H2-DRI (EuRIC, 2020). Given the low price of pig iron, **BFs do not currently use as much scrap as they could, effectively leading to more emissions, lower incentives to collect scrap and more exports to third countries**. Researchers calculated that the use of 50% scrap for steelmaking in the EU, in a scenario using the H_2-DRI-EAF route has the potential to reduce the demand for green hydrogen for steel by 50% (Torres-Morales, Maltais, & Gong, 2024). Other researchers obtained similar results, depicting a scenario where the demand for iron decreases from 131 to 82 Mt in the next decade, which would lower natural gas or hydrogen needs by 60% starting from scrap. They advocate for accelerating the transition from BF-BOF to scrap via DRI and EAFs by strategically aligning scrap grades with corresponding steel grades. This approach focuses on phasing out BF-BOFs for less demanding steel grades – such as those used in construction materials such as rebars, which have lower purity requirements – during a transitional period. This would allow initial EAF operations to incorporate a higher proportion of scrap while ensuring more demanding steel grades continue to meet stringent specifications.[5] Experts from Midrex Technologies, Inc, and Kobe Steel also argue for a more immediate switch to DRI using natural gas (Astoria, Hughes, & Mizutani, 2022), but the low profitability of ArcelorMittal's Hamburg plant makes this case too premature (Hamburger Abendblatt, 2023).[6]

The other side of the debate focuses on whether scrap can meet the quality requirements of final steel products, such as high

[5] Importantly, the quality loss from lower grade steel scrap also stems from market choices, as many customers opt for cheaper raw materials over investing in higher-quality recycled options. Large recyclers like EMR and TSR are investing in advanced processing to produce premium recycled materials but need stronger demand to sustain these efforts.

[6] To explain this, experts have responded that the demand for sponge iron is still low as of 2024 because of the availability of free allowances, a phenomenon that will change in 2050, when over 50% of free allowances will be taken out.

tensile strength, ductility, smoothness, and uniformity—key characteristics for applications like automotive body panels and high-strength structural components. The American example, where BF-BOF steelmaking accounts for less than a third of iron production, provides a useful reference. Nucor, for instance, produces steel with over 60% recycled content, including more than 28% post-consumer scrap, demonstrating the potential of scrap utilisation for flat products (Nucor, 2023). Similarly to Nucor in the US, Swiss Steel Group (SSG) exemplifies Europe's leadership in recycled steel production, with its Green Steel Stainless+ product containing over 95% recycled scrap (Greentech.LIVE, 2024; Mining Weekly, 2024).

These debates are understandably politically charged, as stakeholders such as EAF operators, recyclers, and BF-BOF owners have competing interests and advocate differing narratives to shape the transition's direction. **BF-BOF proponents argue that ore-based steelmaking requires stronger regulatory support to incentivise investment, while EAF advocates warn that policies disproportionately favouring BF-BOF steelmakers could undermine the economic appeal of steel scrap recycling**, thereby hindering climate mitigation and circularity efforts. This tension is also evident in discussions surrounding decarbonisation glidepaths and standards for low-emission steel, addressed in Chapter V.

Recyclers and EAF steelmakers argue that the externalities of ore-based steelmaking are not reflected in the current regulatory framework, with BF-BOF steelmakers receiving a substantial push by the state and sintered ore and coke coal imports excluded from the EU-ETS and the CBAM. Aside from the CO_2 emissions, methane emissions from coke coal[7] contribute an additional 27% to the steel industry's carbon footprint and have a greater warming impact than the entire CO_2 emissions of Germany (EMBER, 2023). Other externalities exclude adverse social and environmental impacts across the value chain of ore-based steel production. The costs of relying on virgin iron include deforestation linked with iron ore mining, negative impact on communities, and transport emissions (Fair Steel Coalition, 2024, p. 21). In 2017 the manufacturing of iron, steel, and ferroalloys had the second-largest estimated human toxicity footprint in the EU (Erhart & Erhart, 2023). For 2021, the European Environment Agency (EEA) estimated the cost of air pollution on human health from 9 nine steel facilities alone at EUR 17.6 billion (EEA, 2024).[8]

Scrap collection

The collection and recycling of steel is well-established in Europe, but with a scrap collection rate estimated at around 82% in the EU, and increasing exports (Yermolenko, 2024), there remains significant potential for improvement starting from scrap. At the same time, it is important to consider that Global South economies still in the process of industrialising will also be dependent on scrap from the Global North for building infrastructure

[7] Metallurgical coal, from which coke coal is processed, has nearly three times higher emissions on average than thermal coal, 254 kg CO_2e per tonne in 2021, according to Wood Mackenzie (Griffin, Simington, & Spalding, 2021).

[8] The environmental costs of BF-BOFs are well illustrated by ILVA Taranto. Once producing over 10 Mt of crude steel annually and employing over 20,000 people, ILVA's outdated facilities and lack of pollution controls led to severe public health impacts. In 2013, the European Commission launched infringement procedures, and a University of Bari study revealed that children in Taranto had a 54% higher risk of respiratory diseases due to high levels of PM10 and other pollutants. Similarly, in Fos-sur-Mer, France, where ArcelorMittal operates a blast furnace, cancer rates are twice the national average, resulting in numerous lawsuits. The European iron and steel industry is estimated to cause 1,900–3,050 deaths per year. (Centre for Research on Energy and Clean Air, 2023)

and their economic growth (Åhman, Nykvist, Morales, & Algers, 2023). In 2023, the EU, Canada and the United States exported a total of 29.9 Mt of steel scrap, mainly to global South countries (World Steel Association, 2024). Increasing the share of scrap-based steelmaking in EU countries that traditionally use the primary route could increase the pressure to resort to ore-based steelmaking in poorer and less developed countries (Verpoort, et al, 2024) although the impact might be minimal considering the excess capacity (543 Mt in 2023), concentrated in Asia (Nakamizu & OECD Steel Committee, 2024). This underscores the need to maximise the recovery and collection of scrap domestically, especially given that the availability of scrap will increase, since steel consumption in the EU has not yet reached its peak (GMK Center, 2023).

The relatively high figure for scrap collection in the Global North is supported by scrap's high value and supportive waste legislation. For ferrous metals in packaging waste for example, the EU's Packaging and Packaging Waste Directive (PPWD) set ambitious household recycling targets of 70% by 2025 and 80% by 2030. Still, recyclable steel packaging, with an EU-wide rate of 58%, offers areas for improvement, with stakeholders arguing that the waste could be better diverted from landfills with revisions to the Landfill Directive (Claus & Van Maercke, 2022).

Scrap contamination

Besides waste collection, an additional issue explaining the recycling gap is metal contamination. Metal contamination occurs when tramp elements including copper, chromium, nickel, and nitrogen, alter steel's properties, weakening its quality and limiting its applications (Åhman, Nykvist, Morales, & Algers, 2023; Systemiq Earth and ThyssenKrupp Steel Europe, 2024). The Commission's Joint Research Centre notes that "*most of the alloying elements are dissipated and not functionally recycled*" (Faraca, Ranea Palma, & Spiliotopoulos, 2024). A white paper commissioned by ThyssenKrupp Steel Europe also notes that "*resolving the quality limitation of scrap would strengthen the position of the EU steel industry in the global steel market; especially due to an increase in supply chain resilience, as dependencies on imports of iron ore and scrap decrease*" (Systemiq Earth and ThyssenKrupp Steel Europe, 2024, p. 12). Bulk shredding and the relatively low economic value of steel scrap are the main business practice and condition standing in the way of better sorting (Panasiuk, et al., 2022; Hundt & Pothen, 2024; Hall, Zhang, & Li, 2021; Maloney, Grimm, & Anctil, 2020; Caro, et al., 2024). An analysis by Sandbag of the EU market highlights this issue, revealing an 8 Mt variation in collected scrap – out of approximately 90 Mt of annual steel scrap consumption – driven by fluctuations in scrap prices (EuRIC, 2020; Sandbag, 2022).

> *"Bulk shredding and the relatively low economic value of steel scrap are the main business practice and condition standing in the way of better sorting."*

Participants at EPICO's workshop emphasised the investments being made by recyclers in advanced technology and equipment to enhance sorting processes, while also noting the potential for greater financial support to facilitate such efforts. The challenges faced by steel recyclers underscore the importance of more comprehensive policy integration at the European level. Workshop discussions suggested that incorporating recyclers more comprehensively into steel, environmental, and trade policy frameworks would better acknowledge their critical role in mitigating emissions, reducing waste, and lowering the EU's material footprint. Enhanced collaboration between recyclers, manufacturers, and policymakers was identified as a key pathway to establishing realistic quality standards and addressing investment needs. Promoting dialogue on the advantages of higher-quality recycled materials could further align customer expectations with industry capabilities, fostering a more effective and sustainable recycling ecosystem. Stakeholders also highlighted specific challenges linked to the automotive sector, including elevated copper and zinc levels in scrap, which stem from practices such as galvanising and the increased use of copper in e-mobility. These issues underline the need for downstream transformers of steel, such as automotive and white goods producers, to play a more active role in the end-of-life management of steel products. Greater involvement at this stage could improve collection rates and recycling outcomes (Panasiuk, et al., 2022).

France introduced a mandatory Extended Producer Responsibility (EPR) scheme for construction activities in 2023 based on the polluter-pays principle. French manufacturers now finance waste recycling and prevention via eco-organisations, covering waste at no charge for builders and individuals. The law boasted a 100% increase in recycling centres after only six months into force (Batiweb, 2024).

Data collection and transparency also present notable gaps. In Germany, the shift of data collection from the Federal Statistical Office to industry bodies like the German Steel Association and the German Forging Federation (BDGuss) has resulted in reliance on voluntary member reporting, which lacks the comprehensiveness and neutrality of public statistical data. The EU should consider prioritising practical and scalable knowledge-sharing initiatives to enhance recycling outcomes across Member States. Encouraging European collaboration through platforms for sharing best practices and compliance tools, such as digital hubs or simplified reporting templates, could address recyclers' operational constraints. Supporting equipment upgrades, like secondary overband magnetic separators in sorting facilities, would help capture smaller steel metals, while establishing EU-wide quality standards at each stage of the recycling process would ensure consistent input quality. Expanding the use of better alloy-sorting technologies, such as Laser-Induced Breakdown Spectroscopy (LIBS), could close the steel cycle by preserving valuable alloy elements (Willman, Wedberg, & Solheim, 2017).[9] Complementing such advancements, the broader potential of AI and digitalisation remains untapped, offering further avenues to enhance efficiency and precision in metal recycling processes. To support such transitions, leading research institutions in the field of metallurgy like KU Leuven, IDDRI, Luleå University of Technology, RWTH Aachen, Montanuniversität Leoben, Ecole des Mines, TU Delft, and the University of Oulu could play a crucial role in assessing not only the costs but also the environmental footprint and technical properties of steel products.[10]

Pre-consumer and post-consumer scrap

Pre-consumer steel scrap, a valuable by-product essential for reducing CO_2 emissions and acting as a cooling agent to lower energy requirements and process temperatures, has declined due to production

[9] Reverse Metallurgy, a research programme in collaboration with Liege University, and financed by the Walloon government and the EU European Regional Development Fund, has been central in designing new cost-efficient ways to sort alloys and other metals (L'Echo, 2021).

[10] These properties include corrosion resistance, embrittlement, strength, and durability.

yield improvements driven by computer-aided design and eco-design principles, but also by deindustrialisation[11] (EUROFER, 2016). Failing to distinguish between pre-consumer and post-consumer scrap, as the CBAM Implementation Act does (Sandbag, 2024) can lead to inaccurate environmental claims (Carbon Market Watch, 2023). Companies may fraudulently generate excess pre-consumer scrap to artificially lower their product's declared emissions, despite increased emissions. Pre-consumer scrap reflects inefficiencies, while post-consumer scrap involves more costly recycling. Stainless steel producers often purchase scrap blends tailored to specific compositions (e.g., 8% nickel), combining pre- and post-consumer scrap. For externally sourced scrap, the origins of the scrap are therefore often unclear.

Recycled steel in cars

In the case of the automotive sector, a regulatory revision of the End-of-Life Vehicle Directive could ensure that scrap is properly sorted and contaminant-free (Dworak, Rechberger, & Fellner, 2022). Expanding the use of scrap in car manufacturing demonstrates the viability of secondary flat steel production, which could drive greater support for using recycled steel in more industries, reducing reliance on BF-BOF steel and lowering emissions. A well-designed policy framework should pave the way for flat steelmakers to improve the use of high-grade post-consumer scrap for their products, for which there is a proven gap attested by the literature (Systemiq Earth and ThyssenKrupp Steel Europe, 2024; Ricardo, 2024; Urban, Nipius, & Egenhofer, 2024; Jhaveri, Lewis, Sullivan, & Keoleian, 2018).[12] Product design that focuses on "designing for recycling" can also play a role in enhancing the degree of recycling in the future (Aydemir, Warnke, Lehmann, & Arens, 2024).

> *"With the EU's steel recycling rate currently at 82%, investing in improvements to this rate offers far greater environmental returns per euro than the more resource-intensive BF-BOF steel production route that relies on imported coke coal, imported iron ore and likely imported fossil-free hydrogen."*

Europe's abundant steel scrap provides a critical comparative advantage in the sector, and while this must be balanced with a political agreement on resilience and strategic autonomy, achieving both cost and material efficiency will depend on fostering innovation and maintaining technological neutrality. With the EU's steel recycling rate currently at 82%, investing in improvements to this rate offers far greater environmental returns per euro than the more resource-intensive BF-BOF steel production route that relies on imported coke

[11] Pre-consumer scrap is also produced by carmakers and their suppliers during processes like stamping, cutting, and machining when shaping steel parts for vehicles. Other producers include machine building, shipbuilding, construction, appliance manufacturing, and metalworking.

[12] Arvedi (Cremona, Italy) and Tata Steel (Ijmuiden, Netherlands) already make flat steel with EAFs, through thin slab casting (Sabella, 2022). 6% of current total scrap steel production in the EU goes into new cars according to Transport & Environment, which sees "no technical limitation" to increasing this (Transport and Environment, 2024).

coal, imported iron ore and likely imported fossil-free hydrogen.

E. POLICY RECOMMENDATIONS FOR THE EU

Enhance Support for Recycling Technologies and Infrastructure

To strengthen steel recycling and meet EU decarbonisation goals, the EU must promote advanced recycling technologies such as Laser-Induced Breakdown Spectroscopy (LIBS) for precise alloy sorting and Material Flow Analyses (MFA) for tracking material flows and contamination. Increased financial and regulatory support is necessary to facilitate technology adoption, complemented by investments in AI and digitalisation to improve efficiency. A robust material tracking system across product lifecycles would preserve information on material composition, reducing delays and improving scrap quality. Leading research institutions should assess recycling technologies' environmental and economic impacts, providing evidence to shape effective policies. The EU should prioritise research into enhancing the utilisation of lower-grade steel scrap for producing high-quality materials, such as flat steel, which demands high tensile strength, ductility, smoothness, and uniformity. These measures will help raise the steel recycling rate above the current 82%, while reducing reliance on virgin iron ore and pig iron imports.

Strengthen Integration and Knowledge Sharing in the Recycling Sector

Recycling must be better integrated into EU steel, environmental, and trade policies to acknowledge its vital role in decarbonisation and emissions reductions. Collaboration between recyclers, manufacturers, and policymakers is critical to establish realistic quality standards, ensure better end-of-life steel management, and support investments in equipment and technological upgrades, such as overband magnetic separators for smaller steel items. Practical knowledge-sharing platforms, such as digital hubs and simple compliance tools, should be developed to address operational constraints. Policies should foster partnerships with downstream steel users (e.g., automotive and white goods sectors) and encourage their active role in improving collection and recycling. Tailored reporting requirements should simplify data collection for smaller recyclers, while larger recyclers handle detailed reporting. Expanding mandatory design-for-recycling standards and binding recycled content targets should help further reduce landfilling of steel scrap.

Improve Circular Economy Policy Frameworks to Promote Demand-side Measures, Material Efficiency and the Reuse of Steel

The EU should elevate measures such as demand substitution and reuse of steel products within its emissions reductions strategies, as these areas remain underutilised despite their significant potential. Future frameworks for steel decarbonisation should address the reduction of ore-based steel, demand substitution using lower-emission materials, reuse strategies, and enhanced material efficiency. Policy initiatives and R&D investments should emphasise demand-side approaches, such as improving product design and lightweight steel, promoting materials with lower carbon footprints as substitutes, and encouraging the reuse of finished steel products, particularly in the construction sector while ensuring that new requirements do not add to the regulatory burden of manufacturers and recyclers. Recent efforts to develop industry standards for the reuse of structural steel represent a positive development in the field and could contribute to bringing this resource-efficient practice into the mainstream.

VI.
CREATING LEAD MARKETS

A. WHAT ARE LEAD MARKETS AND ARE THERE ANY?

Lead markets are conceived as pioneering end-use markets that set the pace for the adoption of innovative and climate-friendly materials and products, leading the way for other end-use markets to follow (Urban, Nipius, & Egenhofer, 2024). The first step for policymakers to create these is to identify sectors. Sectors chosen should have three characteristics: (1) a lower green premium (the extra cost associated with the innovative and climate-friendly material and product), (2) a higher ability to pay (sectors that can absorb higher costs and/or pass them on to consumers or taxpayers), (3) a greater degree of public influence (where regulatory influence or public-sector ownership can push sustainable choices more effectively) (Agora Industry, 2024, p. 18). Secondly, clear and marketable standards must be established, followed by carbon accounting and reporting requirements to make environmental performance visible to consumers, such as Product Carbon Footprints (PCFs) and Environmental Product Declarations (EPDs).[1] Thirdly, lead markets must be driven by instruments such as mandatory criteria in public procurement, regulation, quotas, and financial incentives, encouraging the adoption of these materials and products. As per one estimate, the lead market for low-carbon steel is at 11% of apparent usage (i.e. not accounting for correction to the present steel stock), representing approximately EUR 8.3 billion (Pérez, Eustermann, & Siimso, 2024).

Two potential lead market sectors identified are construction and automotive, accounting for 35.5% and 19% of finished steel products in the EU, respectively (EUROFER, 2024). Wind turbines and other energy-related products are also often cited as other examples of a possible lead market.[2] **There are significant divergences in opinions about whether these lead markets already exist or not**. Axel Eggert, Director General of EUROFER, the European Steel Association, stated in March 2024 that "*there are no lead markets*".[3] This opinion is shared by the German Automotive Industry Association (VDA), which cites the difficulty in predicting the additional cost of low-emission steel for producing finished cars (Packroff, 2024). Yet, numerous carmakers have signed offtake agreements with steelmakers for green steel in recent years.[4] According to the International Council on Clean Transportation,

[1] Environmental Product Declarations (EPDs) gained prominence in the EU thanks to the European Commission promoting them through the Integrated Product Policy (IPP) launched in 2003, which promoted lifecycle-based sustainability, and the 2011 Construction Products Regulation (CPR), mandating environmental performance information for construction products.

[2] Additionally, wind turbine manufacturers and the packaging industry have also taken steps to purchase low-emission steel (Vestas, 2024) (Aydemir, Warnke, Lehmann, & Arens, 2024).

[3] EUROFER event on "the future of EU industry: value chain resilience or dependence?" on 9 April 2024.

[4] In the United States, steel producer Nucor launched Econiq™ in 2022, as a certified low-embodied carbon flat steel, which has since entered agreements with General Motors and Mercedes-Benz (Nucor). In Europe, Audi

"*the automotive industry is [...] uniquely positioned to act as a lead market for primary fossil-free steel uptake*" (Negri, Bui, Ordonez, Bieker, & Isenstadt, 2024, p. 29). The additional cost of a car made with low-emission steel is estimated at 1–2% of the final price, a minor green premium that could more easily be passed on to consumers with suitable labelling (Zaccaro, 2024; Transport and Environment, 2024, p. 24; World Economic Forum, 2021; Negri, Bui, Ordonez, Bieker, & Isenstadt, 2024).

"Construction should be distinguished from the premium steel segment, such as the automotive industry, as it already uses high shares of low-emission, scrap-based steel."

The construction sector, characterised by relatively high shares of public procurement, is another potential lead market. Importantly, construction should be distinguished from the premium steel segment, such as the automotive industry, as it already uses high shares of low-emission, scrap-based steel (Cherhat, 2024). Therefore, the sector has the opportunity to lead the decarbonisation of both ore-based steel and scrap-based steel (Åhman, Nykvist, Torres Morales, & Algers, 2023).

Public procurement represents 15% of the EU's GDP, with some countries showcasing a high share of steel in public procurement of construction in total steel use, such as France (17%) and Sweden (18%) (Nilsson Lewis, Kaaret, Torres Morales, Piirsalu, & Axelsson, 2023; Wyns, Kalimo, & Khandekar, 2024). Integrating criteria that reward products and materials with higher reuse and recycling potential could enhance the impact of public procurement. Although these materials may involve higher upfront costs, this approach could mitigate future expenses related to climate change and public health impacts from high-carbon activities, such as emissions from metallurgical coal mining in iron ore production.

By prioritising materials that support a circular economy, public procurement could advance sustainability while reducing long-term economic and social burdens (Cherhat, 2024). A study by Ramboll for the Environmental Coalition on Standards found that applying basic-level **Green Public Procurement (GPP) criteria could cut 11.9 Mt CO_2 in steel and concrete annually at an additional cost of 1.6% in public procurement volume, yielding an abatement cost of EUR 34.46 per tonne – well below current EU-ETS carbon prices** (Steinmann, Le Den, Witteveen, Kovacs, & Pirttikoski, 2024). However, at present, different standards for public procurement exist within the EU Member States, and they are not always focused on environmental criteria. Italy is the only EU Member State which has implemented mandatory GPP minimum environmental standards to 18 priority groups, including construction and road transport since 2015 (Nilsson Lewis, Kaaret, Torres Morales, Piirsalu, & Axelsson, 2023).[5]

has also entered a research project with voestalpine to explore the use of post-consumer scrap in new cars, for instance in the outer roof section and inner door parts (Audi, 2023). Volvo has signed agreements with both Hybrit and Stegra, and Ford with ThyssenKrupp, Tata Steel and Salzgitter (Ford, 2022a; Ford 2022b; Volvo Group 2021; Volvo Group 2023). And as recently as October 2024, Volkswagen Group signed a memorandum of understanding (MoU) with and Thyssenkrupp Steel (Volkswagen Group, 2024).

5 Structural steel requires a minimum recovery of 75% for unalloyed EAF steel, 60% for alloyed EAF steel, and 12% for integral cycle steel, while non-structural steel needs 65%, 60%, and 12%, respectively.

Policy discussions in Brussels and around the EU are increasingly debating optimal regulation to materialise the so-called lead markets. One option is recycled content requirements for steel in the automotive sector. Some BF-BOF steelmakers say it may divert higher-grade scrap from long steel applications, where the routes compete (beams, rebar, wire rod, etc.) and end in a zero-sum game. However, several NGOs and EAF steelmakers argue that this would raise the value of steel recycling, and therefore create a positive technological spillover throughout the steel industry. They argue that high-quality post-consumer scrap should increasingly be destined for flat products, rather than expand BF-BOF steel to long products. Another option instead of recycled content are quotas for low-emission steel in cars which could recognise LCAs, EPDs and PCFs. A third option could be to include distinct CO_2 standards specifically for automotive steel and competing materials such as aluminium in cars, potentially expanding to include trucks, trains, and buses in the future.[6] Under such a framework, carmakers would have an average target to meet across their vehicle range, allowing them to first apply it to premium models before scaling down to more affordable vehicles, effectively creating a lead market. A fourth option is for the European Commission to mandate the establishment of an eco-score, combining energy efficiency (in kWh/km) and carbon footprint at the vehicle's production stage from elements such as the battery, steel and aluminium (in $kgCO_2e$) (IDDRI, T&E and BEUC, 2024). This would have the additional advantage of providing visibility to end consumers, and fiscal incentives could embed the scoreboard. **The chosen option could be integrated into the End-of-Life Vehicles (ELV) Directive, which the European Commission wants to turn into a Regulation**.

For construction, the equivalent would be WLC legislation, showcased in an explanatory box on page 30. WLC regulations should integrate product-specific benchmarks and account for lifecycle benefits of low-carbon materials to avoid overemphasising downstream phases such as operational efficiency over critical upstream measures, such as increasing DRI or scrap content in steel, or reducing the clinker-to-cement ratio in concrete, which are vital for reducing embodied carbon from the outset. **The EPDs as part of the CPR acquis need to reflect this ambition, and be more attuned to the realities of the ground, more actively rewarding low-emission production of building materials**. Product-specific standards within the Construction Products Regulation (CPR) could address material efficiency, using Environmental Product Declarations (EPDs) that track embodied carbon and recycled content. Product category rules (PCRs) are meant to enable comparison between the PCFs: there is a PCR for construction, for non-construction final products and for intermediate non-construction products, consistent with ISO 14025.

B. OVERVIEW OF SELECTED CERTIFICATIONS AND STANDARDS

Establishing visibility for Product Carbon Footprint (PCF) and Global Warming Potential (GWP) data from Environmental Product Declarations (EPDs) for construction materials is essential for integrating these metrics into a supportive policy framework. This must be done transparently to highlight low-emission steel while avoiding greenwashing and preserving the credibility and value of EPDs.

[6] The CO_2 emission performance standards for cars and vans should not be reopened, as this legislation is already facing challenges from segments of the automotive industry and risks opening a Pandora's box, particularly given the politically divisive debate surrounding the 2035 ban on internal combustion engines (ICEs). Furthermore, electric vehicles (EVs) require more steel than ICEs due to the need for battery protection and reinforced chassis and frames. Imposing similar requirements for both risks exacerbating the difficulties currently faced by the EV sector.

Certifications and standards are valuable tools for defining effective decarbonisation pathways that reflect real progress in material quality.

In the absence of globally uniform standards, private companies have developed their own initiatives, such as XCarb (ArcelorMittal), bluemint (ThyssenKrupp), Econiq (Nucor), and Stahlo (a German steel service centre). Klöckner & Co.'s Nexigen®, a five-tier system ranking steel by CO_2 emissions, helps customers manage their CO_2 balance sheets (Klöckner & Co). The latter strongly advocate for a standardised approach to Product Carbon Footprint (PCF) calculations in the green steel market to ensure transparency, comparability, and also value chain integration (Voigt, et al., 2023).

As opposed to certificates, **green steel standards are frameworks applied across the industry to ensure consistency and comparability among producers and avoid greenwashing** (Sorge, 2023).

The Science Based Targets initiative (SBTi) and the Steel Climate Standard by the Global Steel Climate Council (GSCC) establish glide paths to guide the industry's decarbonisation efforts. Other suggestions include the Low Emission Steel Standard (LESS) by the German Steel Federation, the original IEA proposal and the China Iron and Steel Association's Low Carbon Emission Steel Evaluation Method, spearheaded by Baowu Steel Group (WWF Finland, 2023; IEA, 2024). The abundance of standards increases the risk of cherry-picking and potential greenwashing. At the global level, SteelZero acknowledges that "*political and legal considerations may lead to different geographies choosing to adopt their own standards and definitions*" (Steelzero 2024).

ResponsibleSteel, launched in Australia in 2015, is an outlier as it acts as an international production standard and certification programme, promoting responsible steel sourcing and production combined with a multi-stakeholder forum.[7] According to its latest Annual Progress Report, it has successfully certified 66 sites in 14 countries employing over 220,000 workers and producing over 120 Mt of steel (ResponsibleSteel, 2024). Still, Responsible Steel used the so-called "sliding scale" approach, which aims to create a level playing field between virgin iron and scrap by neutralising the effect of scrap on emissions.

The EU's Joint Research Centre is currently conducting a preparatory study on the environmental and techno-economic aspects of iron and steel products, aimed at providing scientific evidence to support future EU product policy discussions, and laying the groundwork for a future Delegated Act under the Ecodesign for Sustainable Products Regulation (ESPR). Article 65 of the ESPR, that came into force in July 2024, stipulates that, in the context of public procurement, "*the minimum requirements shall be based on the two highest performance classes, the highest scores or, when not available, on the best possible performance levels as set out in the delegated act adopted*" (European Parliament and Council of the European Union, 2024).

The Low Emission Steel Standard (LESS)

The LESS proposal claims alignment with the IEA framework adopted by the G7 in 2022, shown in *Figure 7* (IEA, 2022). However, the IEA framework was developed under Germany's G7 presidency and funded by the Federal Ministry for Economic Affairs and Climate

[7] The First Mover Coalition (WEF), the Climate Group's 'SteelZero' initiative, and 'Drive Sustainability' (Raw Materials Observatory) provide additional cases of how companies can collaborate with NGOs to work towards standards and address ESG performance and impacts in their supply chains. Horizon Zero (Rocky Mountain Institute) and the Mission Possible Partnership (launched by the World Economic Forum) have attempted to focus on both production and demand.

Action. It notably excluded participation by any EAF steelmaker. The LESS, designed by the German Steel Association, was then officially endorsed by the same Federal Ministry for Economic Affairs and Climate Action in May 2024 (Bundesministerium für Wirtschaft und Klimaschutz, 2024). The framework follows the "sliding scale" concept, standardising how different types of steel are classified into performance categories based on carbon emissions and recycled content. By introducing varied thresholds for carbon dioxide equivalent (CO_2-eq) depending on the amount of recycled steel used in the production process, it aims to create a system that decarbonises both routes. The fundamental principle is that steel with higher recycled content should meet stricter emissions criteria, a principle guided by the limits of scrap in terms of availability and quality. It also argues that the decarbonisation of ore-based steelmaking needs a stronger business case in order to drive investment and the construction of DRI furnaces.

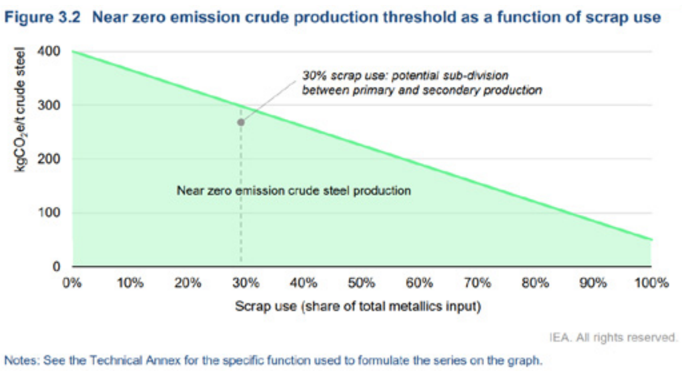

Figure 7: Steel Standard proposal by the IEA (2022)

The LESS sets two different standards, for the categories of "quality" steel and another one for "construction" steel, which are defined by a set range of properties, with slightly lower CO_2-eq emission thresholds for the latter, as shown in *Figure 7*. The system is designed to be reviewed every three years, potentially incorporating additional manufacturing processes such as continuous casting and forging, more diffuse in China (Berlepsch, 2024). Product Carbon Footprint (PCF) and Global Warming Potential (GWP) can be reported.

One positive element of the LESS framework is its inclusion of not only production emissions (Scope 1) and energy procurement emissions (Scope 2) but also upstream emissions from input production (Scope 3) (Wirtschaftsvereinigung Stahl, 2024). Interestingly, the LESS opted to focus on hot rolled coil (HRC) as the benchmark product instead of crude steel, recognising the limitations of assessing emissions and improvements at the crude steel production stage.[8]

Labelling emission factors with weight-based adjustments might discourage the recycling of carbon-intensive alloys such as chromium, nickel, and manganese, potentially making the production of virgin ferroalloys more economically attractive despite their significantly higher emissions (e.g., ferronickel production emits up to 20 times more due to the low nickel content in ores). The improper separation of ferritic stainless steel from carbon steel during dismantling – both being magnetic and hard to distinguish post-shredding – already limits the global end-of-life recycling rate for stainless steel to just 70% (Worldstainless, 2023), and this approach risks further undermining recycling efforts. Alloys containing metals like chromium – largely sourced from South Africa – and nickel, with an overcapacity issue in Indonesia, are essential in steel production. However, if not carefully separated, these ferroalloys can lead to contamination, causing brittleness and complicating processing. Metal contaminants such as copper, tin, nickel, chromium, lead, and zinc pose additional challenges as

[8] This decision was made to account for innovative processes and efficiency improvements that are specific to downstream operations, particularly in EAFs, in order to account for the variations in production methods or energy inputs that occur downstream.

they compromise steel quality, processing efficiency, and environmental standards. Despite these factors, the LESS standard could disincentivise recycled content, which could impede investment in advanced sorting and recycling, making bulk shredding more common. Such an approach overlooks the high carbon costs of not recycling ferroalloys; for instance, ferronickel production emits between 45 and 70 tonnes of CO_2 per tonne of nickel content, underscoring the importance of sustainable recovery in reducing dependency on volatile global supply chains and enhancing sustainability (Nickel Institute, 2020, p. 4; GIZ, 2022, p. 45).

Labelling plays a crucial role in establishing the economic viability of steel recycling, complementing indirect cost compensation, the decarbonisation of the electricity mix, and carbon pricing. In a market-driven economy, resilience and circularity can be significantly strengthened through carbon pricing and prioritising the recovery of high-value metals from carbon-intensive ferroalloys.

Adopting the LESS framework at the national or EU level could disincentivise scrap recycling, therefore undermining emissions reductions objectives, and artificially alter existing market dynamics. Given how price-sensitive scrap and steel industries are, the sliding scale could discourage investment in scrap recycling, and lead to more pig iron usage in EAFs, a phenomenon already witnessed in recent years. It could hinder the European steel industry's own circular economy goals by disincentivising research, innovation, and the development of processes for utilising lower-grade recycled steel and improving collection rates. This, in turn, could negatively impact Europe's strategic resilience and long-term sustainability in steel production.

By allowing higher-emission steel producers to classify their products as "green" without making the necessary shifts to available less carbon-intensive methods, it also presents a high risk of greenwashing (Global Steel Climate Council, 2024; Sandbag, 2022). Allowing both high-polluting and lower-emission steel production routes to compete for "green" labels risks devaluing the credibility of of PCFs and EPDs, which the Commission has worked to establish as the benchmark standard in recent years. The approach could slow down the phasing out of BF-BOFs by permitting coal-based steelmaking to compete with EAFs, justifying incremental, costly abatement measures such as TGR, and hydrogen and biochar injection, which may hinge on public funding and extend coal dependency.

A standard disincentivising recycled content overlooks the high social and environmental costs associated with iron ore mining, including strategic autonomy and resilience, as iron ore reserves in Sweden and Ukraine are likely not enough to satisfy demand from European steelmakers. It must be noted that the recycling industry, especially on a global scale also poses concerns related to ESG performance.[9]

In addition to altering the existing structure of the European steel industry, the sliding scale could potentially favour non-European producers who are more advanced in DRI processes, but still use fossil fuels such as natural gas, and benefit from various competitive advantages such as cheaper energy, undermining circularity and the use of domestically available scrap. Algerian rebar

[9] Hazardous working conditions, labour exploitation, pollution, and financial misconduct like money laundering are common risks in global scrap supply chains. Transparency issues, such as proprietary sourcing and material mixing, hinder traceability, making it harder to monitor impacts and increasing reputational risks (ResponsibleSteel, 2024).

with less than 10% scrap charge[10] could be favoured, and would get a better label than Italian rebar, with half the PCF and using 76% of scrap charge.[11] If this is not the case, it suggests that the LESS framework, as shown on *Figure 8*, does not simply reflect the PCF, especially in this case, EPD and LESS cover the same emission scopes up to the hot rolled coil stage—namely, direct emissions in A3, indirect electricity emissions in A3, and upstream emissions in A1-A2. By limiting recognition of the environmental benefits associated with the European EAF-scrap route, the sliding scale may affect the long-term viability of this segment of European steel production, which is characterised by its circularity, local sourcing, and comparatively low carbon footprint.

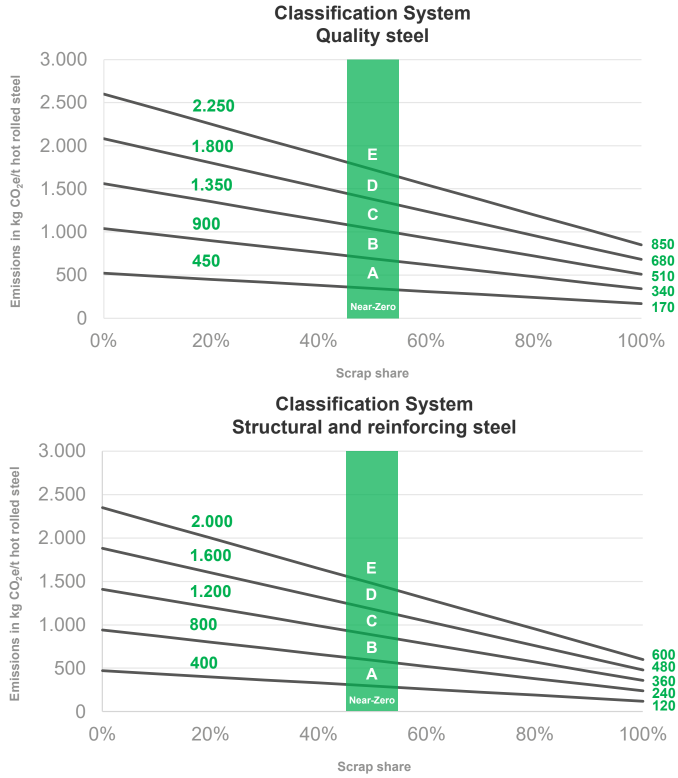

Figure 8: The LESS standard (Wirtschaftsvereinigung Stahl, 2024)

The GSCC Steel Climate Standard

Another proposal comes from the Global Steel Climate Council (GSCC), an international coalition of steel producers and stakeholders, including the US-American Nucor, the Spanish CELSA Group, the Italian Riva Group, Turkey's Çolakoğlu Metalurji, as well as the recycling industry, in the form of the Bureau of International Recycling (BIR) and the European Recycling Industries' Confederation (EuRIC). Importantly however, not a single BF-BOF steelmaker supports the Steel Climate Standard. Central to their efforts is the Steel Climate Standard, a glidepath that opposes the sliding scale neutralisation of scrap advantage. It covers Scope 1, 2, and 3 emissions, from mining and resource extraction to the hot rolling process. Its standard is seen as a counter to the LESS, favouring the secondary route over ore-based steel. It focuses on reducing emissions intensity (measured in tonne of CO_2-eq per tonne of hot-rolled steel) from 2022 to 2050. For flat steel, it starts at 1.84 t CO_2e/t in 2022 and aims to fall to 0.12 t CO_2e/t by 2050. For long steel, it starts at 1.47 t CO_2e/t in 2022, converging with flat steel at 0.12 t CO_2e/t by 2050.

The reporting must be accompanied by third-party verification, ensuring that the emissions calculations are accurate and credible. Additionally, companies are obligated to establish Science-Based Emissions Targets (SBETs) within two years of joining the GSCC,

[10] As visible in the Environmental Product Declaration (EPD) for DRI-made steel rebar (80-90% DRI) by Turkish steelmaker Tosyalı, published in 2024, the total Global Warming Potential (GWP) amounts to 1540 kg CO_2eq for production (A1-A3), with an additional 34 kg CO_2eq from end-of-life stages (C1-C4), including deconstruction, transport, and disposal. Tosyalı, a leading producer in Algeria, targets 5 Mt of DRI production, with plans to transition to fossil-free hydrogen under an MoU with Sonatrach, Africa's largest company (Tosyali Algerie, 2024; SEAISI, 2024). As a reference, 5 Mt is more than Sweden's current crude steel production.

[11] The total Global Warming Potential (GWP) for rebar produced by Pittini, an Italian EAF steelmaker, amounts to 775 kg CO_2eq for production (A1-A3), with an additional 41 kg CO_2eq from end-of-life stages (C1-C4) (EPB Italy, 2024).

which must align with the standard's decarbonisation trajectory. Unlike the IEA standard, the GSCC standard includes a broader range of upstream emissions, encompassing the extraction of metals, collection, processing, and transport of scrap metal, processing of metals for alloys and additives, production of refractories, electrodes, and graphite for EAFs, as well as the upstream production of industrial gases such as nitrogen and argon, and steam. Several NGOs have criticised this approach, arguing that the stakeholder process lacked inclusivity and transparency, favoured Global North countries with greater scrap availability, and set thresholds that are unrealistic for flat steel while exceeding current average emissions for long steel in Europe and the United States (Open Letter by Civil Society Groups, 2023). When contacted, a member of the GSCC responded that unlike ResponsibleSteel and LESS, the GSCC did not choose collaboration with NGOs as a strategy to manufacture consent. Pertinently, the Standard has found a certain degree of recognition and is more advanced in application than the LESS, having been endorsed by the UK Construction Leadership Group, with six organisations including Heathrow Airport and National Highways signing up to the CLG's five Client Carbon Commitments, which include

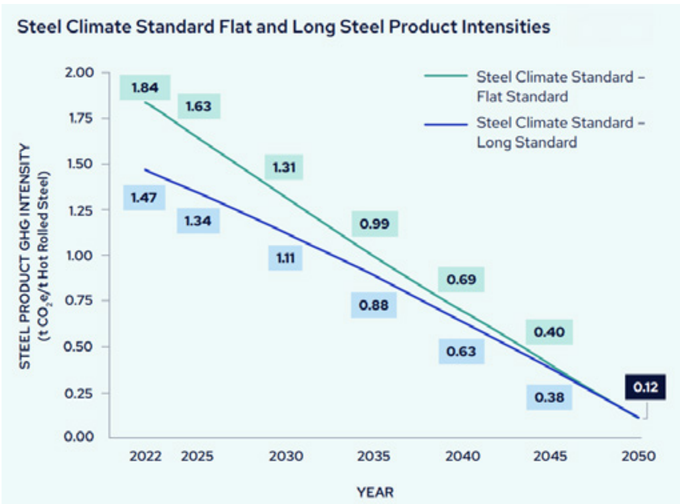

Figure 9: The Steel Climate Standard (Global Steel Climate Council, 2024)

reference to the GSCC Standard (National Highways, 2024).

C. POLICY RECOMMENDATIONS FOR THE EU

Adopt a common European labelling system for steel to provide clarity and avoid greenwashing

The EU-27 should adopt a standard for steel decarbonisation, which is holistic and forms part of the upcoming EU Delegated Act for iron and steel under the Ecodesign for Sustainable Products Regulation (ESPR) 2024/1781. It should cover all major types of steel, including alloyed steel, and integrate the costs of sourcing virgin alloys such as nickel, chromium, and manganese. The standard should prioritise technological neutrality by allowing multiple decarbonisation pathways, such as scrap use, DRI and Carbon Capture and Storage (CCS), and exclude offsets. Adjustments, Guarantees of Origins and resource reshuffling, such as are allowed in the LESS, should be strictly regulated and be the exception, not the norm. The system should include Scope 1, 2 and 3 emissions, accounting for the entire value chain, including mining and raw material extraction, and include certification pertaining to ESG criteria and impact on communities. A labelling system that allows for the decarbonisation of both routes, whilst providing transparent and objective data to downstream customers on the actual emissions and carbon intensities of their purchased steel, will improve circularity and investment in clean technologies such as H2-DRI+scrap-EAF, better collection, sorting and treatment of metals and alloys without a subsidy race that would end up diverting costs. The labelling system should include a common EU-wide framework for certifications, stricter signals against greenwashing (e.g, via guarantees of origin[12] and Scope 4 emissions[13]), and a focus on decarbonisation roadmaps. To align with existing EU regulations, the new standard must comply with the political objectives of principal EU legislation such as the Construction Product Regulation (CPR), the European Building Performance Directive (EPBD), and the Ecodesign for Sustainable Products Regulation (ESPR).

Reform the Public Procurement Directive to stimulate demand for low-emission steel

To align the EU's Public Procurement Directive (2014/24) with climate and sustainability targets, comprehensive reform is needed to shift away from the price-only criterion. The revised Directive should align the use of public funding with political objectives such as decarbonisation and better working conditions. GPP policies with binding criteria can promote the uptake of low-emission steel and act as a crucial lever for steel decarbonisation. EU-wide harmonisation is essential to facilitate cross-border public procurement projects, simplify processes, foster competition and set unified standards.[14] As part of the reform, national regulatory hubs should be introduced to provide clear and accessible guidance on product-specific regulations and rules relating to the Directive, but also the CPR, the EPBD and the ESPR should be part of the reform.

Implementing product-specific guidelines, especially for high-CAPEX materials like flat steel, would support technological transitions in the steel industry, such as the shift to DRI-EAF. Additional reforms should mandate pre-demolition or strip-out audits in public projects to enhance material reuse, recycling, and waste reduction, fostering a circular economy. Improved data-sharing across companies and Member States would drive a competitive race to the top. The reform of the Directive should be accompanied by an EU Skills Plan for capacity-building in procurement. This should include training in whole-life cost assessments and GPP, in close collaboration with UNIDO and city-led initiatives such as C40, ICLEI and Eurocities, in order to shift the administration culture from price-only to lifecycle costing.

Adopt product-specific standards coupled with evolving Lifecycle Carbon Limits

The EU should further encourage Whole Lifecycle Carbon (WLC) caps and Life Cycle Assessment (LCA) approaches to decarbonise steel for sectors such as construction and automotive. By setting progressively lower emission thresholds, these standards can guide infrastructure, consumer products, and other industrial sectors toward emissions reductions targets, while allowing for technological neutrality by enabling material

[12] Permitted by the LESS.

[13] Pushed by ore-based steelmakers, scope 4 emissions represent "avoided emissions", a voluntary metric introduced by the World Resources Institute that covers avoided emissions occurred outside of a product's life cycle or value chain but as a result of the use of that product. Intended to prioritise the use of virgin materials over recycling, the inclusion of scope 4 emissions would constitute a significant instance of greenwashing and undermine efforts to advance a more circular economy in Europe (Young-Ferris, Malik, Calderbank, & Jacob-John, 2024).

[14] The EU Level(s) framework currently only covers assessment and reporting but is not a certification system similar to the US LEED and the UK BREEAM ones, the latter being often used even in the EU, given the absence of an EU certification. The German Sustainable Building Council could be a starting point here. Expanding the Level(s) framework into an EU-wide certification system, akin to LEED or BREEAM, would enhance uniformity across the EU's sustainable building initiatives. A network of accredited third-party assessors and a tiered scoring system could incentivise the adoption of sustainable materials while promoting a "race to the top" in construction practices. A Sustainable Materials Passport aligned with EN 15978 and WLC limits would also provide transparency and facilitate cross-border material reuse in public projects.

competition with other materials. Adopting an eco-score combining energy efficiency and the PCF of a car's main components will ensure visibility for consumers and genuine emissions reductions. In the case of construction materials, comprehensive whole life cycle regulations for buildings need to be complemented with ambitious EPDs that further ensure the derisking of business investments in material decarbonisation. The CPR can be strengthened by establishing transparent, science-based EU-wide standards on key environmental indicators, including recycled content and embodied carbon. Transparent data disclosure through EPDs and PCFs should be prioritised to ensure consistent reporting of CO_2 emissions, circularity, and toxicity across product life cycles. Executive Vice-President for Prosperity and Industrial Strategy, Stéphane Séjourné, should, in collaboration with Commissioner-designate for Implementation and Simplification Valdis Dombrovskis, take a leading role in ensuring these legislative elements are coherent and ideally complementary, working toward unified goals and providing predictability for all sectors involved. This leadership should include active engagement with affected stakeholders, ensuring that feedback from industry and civil society alike is integrated to streamline processes.

VII.

THE GLOBAL DIMENSIONS OF STEEL DECARBONISATION

A. TRADE-RELATED TENSIONS IN THE STEEL SECTOR

As a heavily traded material that is important as a building block for all sectors of the economy, steel is a material with significant implications for global trade relationships. **Excess capacities distorting the global market by pushing prices down, estimated by the OECD to be 543 Mt in 2023** (Nakamizu & OECD Steel Committee, 2024)**, are at the heart of trade tensions in the steel sector**. The decrease in domestic demand for steel in China due to a slowdown in the real estate market has increased the supply of steel internationally in the form of exports (Nakano, 2024). This has exacerbated the problem of excess capacity since capacity growth in excess of demand conditions leads to falling prices (de Carvalho & Nakamizu, 2024).

In recent times, the steel industry in Europe has called for defensive trade instruments, such as anti-dumping, anti-subsidy and safeguard tools to counter global excess capacity in the steel sector (IndustriAll and EUROFER, 2024). Similar demands have been made by political actors from Germany, who have additionally sought the enforcement of a minimum price for steel imports (CDU/CSU-Gruppe in der EVP Fraktion im Europäischen Parlament, 2024). The re-election of Donald Trump in the United States (US) has brought back concerns around tariffs in the EU, particularly as the negotiations between the United States and the EU on a Global Arrangement on Sustainable Steel and Aluminium (GASSA) under the administration of President Joe Biden had stalled (László, 2024). At the same time, trade partners, particularly from the BASIC (Brazil, South Africa, India, and China) countries, have characterised the CBAM as a unilateral trade barrier, violating the principle of common but differentiated responsibility (South African Government, 2021), with some reportedly contemplating retaliatory action (Yin, 2024).

With a view to countering global excess capacity for steel production, in 2018, US President Donald Trump imposed a 25% tariff on steel articles imported into the United States under Section 232 of the Trade Expansion Act of 1962, citing circumstances threatening the national security of the US (Executive Office of the President, 2018). In 2021, under the administration of President Biden, these were replaced with a system of bilateral tariff rate quotas (TRQs), allowing the EU to export 3.3 Mt of steel into the United States duty-free (Peterson Institute for International Economics, 2021). The TRQs were extended in December 2023 to the end of 2025, but with the aim of finding a long-term solution through the finalisation of a GASSA. These negotiations have been, and with the election of Donald Trump in 2024, they may be jeopardised with the potential reinstatement of the tariffs (Daniel & Reinsch, 2024).

Deliberations at EPICO's workshop focused on the implications and gaps of CBAM, the relevance and role of international cooperation mechanisms, and the conflict between the offshoring of steel production and ensuring of strategic autonomy as regards steel.

B. CARBON LEAKAGE AND THE CBAM

Carbon leakage refers to the phenomenon whereby higher costs of production due to domestic climate policies lead businesses to transfer their production to other countries (European Commission) Concerns around carbon leakage have been central in shaping EU policy on the topic in recent years, with the establishment of the CBAM through a new Regulation (European Union, 2023) (hereinafter "CBAM Regulation") a key development that will impact the steel industry within and outside Europe, with iron and steel included in the list of goods covered by the CBAM.

The effect of the CBAM Regulation will be to phase out the free allocation of emission allowances to industrial entities under the EU-ETS, while simultaneously phasing in the obligations of third-country importers to declare the embedded emissions in their goods and concomitantly surrender the CBAM certificates (Article 6, CBAM Regulation). While certain provisions of the CBAM Regulation have taken effect already or will be applicable from 31 December 2024,[1] the CBAM will apply in its definitive regime from January 1, 2026, when EU importers of goods covered by CBAM will need to declare their embedded emissions and pay the applicable carbon price (European Commission).

As a reaction to the CBAM, a phenomenon known as resource reshuffling, has become a focal point in policy discussions surrounding the CBAM. The phenomenon describes a scenario where products made using clean energy are exported to the EU, while those created with fossil fuels such as coal power will be exported to poorer countries without similar carbon pricing regulations, or for the domestic market (Hancock & Pfeifer, 2024). **When countries with high-carbon production concentrate their exports on low-emission products, this has the potential of leading to a zero-sum effect on global emissions.** Before January 1, 2028, as well as every two years thereafter, the European Commission shall present a report to the European Parliament and to the European Council on the application of the CBAM Regulation and the functioning of the CBAM, which will also include an assessment of the impact of CBAM on international trade, including resource shuffling (Article 30(6)(vi)) (European Union, 2023).

C. CLIMATE DIPLOMACY AROUND LOW-EMISSION STEEL

Even as trade relations have deteriorated in recent years—with Trump's steel tariffs, China and India heavily investing in BF-BOFs, flooding markets like Thailand and Malaysia with cheap subsidised steel, and having exited the Global Forum on Steel Excess Capacity (GFSEC)—international cooperation in the steel sector remains crucial. Despite the difficulties experienced with initiatives like the Global Arrangement on Sustainable Steel and Aluminium (GASSA), collaboration can still play a key role in facilitating knowledge sharing, coordinating R&D efforts, establishing common decarbonisation rules and roadmaps, providing policy guidance, and improving access to critical technologies (Kumar, et al., 2023; Oberthür, Khandekar, & Wyns, 2021; Otto & Oberthür, 2024; Åhman, Nykvist, Morales, & Algers, 2023). However, **international climate diplomacy as a component of industrial decarbonisation policy has remained underdeveloped** as part of EU policy (Kumar, Klimaklub als Teil einer ganzheitlichen Industrieagenda voranbringen, 2023). The need for international partnerships

[1] The initial phase of the CBAM Regulation between 1 October 2023 and 31 January 2025 is described as the "transitional phase" (European Commission, 2024a).

is also underscored by the need to find international partners for green hydrogen to decarbonise the steel sector. **With growing attention to the competitiveness of EU energy-intensive industries, EU policy increasingly acknowledges the importance of industrial decarbonisation's international dimension. The Draghi Report emphasises international alliances, global climate standards, and joint efforts to decarbonise and address non-market excess capacity, including through initiatives like the Climate Club** (European Commission, 2024e). Stakeholders at EPICO's workshop also emphasised the role of climate diplomacy in connection with knowledge-sharing and support for third countries seeking to establish emissions trading systems, particularly driven by the phasing-in of the CBAM.

Efforts for greater international cooperation in the steel sector are also underway through a variety of initiatives, such as LeadIT and the Breakthrough Agenda, with the latest being the Climate Club.

The Climate Club consists of 43 member countries, and describes itself as a "leading high-ambition intergovernmental forum for exchange on industry decarbonisation", with an initial focus on the emission-intensive sectors of steel and cement (Climate Club, n.d.). Notably, China and India are not members of the Climate Club.

Some industry and academic stakeholders at the EPICO workshop highlighted a "surplus" of steel-focused efforts, the "fatigue" caused by their proliferation, and the need to streamline tasks, set clearer priorities, and promote greater institutionalisation. Indeed, the number of international institutions focused on the decarbonisation of emission-intensive industries has grown in the 2020s, with one study putting the number at 30 at the end of 2023 (Otto & Oberthür, 2024). At the same time, binding sectoral emission reduction targets and rules to address competition and carbon leakage have remained elusive in the international efforts to address emission-intensive industrial sectors (Otto & Oberthür, 2024). The polarising nature of discussions surrounding steel highlight the challenges of achieving consensus in the sector. For example, negotiations on a bilateral agreement on steel and aluminium between the EU and the USA (the Global Arrangement on Sustainable Steel and Aluminium (GASSA)), who are traditional allies, have been stalled due to differing visions and priorities (Unger & Quitzow, 2024). The Climate Club established at COP28 appears to be well-positioned as a plurilateral format to take discussions forward on the decarbonisation of the steel industry.

Figure 10: Members of the Climate Club (Source: Climate Club Website)

At the UNFCCC Conference of Parties (COP 29) in Baku in November 2024, the members of the Climate Club in their Joint Statement noted that it would deepen the conversation, *inter alia*, on "*risks related to market fragmentation and the continued installation and maintenance of new capacities that do not* *meet current market demand in hard-to-abate sectors – notably, steel, cement, aluminium, and chemicals – which would be incompatible with the transition towards net zero"* (Climate Club, 2024). Additionally, emphasis was placed on "adopting definitions in domestic polices to support the development and scale-up of lead markets" while highlighting the need to strive towards interoperability in the standards, methods, and threshold values, and aligning positions on threshold values (Climate Club, 2024). COP29 also saw the launch of the Global Match-Making Platform, a key support mechanism of the Climate Club that "leverages international cooperation, finance and technology to support countries to transition smoothly to zero and low-carbon industrial products and practices aimed at achieving the goals of Paris Agreement" (Global Matchmaking Platform, n.d.). This platform aims to support emerging and developing economies in reducing their industrial emissions by connecting them with financiers, technology developers, and experts from around the world.

In order to be successful and set itself apart from other initiatives in the sector, the Climate Club requires greater institutionalisation in its processes, and a clear roadmap with objectives for accelerated steel decarbonisation, and pledges from its member countries. Additionally, it should ensure membership from a critical mass of industrialising, emerging, and least developed economies, whose steel demand is expected to rise exponentially, making them important stakeholders for an initiative with a focus on steel decarbonisation (Bataille, Stiebert, & Francis, 2024), and in particular China and India, who are key to reducing steel emissions worldwide. International partnerships for green hydrogen and Hot-Briquetted Iron (HBI) could be a potential focus area for the Climate Club (Kumar, et al., 2023). The Climate Club should offer clear incentives for countries to join. The Global Matchmaking Platform could offer a step in the direction.

After building initial trust and goodwill through a focus on partnerships, the Climate Club could explore discussions on more contentious issues (Kumar, et al., 2023). This could include the challenges posed by CBAM, as well as other contentious issues, such as the aforementioned excess capacity in BF-BOF steelmaking. The German concept of the LESS steel label mentions the potential to use the Climate Club to discuss labelling and standards on a global level, underscoring the importance of standards and labels as a concrete area for future deliberations in the Climate Club (Bundesministerium für Wirtschaft und Klimaschutz, 2024).

"In order to be successful and set itself apart from other initiatives in the sector, the Climate Club requires greater institutionalisation in its processes, and a clear roadmap with objectives for accelerated steel decarbonisation, and pledges from its member countries."

D. THE POTENTIAL EVOLUTION OF THE STEEL SUPPLY CHAIN

The decarbonisation of EU's steel industry will require access to green hydrogen and affordable renewable energy, as outlined in Chapters I and II of this paper. Since these are expected to be in short supply in the EU at least in the short-term, the EU will need to rely on hydrogen imports for the EU for the decarbonisation of emission-intensive sectors such as steel, as acknowledged in most EU Member States' national hydrogen strategies and industrial policies (IEA, 2019). The need for steel production facilities, traditionally located close to their fossil-fuel-based energy sources, to access low-cost renewable energy is expected to influence global energy geopolitics (Hussain, Colak, & Gretener, 2024). Steel supply chains have already started shifting toward regions with abundant cheap renewable energy and iron ore (IEEFA, 2023). The creation of green iron in the form of HBI, involves compressing porous DRI pellets into larger and higher-density briquettes, with reduced surface area (Flesch, et al., 2024). **HBI offers advantages in comparison to DRI, since it is less reactive and compacted, enabling better storage and transportation over long distances** (Lopez, Galimova, Fasihi, Dmitrii, & Breyer, 2023). Additionally, trade in HBI allows transferring electricity and hydrogen consumption where it is cheapest and cleanest (Bataille, Stiebert, & Francis, 2024).

The cost of global steel production is going to increase with a shift from the conventional BF-BOF steelmaking route to H2-DRI, as well as the costs of implementing CCS (Bilici, et al., 2024). **The lower production cost of renewable energy in non-EU countries may lead to competitive disadvantages for ironmaking in Europe, partly because of the high costs of transporting hydrogen to Europe** (Lopez, Galimova, Fasihi, Dmitrii, & Breyer, 2023). There are already initial estimates of the cost savings associated with the so-called "renewables pull" – defined as the "*pull factor for industrial production triggered by exceptional renewable energy conditions in certain regions of the world*" (Samadi, Fischer, & Lechtenböhmer, 2023). The coincidence of available iron ore and cheap renewable energy, for example, in countries like Australia, Brazil, South Africa, Namibia, and Sweden (Verpoort, et al., 2024), may trigger a change in the iron and steel supply chain.

Recent literature shows that relocating DRI/HBI production to countries with iron ore reserves and more readily available green hydrogen (characterised as "sweet spots") could lead to significant savings in low-emission steel production costs and therefore reduce the green premium for low-emission steel (Bilici et al., 2024; Devlin & Markkanen, 2023; Flesch et al., 2024; Gielen, Saygin, Taibi, & Birat, 2020; Rystad Energy, 2024; Trollip, Berghmans, & Khandekar, 2024; Verpoort, Gast, Hofmann, & Ueckerdt, 2024). The exact degree of cost savings would depend on the EU Member State and the extent of outsourcing, which could range across a spectrum of importing hydrogen, green iron in the form of HBI, and importing semi-finished products.

A recent analysis by the Potsdam Institute for Climate Impact Research (PIK) finds savings ranging between 18% and 32% (based on an electricity price range between EUR 40 per MWh and EUR 70 per MWh) through relocation from renewables-poor

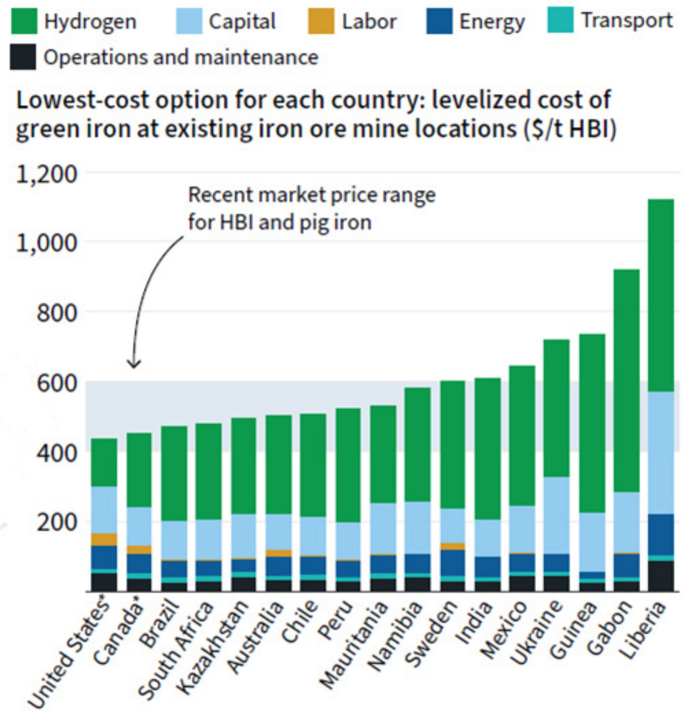

Figure 11: Levelised cost of green iron at existing iron ore mine locations (Flesch, et al., 2024)

to renewables-rich countries in the case of HRC (a semi-finished steel product), making hydrogen imports aimed at continuing existing production patterns risky and costly in comparison (Verpoort, Gast, Hofmann, & Ueckerdt, 2024). An analysis of the potential shift of steel production from the EU to South Africa suggests lower input costs for EU steelmakers, alongside economic gains and benefits for South Africa's economy and decarbonisation pathway (Trollip, McCall, & Bataille, How green primary iron production in South Africa could help global decarbonization, 2022; Hermwille, Khandekar, Wyns, Ramiro, & Trollip, 2019). Countries with ample renewable energy resources (e.g., the MENA region, Australia) are shifting their focus from green hydrogen exports to HBI, recognising that domestic production of DRI or HBI may be more efficient (Basirat & Nicholas, 2023), particularly in view of the substantial energy losses (30–40%) associated with liquefying hydrogen (Parkes, 2024).[2] A more moderate reshuffling within the EU also warrants closer examination, especially given the higher availability of renewable energy in southern Europe (Lopez, Galimova, Fasihi, Dmitrii, & Breyer, 2023), the coincidence of iron-ore reserves and higher renewable energy potential in Sweden, and the advantage of certain industry clusters located close to ports (Lot & Frida, 2024). **The emergence of the aforementioned "sweet spots" could motivate the "friendshoring" of parts of the steel value chain within and outside the EU,**[3] and even to multiple locations, particularly since trading in low-intensity HBI from multiple suppliers provides greater flexibility and security (Bataille, Stiebert, & Francis, 2024).

The debate is intensifying over whether steelmakers can produce competitive green steel in Europe, despite receiving billions in subsidies (over EUR 7 billion for Germany alone) to support this endeavour, given the high costs of green hydrogen—an issue highlighted, for example, by recent statements from Arcelor Mittal (Parkes, 'Green hydrogen is too expensive to use in our EU steel mills, even though we've secured billions in subsidies', 2024). ThyssenKrupp is also reportedly reconsidering the building of its H2-DRI plant in Duisburg, Germany, for which it has already received EUR 500 million in subsidies, out of a total subsidy package of EUR 2 billion (Wermke, Murphy, & Olk, 2024). The challenges of transitioning to green steel have been made further evident by announcements in November 2024 by ThyssenKrupp that it would reduce its workforce from 27,000 to 16,000 within six years (Deutsche Welle, 2024), and by Arcelor Mittal that it would be pausing some of its earlier declared plans to build DRI plants and convert BOFs to EAFs (Taylor , 2024).

The effects of the renewables pull are already being witnessed in the steel business, within and outside the EU. For example, Stegra's future projects, potentially in Portugal, Canada, and Brazil, will be "*characterized by locations where the company's customers need help with value-chain decarbonization and which offer abundant access to renewable electricity and strong grid connections*" (Stegra, 2024). Backed by the German federal government, HyIron, owned by a consortium of German and Namibian players including the TS Group, LSF Energy and CO2Grab has built an H_2-DRI plant in Namibia, scheduled for commissioning in Q4 2024, with plans to switch to green

[2] The primary limitation of using liquid hydrogen for storage and transmission is the substantial energy loss, with liquefaction alone consuming approximately 41.5% of the hydrogen's energy content, based on its lower heating value (LHV) of 33.33 kWh/kg (with an average energy requirement of 13.83 kWh/kgLH$_2$). Additionally, boil-off losses during storage, which can range from 1–5% per day, further compound the inefficiency, leading to potential total energy losses exceeding 50%, especially with prolonged storage durations (Zhang, et al., 2023).

[3] The term "friendshoring" refers to an import strategy to source critical industrial inputs from geopolitical allies to reduce geopolitical risks to domestic supply chains to a minimum (Fragkos, Hermwille, & Fragkiadakis, 2024).

hydrogen (Climate Fund Managers, 2024). ArcelorMittal has already announced imports from its newly acquired DRI site in Texas, and an agreement with a Mauritanian iron ore mining company (ArcelorMittal, 2022; ArcelorMittal, 2022).[4]

Meanwhile, **steelmakers outside the EU are already advancing in export-oriented low-emission steel production**. Egypt's Ezz Steel and Tosyalı in Algeria are producing 5 Mt of DRI with natural gas annually, with plans to switch to green hydrogen (AISU, 2024; Tosyalı Algérie). Volkswagen signing an MoU with Oman-based Vulcan Steel (Volkswagen Group, 2024) shows that offtakers of low emission steel are not waiting for EU ore-based steelmakers to fully adopt DRI, as steel remains globally traded.[5] Meanwhile, low-emission competitors in the US and Turkey adopted DRI-EAF technology back in the 1990s, while leading European steelmakers are still in the early stages of deploying DRI for steelmaking (ThyssenKrupp in Duisburg in 2026, ArcelorMittal in Dunkirk in 2027).

The debate on industrial resilience in the EU, particularly in Germany, often pits offshoring against competitiveness, without adequate analysis of the resultant economic and environmental benefits in the form of reduced emissions across the value chain. Importing green iron ore as HBI could reduce emissions more effectively than importing both green hydrogen and iron ore.[6] Many traditional steel manufacturing locations in the EU (for example, in Germany) suffer from the geographical disadvantage of lacking access to iron ore and cheap renewable energy, both of which are essential for ore-based steelmaking. But even if traditional steel-making countries start to import green iron in the form of HBI, they may still be able to maintain a substantial part of their skilled workforce, since the downstream jobs associated with steelmaking and manufacturing make up a substantial share of steel sector jobs (Flesch, et al., 2024).

As per one analysis from Germany, the production of pig iron, steel and products of primary processing accounted for EUR 9.1 billion of gross value added and 121,000 jobs in 2019, in contrast to downstream economic sectors using steel products (such as metal production, motor vehicles, mechanical engineering, construction, foundry production and electrical equipment) accounting for EUR 467 billion of gross value added and 5.6 million jobs (Verpoort, et al., 2024). While downstream industries in Germany which require steel will be affected to some degree by the relocation of the production/processing of steel (with the degree of impact depending on the degree of relocation), they are likely to continue to have a base demand for domestically produced steel that cannot be easily substituted by foreign imports (Verpoort, et al., 2024; Bähr, et al., 2023).

In light of the developments in the steel industry highlighted above, it appears that

4 In 2016, voestalpine explained that "average industrial gas prices in Austria over the longer-term are around three times as high, and electricity prices around twice as high as those in the USA. The annual costs of operating an identical DRI furnace in Austria would be around EUR 200 million higher than in Texas."

5 Volkswagen AG has signed a Memorandum of Understanding (MoU) with Vulcan Green Steel, a subsidiary of the Jindal Steel Group, to source low-carbon steel for its automotive production starting in 2027. Vulcan's facility in Duqm, Oman, currently under construction and slated to commence operations in 2026, will initially utilise natural gas before transitioning to green energy, aiming to reduce carbon emissions by 70% upon completion of the switch.

6 For example, despite Germany's financial strength and its 13 blast furnaces (producing an average of 43 Mt annually from 2010-2018), it lacks surplus renewable electricity and fossil-free hydrogen. Reducing the carbon intensity of the electricity mix and addressing hydrogen infrastructure gaps are critical challenges (Harpprecht, Naegler, Steubing, Tukker, & Simon, 2022, p. 9). Achieving this transformation will require a very big shift similar to the solar PV boom.

retaining the production of iron and steel within the EU in its current form could come at higher costs, for which it must be willing to commit substantial public funds through continuous long-term subsidies to close the gap. Many steel companies in the EU have already benefited from large subsidies, despite scepticism about whether this will lead to cost-competitive green steel in the short or medium-term. To counter the pull of cheaper green iron and steel produced outside the EU, and to retain competitiveness, the EU will likely need to directly support domestic green steel production through the use of public funds. These funds may be required not only during an initial transitional phase to accelerate the transition when the technology required for H2-DRI is in a nascent stage, but also in the long run, when the effects of the renewables pull will be palpable in the form of cheaper production of green iron and steel elsewhere in the world.

Financing a shift to DRI for the entire European steel industry through subsidies seems infeasible, and also poses the danger of diverting funds from other initiatives with better prospects for climate change mitigation and potentially lower costs or higher economic growth (Lot & Frida, 2024). As reducing electricity costs becomes a priority in the EU (an issue highlighted in the Draghi Report), public funds will likely be needed to lower these costs, requiring careful decisions on the allocation of these funds to support industrial decarbonisation, and prioritisation of the allocation of funds to certain parts of the value chain. Here the nature and degree of public financing required for bringing down energy prices, and decoupling them from gas, will be relevant considerations. The potential for market distortion within the single market due to these subsidies should not be underestimated.

The evolving supply chain reshuffle also has social implications for the employees of the steel industry in the EU. Until now, policymakers have hesitated to embark on this discussion. But as questions of resilience and competitiveness increasingly gain prominence in the EU industrial policy agenda, discussions around the ground reality and international trends in the steel industry will need to be factored into the decision-making on future policies, and in particular, the allocation of public funds. The changing iron and steel patterns could impact countries' decisions on different parts of the value chain, which could require workforce transition support on a sub-regional level (Flesch, et al., 2024).

Experts studying the renewables pull have highlighted the urgent need to engage in a scientifically informed broad societal debate about the role of a country in global industrial production that includes a diversity of perspectives from RE-scarce and RE-rich countries on industrial relocation based on the renewables pull (Verpoort, Gast, Hofmann, & Ueckerdt, 2024). This would include an assessment of the most efficient use of hydrogen and public money for emission-intensive industries, and in particular, which part of the value chain would generate most economic value and jobs (Verpoort, et al., 2024). Here, the role of "friendshoring" to renewables-rich countries in the north and south of Europe and to partner countries outside of the EU will be an important consideration. An additional consideration would be the energy security concerns arising from the need to import hydrogen versus the productive capacity security concerns arising from the need to reliably source HBI for steelmaking with reduced emissions (Torres-Morales, Maltais, & Gong, 2024). Further, policy frameworks in the host countries and funding mechanisms will also be relevant factors for the success of such projects (Muslemani, Craen, Butterworth, Duma, & Lambert, 2024). **Lastly, strategic security concerns will also play an important role in the discussion on**

resilience in the EU, for example, with the need to retain the domestic production of defence equipment, necessitating the retention of a certain degree of domestic steel production (Verpoort, et al., 2024; Lot & Frida, 2024).

E. POLICY RECOMMENDATIONS FOR THE EU

Engage in focused climate diplomacy to address steel sector decarbonisation

The Climate Club has commenced its operations after its official launch in 2023, and has positioned itself as a plurilateral body focused on increasing the global ambition on decarbonising emission-intensive sectors. Future EU policy should provide greater attention to the international dimension of industrial decarbonisation. A concerted international climate diplomacy package should address the potential for international partnerships and cooperation. In this context, the potential of the Climate Club should be fully utilised as part of an EU policy toolkit to enhance dialogue on important issues pertaining to steel decarbonisation. As an intergovernmental body with 43 members, the Climate Club can lead to the advancement of discussions requiring international cooperation such as the setting of standards for low-emission steel, and upon building trust and goodwill, to address more contentious issues such as carbon leakage and overcapacity.

Concrete future steps on the Climate Club agenda should include seeking the endorsement of its members on steel decarbonisation pledges and pathways with clear timelines and milestones, as well as gaining China and India as members of the Climate Club for meaningful discussions on steel decarbonisation.

Avoid using the CBAM to solve trade issues and strengthen it for decreasing steel industry emissions worldwide

The CBAM must focus on preventing carbon leakage rather than addressing broader trade issues. While dumping and unfair competition should be tackled by the European Commission, CBAM cannot regulate entire foreign production or fully protect against less carbon-intensive imports. Using CBAM as a retaliatory trade tool risks undermining its acceptance by trade partners (Saussay, 2024). Instead, efforts should improve its effectiveness, close loopholes, and recycle revenues to assist least developed countries (LDCs),[7] ensuring the system is efficient and less burdensome. Enhancing scrap treatment within the CBAM framework could significantly reduce steelmaking emissions. The phase-out of free allocations and CBAM's implementation may boost EAF competitiveness and recycling efforts (Rossetto, 2023; Sandbag, 2022; Sandbag, 2024), with the 2028 CBAM review crucial to address resource shuffling.

Minimising red tape and supporting EU importers in compliance will be critical. The EU should assist exporters with CBAM-compliant PCF and EPDs and invest in carbon accounting and capacity building to help exporting countries meet requirements. Revenue recycling to develop embodied carbon accounting systems could improve CBAM acceptance in developing nations (Brandi, 2021) and reduce its perception as punitive.

[7] In its original report on the CBAM in 2021, the European Parliament's Committee on the Environment, Public Health and Food Safety called for the mechanism to avoid hampering the sustainable development of least developed countries and to consider their specific circumstances (European Parliament, 2021).

Policy discussions on resilience and competitiveness should take into account the evolving supply chain in the steel sector

In the EU, policy discussions on industrial policy in general, and steel decarbonisation in particular, have started focusing on questions of resilience and competitiveness. These discussions will need to be cognisant of the new ground reality and international trends in the steel industry, for example, arising from the effects of the renewables pull, and expected shifts in the supply chain with renewables-rich regions increasingly appearing to favour the export of HBI instead of green hydrogen due to their lower costs and emission profile. The steel sector transition in the EU relies extensively on the supply of green hydrogen, which requires public support in a ramp-up phase. Many steel-makers in the EU have benefited from large subsidies. At the same time, doubts are already being expressed on the cost competitiveness of European green steel using green hydrogen, owing to factors such as the challenges of importing green hydrogen and the high energy costs in the EU. Policy measures to bring down the price of electricity for industry are also gaining prominence, and might also require the allocation of public funds.

Future-oriented discussions on EU steel decarbonisation policy must simultaneously address the reality of shifting supply chains while assessing the future competitiveness of European steel, the use of public money for assisting industrial decarbonisation most efficiently along the value chain, the priorities for resilience (including self-sufficiency in strategic sectors), the retention of production of strategic goods, and the just transition of the workforce affected by imminent changes. The benefit of "friendshoring" to renewables-rich regions in the north and south of Europe and to partner countries outside of the EU should also be considered by policymakers.

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