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The geography of green iron and steel: New opportunities for Europe and North Africa

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Steel – accounting for 8% of global emissions – is a critical sector in which the technology exists to decarbonise production. The transition to green steel production, therefore, is an important cornerstone of Europe's climate neutrality ambitions. Yet, high energy prices, delayed hydrogen projects and competitive pressures have left European steelmakers at a crossroads. This paper investigates how complementing domestic steel decarbonisation with imports of hydrogen-derived Hot Briquetted Iron (HBI) from North Africa could support the greening ambitions.

Moreover, such a strategy could alleviate pressures on European steelmakers from high energy prices, diversify supply chains and strengthen Euro-Mediterranean political and economic integration. For North African countries, it represents an opportunity to attract green investment, develop local hydrogen economies and access the EU's greening market. However, political sensitivities around industrial job security in Europe and the challenges of financing green industries in North Africa complicate collaboration.

The analysis concludes that a balanced approach, integrating local and imported decarbonised steel inputs, can enhance competitiveness, create regional synergies, and scale up global markets for green industrial products. Key recommendations include fostering interdependence through policy alignment, derisking initial investments and ensuring equitable benefits for all stakeholders.

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Acronyms

BF	Blast Furnace
BOF	Basic Oxygen Furnace
CBAM	Carbon Border Adjustment Mechanism
CO2	Carbon dioxide
COVID-19	Coronavirus Disease 2019
DRI	Direct Reduced Iron
EAF	Electric Arc Furnaces
EIIs	Energy Intensive Industries
ETC	Energy Transitions Commission
ETS	Emissions Trading System
EU	European Union
EVs	Electric vehicles
FDI	Foreign Direct Investment
GDP	Gross domestic product
H2	Hydrogen
HBI	Hot Bricketed Iron
IMF	International Monetary Fund
MoU(s)	Memorand(a)um of Understanding
SNIM	National Industrial and Mining Company (*Société Nationale Industrielle et Minière*)
TWh	Terawatt-hour
US	United States (of America)

1. Introduction

Decarbonising energy-intensive industries is critical to achieving climate neutrality within a reasonable timeframe. Energy Intensive Industries (EIIs) are responsible for around 25% of global emissions, and 15% of European emissions (UNECE 2024; DG-RTD 2023). Yet many EIIs are also hard-to-abate sectors, meaning they require major technological changes and significant capital investments to decarbonise. Steel – accounting for 8% of global emissions (Agora Industry 2023)[1] – is a critical sector in which the technology exists to decarbonise production, but progress to effectively bring down emissions worldwide remains off track due to several reasons (Torres Morales and Birch 2024; Agora Industry 2023).

Decarbonising steel requires shifting from conventional Blast Furnace (BF) and Basic Oxygen Furnace (BOF), powered by coal to producing Direct Reduced Iron (DRI) using green (or low-carbon) hydrogen (H2) and further processing into steel in Electric Arc Furnaces (EAF), powered by renewable electricity (see figure 1). This shift is not only technologically complex, it also entails a move toward large-scale use of green hydrogen and affordable renewable electricity, neither of which are currently easily available in major industrial centres in Europe.

The reliance of green steel production on green hydrogen and renewable electricity also calls for re-evaluating the geography of industrial production. European steel producing regions today may not be as well placed to house the full process of iron and steel production as they were for BF-BOF with (imported) coal.[2] While EAF adoption is on the rise, high energy prices and distance from large-scale hydrogen production risk delaying the shift to DRI, or require an extremely costly (subsidised) decarbonisation process. North African countries[3] in turn are positioning themselves as major green hydrogen suppliers, and are looking to attract investments in hydrogen-derived products, ranging from molecules (ammonia, methanol) to intermediary products like Hot Briquetted Iron (HBI) produced through DRI with green hydrogen. Other countries with more favourable renewable energy conditions, including Australia and Brazil are also rapidly positioning themselves to become major players in the hydrogen economy, both for molecules and industrial goods.

There is a theoretical, technical and political case for European Union (EU) imports of green energy or hydrogen intensive intermediary goods from developing countries in the EU's Southern Neighbourhood. For Europe, it can bring down the costs of decarbonisation, make more optimal use of renewable energy endowments, diversify supply chains for a more secure access to key industrial products, and strengthen the EU's Mediterranean alliances through job creation and industrialisation. For North African countries it can spur investments in local

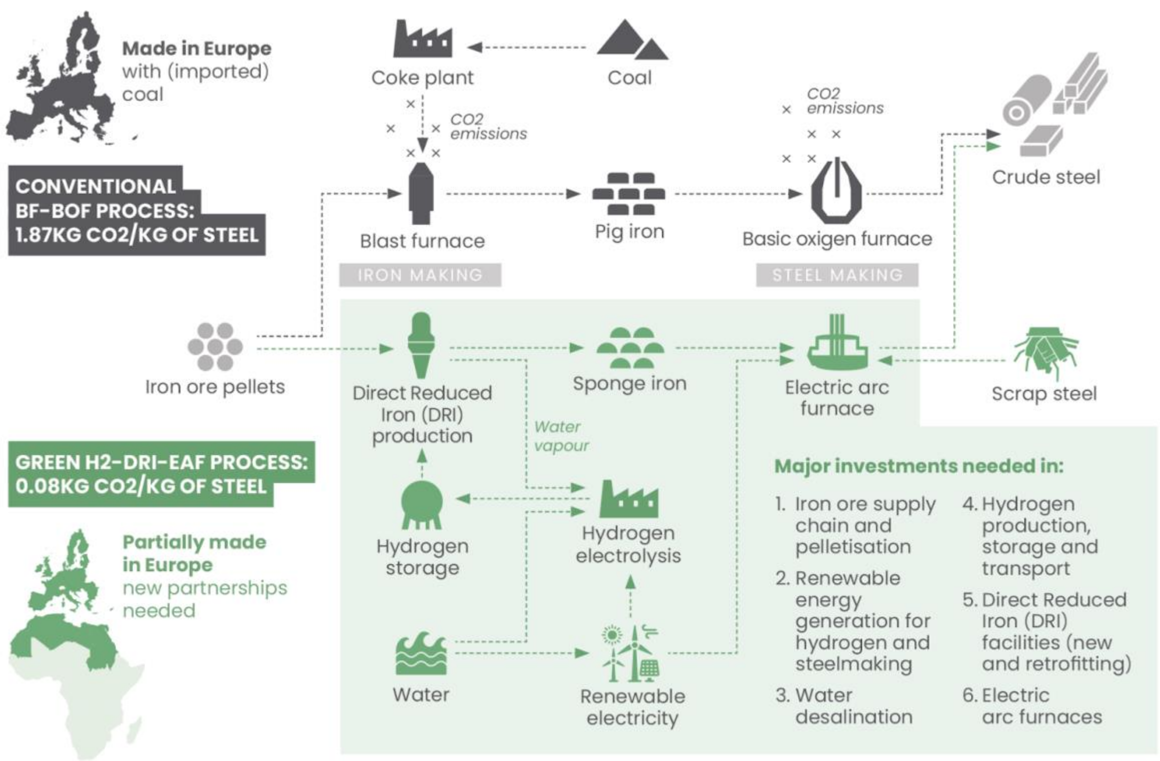
[1] It accounts for 5% of the EU's total emissions (Torres Morales et al. 2024). In China, South Korea and Japan it is 15%, 14% and 12% respectively (Copley 2024).

[2] Most current European steel production sites are located close to where coal was extracted historically, but shifted to imports when mines were depleted or became less commercially viable within Europe.

[3] This paper uses North African countries interchangeably with Southern neighbourhood countries. It includes Mauritania even though it is strictly speaking not a Southern Mediterranean country because in terms of hydrogen economy objectives, it shares a number of critical features, including proximity to Europe, exceptional renewable energy potential and a long coastline, in addition to being a major iron ore exporter.

hydrogen economies, building competitive access to a greening EU single market covered by the Carbon Border Adjustment Mechanism (CBAM), and develop a long-term pathway for green industrialisation and economic transformation. On paper, therefore, the EU's needs (green energy, decarbonisation of industry, competitiveness), and North Africa's ambitions (green industrialisation, cheap renewable energy production) make a strong case for industrial partnerships where North African needs for financing and other resources can be met by the EU's ambition to forge strong international partnerships.

Figure 1: BF-BOF and H2-DRI-EAF routes for iron and steel production



Source: authors based on Hybrit

At the same time, this is a deeply complex and politically sensitive issue, especially in Europe. The technical difficulty and costs associated with decarbonisation fuel fears of further de-industrialisation (EuroStat 2024a; ETUC 2024). Steel is a historically strategic industry for Europe. With a turnover of €152 billion, the industry directly employed some 303,500 workers in 2022, producing 126 million tonnes in more than 500 sites spread across the bloc (EUROFER 2023). Yet it is also a sector in crisis, with both output and employment steadily declining over the past decade (EUROFER 2024), in part due to substantially higher energy costs in Europe than in other major industrial centres. Industries and trade unions are calling for subsidies and trade protection in order to maintain European competitiveness (Eurofer and IndustriAll 2024). Politically, further job loss in the iron and steel industry is seen as a major risk, not only for support for the green transition agenda, but because rightwing extremist groups have been successfully capitalising on the cost-of-living crisis across Europe.

North African countries on the other hand have significant renewable resources. Yet, they have struggled to attract the necessary investments needed for what is essentially an entirely new and highly capital-intensive industry. Macroeconomic management remains a challenge as countries still recover from the COVID-19 shock with high debt burdens, especially in Egypt. Export-driven projects may create much needed opportunities, but they may also strain social cohesion with few tangible benefits for local communities in a context of high levels of unemployment and relatively scarce water resources. Governance therefore remains a concern with perceived reputational risk for EU firms. Finally, there are several points of tension in relations with the EU.

While European energy intensive industries are clearly under pressure, analysts argue that better collaboration between the EU and countries in the Global South can actually support European industry decarbonisation and competitiveness, as well as supply chain security in the long term (Agora Industry 2024a). Steel is seen as a critical sector in which the benefits of importing intermediary products may outweigh the costs, by increasing efficiency and ultimately the resilience of the sector. Doing so, however, is easier said than done. It requires balancing and complementing domestic decarbonisation with international partnerships (Tagliapietra and Trasi 2024), and a rethink of the geography of European industrial production.

This paper explores the potential and challenges for better integration of steel decarbonisation and industrialisation objectives between Europe and (North) African countries. It highlights not just the complexity of green steel as a sector, but also the context in which the EU will have to establish industrial partnerships.

It concludes that:

1. Importing hydrogen-derived products like HBI from North Africa can complement Europe's domestic decarbonisation, reduce costs, and secure industrial competitiveness while preserving jobs.
2. Euro-Mediterranean partnerships could offer mutual benefits by fostering European supply chain resilience and supporting North African green industrialisation and economic transformation.
3. Political and economic challenges, including fears of European deindustrialisation and barriers to investment in North Africa, will need to be addressed in order to maximise opportunities.
4. A balanced, long-term strategy combining domestic production with regional imports (from North Africa) can enhance decarbonisation efficiency, strengthen industrial resilience, and deepen geopolitical ties.

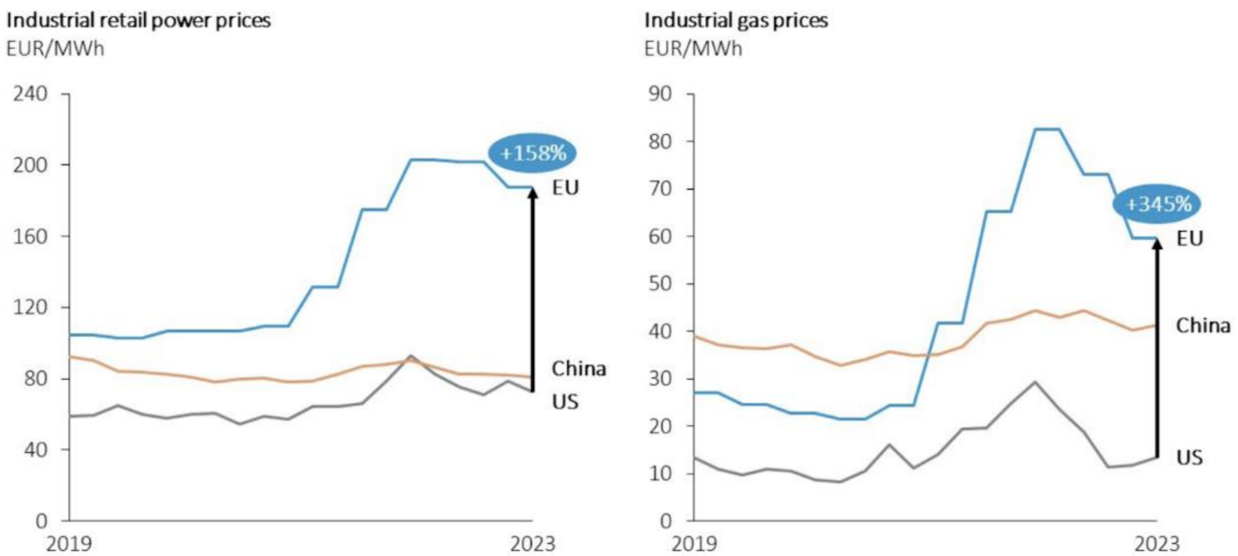
2. Industrial partnerships between the EU and North African countries

2.1. European decarbonisation and international partnerships

European industrial decarbonisation is facing a moment of truth at the end of 2024. The first Ursula von der Leyen Commission shepherded the EU through important legislative changes including the reform of the European Emissions Trading System and a new Carbon Border Adjustment Mechanism. These measures have raised the stakes for the EU's decarbonisation, and are meant to create both incentives and a more favourable environment for decarbonising industries. In the past two years, the EU however, also saw a shift from a regulatory vision on decarbonisation towards an industrial competitiveness driven agenda. Aggressive tax credits and subsidies for green technologies under the 2022 United States Inflation Reduction Act (IRA), and rapid growth in Chinese exports of electric vehicles (EVs) and batteries to the EU, in addition to its established dominance in solar photovoltaics (PV) (Sanzay and Tsang 2024), has led to a recognition of the relative weakness of European industries on the one hand faced with overcapacity and on the other competing against greater spending power in China and the United States (US).

Mario Draghi's 2024 report on the EU's economic competitiveness made a blunt assessment of Europe's dwindling industrial power, citing historical underinvestments, high energy costs and an overall fragmented and complacent industrial strategy (Draghi 2024a). Energy intensive industries have faced significant headwinds, not least since the gas price crisis in 2022 (see figure 2) (Draghi 2024b; Byiers and Medinilla 2024).

Figure 2: Europe's industrial electricity and gas price gap



Source: based on Eurostat (EU), EIA (US) and CEIC (China), 2024. Cited in Draghi 2024a

The EU is preparing a new Clean Industrial Deal in 2025, which is meant to address these shortcomings, but also reckon with the insufficiencies of its industrial policies and conservative state-aid approach from the past. Experts and the climate movement are calling for an ambitious approach, leveraging the full set of tools at the EU's disposal to maintain its targets, including public procurement to create and structure domestic demand, innovative subsidy mechanisms like carbon contracts for difference and dual auction systems (Pisani-Ferry et al. 2024). Yet while European industry decarbonisation remains on the agenda, it is also more fragile than ever before, with European conservatives calling for a more pragmatic approach to European regulations, including for example on the EU's 2035 internal combustion engine phaseout target (Liese 2024; Draft European People's Party (EPP) position paper).

Europe's pressured decarbonisation process is likely to have an effect on partnerships with third countries. The prospect of a green transition has altered the way Europe looks at countries in the Southern Neighbourhood and North Africa, and is spurring investment in major electricity interconnections between Morocco and Spain, Egypt and Greece, Tunisia and Italy, and Algeria and Italy, in anticipation of a major increase in cheap solar and wind power generation in North Africa (Cassetti and Annunziata 2023; Cassetti and Annunziata 2024; Peverieri and Kacher 2024). Similarly North African countries, but also several other African countries (including Namibia) are poised to become major exporters of hydrogen and derivatives to European demand centres (Martin 2024; Dekeyser and Medinilla 2024). Germany, Austria and Italy are working together to develop a pipeline import corridor from North Africa through Tunisia (BMWK 2024), and in late 2024, Egypt and Germany concluded a first international pilot auction under the H2Global facility to deliver close to 400,000 tons of renewable ammonia from Egypt to Europe by 2032 (Pearce 2024).

Energy interdependence, along with security and migration management is one of the main drivers behind the call for a New Pact for the Mediterranean, an attempt to reboot partnerships with North African countries following a decade of political disengagement (de Larramendi and Azaola Piazza 2024). The region, led by Morocco and Egypt is also well positioned to play a connecting role, leveraging market access to the EU, and strong trade relations globally. Overall, global greenfield foreign direct investment (FDI) in manufacturing (including but not limited to EU FDI) in countries like Morocco and Egypt, but also parts of Central and Eastern Europe has been on the rise since the COVID-19 pandemic years (Irwin-Hunt 2024). Within the Southern Neighbourhood, Morocco has emerged as an effective nearshoring destination, building on past investments in port infrastructure, as well as recent growth in automotive manufacturing (Rizzi and Varvelli 2023; O'Farrell 2023). The 2024 Egypt-EU investment conference also sought to present Egypt's potential as an industrial nearshoring hub for European companies (SIS 2024).

The need and potential for industrial partnerships is widely recognised and policy discourse on both sides of the Mediterranean reflects opportunities for nearshoring, and leveraging respective advantages and capabilities, including in energy intensive industries. Yet this is still far from a unified vision for a shared industrial geography. While some see benefits in diversifying imports, sourcing intermediary goods from third countries (Parkes 2024a), others will see any production outside of the EU as a threat (Jäger 2024a). As the commission seeks to strengthen its toolbox for industry transition with the Clean Industrial Deal, much of the focus has been on (1) energy prices, (2) subsidies, (3) finance, and (4) trade policy protections (including CBAM and tariffs).

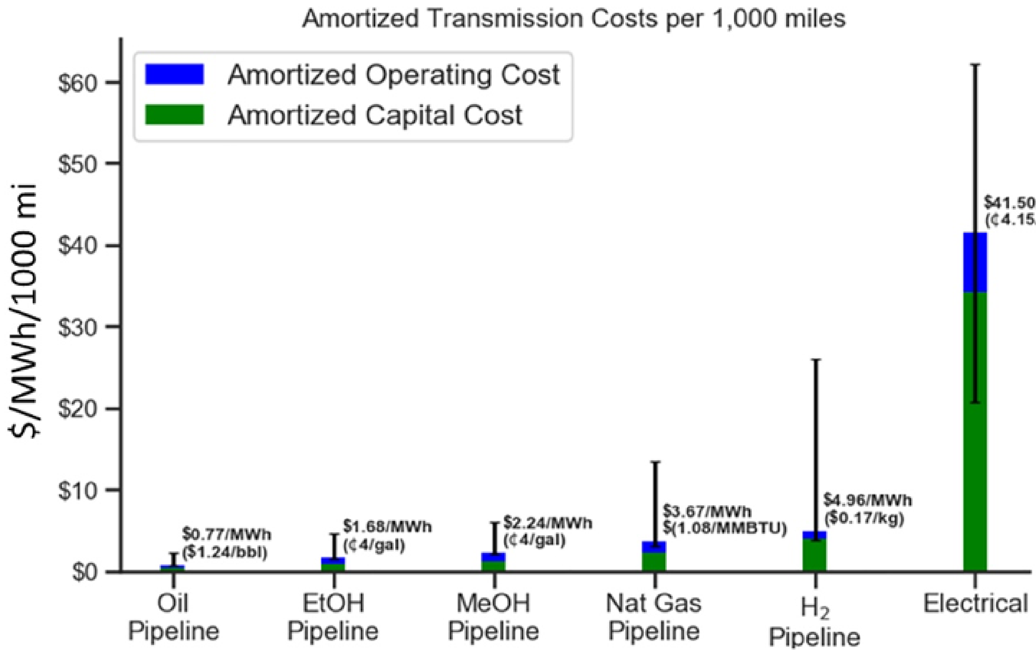
Internationally, several policy initiatives are underway, including a new pact for the Mediterranean, a Trans-Mediterranean energy and clean tech cooperation initiative, and a new generation of Clean Trade and Investment Partnerships (CTIPs) (von Der Leyen 2024). As the EU develops its toolbox for economic foreign policy, however, it will need to balance short term concerns like security of supply and maintaining jobs, with long-term objectives of competitiveness, market access and diversification. The following sections look at how integrating green iron and steel production between the EU and North African countries can be a basis for a more forward-looking industry decarbonisation, building on respective strengths and capabilities to lower costs, and increase economic competitiveness and security.

2.2. A technical and economic case for green iron and steel production in North African countries

Decarbonisation is more than the shift from one energy source to another. It can also alter the geography of energy intensive industries. Europe's major heavy industrial centres were built around easy access to (increasingly) imported fossil fuels.[4] The energy density of fossil fuels is such that they can be relatively easily (and cheaply) transported over great distances. Renewable energy, solar, and wind, as well as new energy carriers and alternative feedstocks like green hydrogen and ammonia can displace the use of fossil fuels, however doing so efficiently and cost effectively requires overcoming the mismatch between (potential) production sites and demand sites. Simply put, the costs of transporting electricity through high voltage direct current (HVDC) transmission lines, or of hydrogen through pipelines over long distances, is a multitude of the cost of transporting oil or natural gas via pipeline (DeSantis et al. 2021).

[4] In 2022, natural gas and other fossil fuels accounted for 48% of final energy consumption in European industries (Eurostat 2024b). This excludes indirect use (e.g., electricity generation, heat).

Figure 3: Transmission costs of different energy carriers per 1,000 miles of pipeline



Source: DeSantis et al. 2021

Clean and cheap energy is unevenly distributed (Jäger 2024). While some European regions are better placed than others, in the longer run, industries may look beyond the EU for the most favourable conditions. Given the inherent loss of approximately 30% of energy, producing these molecules with electrolysis requires substantial volumes of cheap renewable electricity, and therefore space that may not be easily available in Europe. Many African countries have the potential to produce renewable electricity as well as hydrogen and derivatives at highly competitive rates. These renewable-rich countries are increasingly well placed to attract the most energy intensive parts of energy intensive value chains (Agora Industry 2024b).

Iron and steel is a sector with significant potential for pairing the respective comparative advantages of European and North African countries. Decarbonising steel production requires shifting from blast furnaces to DRI production using (green) hydrogen and EAF powered by renewable electricity for making steel. The production of iron from iron ore is easily the most energy intensive part of the process, but in the case of German steel it also accounts for just 4.8% of direct employment (Wirtschaftsvereinigung Stahl 2024).[5] In other countries, with higher EAF adoption, this figure could be even lower. For businesses facing structurally high hydrogen costs (either due to the high cost of renewable electricity or of the transport of imported H2), it may make more commercial sense to import HBI from third countries. Imported HBI can also supplement existing scrap steel processing through EAF, which today accounts for 43% of the EU steel market (Eurofer 2023), as well as early stage European DRI production, which may not be sufficient to meet industrial demand.

[5] Figure for employment in German Blast Furnace operations in 2022 (Wirtschaftsvereinigung Stahl 2024).

Several countries in the wider Middle East and North Africa (MENA) region are potentially well positioned to become major players in green iron and steel production, joining Australia and Brazil, which are generally seen as ideally placed, combining high-grade iron ore extraction, established industries, and excellent renewable energy (and hydrogen) potential. Not only is the MENA region poised to be a major player in green hydrogen production and export, several countries in the region have established DRI production capabilities, which can be (gradually) shifted from using natural gas to hydrogen as a reducing agent (Basirat 2024). The iron and steel sector can also be a major early-stage offtaker for countries looking to position themselves as major hydrogen economy hubs, and is estimated to consume around 1/4th of total hydrogen production by 2050 (Hostert 2024, cited in Basirat 2024).

Across the region, new greenfield DRI-EAF projects are being developed or under consideration. This includes projects using green hydrogen from the start (e.g., Mauritania, Egypt) and projects that foresee a gradual transition from natural gas to hydrogen (Libya and Algeria) (Basirat 2024; Yermolenko 2024). While there are clear technological similarities, each country has its own set of advantages and disadvantages for entering into green iron and steel production.

Mauritania, for example, is Africa's second largest iron ore producer with high-grade ore. There are several plans for gigawatt-scale hydrogen plants in the country. The *Aman* project, by CWP global, is developed further than most other hydrogen projects with plans to develop 20GW of green hydrogen powered by 18GW of wind and 12GW of solar with an initial phase involving a plant of about 5GW by 2030. CWP has signed agreements with national industrial and mining company (SNIM) in Mauritania and the Corner Brook Port Corporation (CPBC) in Canada to produce green iron alongside its green hydrogen facilities (CWP Global 2024; Basirat 2024). In addition, ArcelorMittal also announced plans to produce green hydrogen to make green iron and steel in the country (Klein 2024).

Egypt is currently Africa's largest steel producer, with experience in producing and using DRI. Though production presently is through natural gas rather than green hydrogen (Bernard 2022), substitution of gas with green hydrogen is possible (Basirat 2024). There is a strong potential for renewable energy expansion with a target of 42% of total electricity by 2030 compared to 20% at the beginning of 2024 (El Sawy 2023), which will be essential for green steel. Italian group Danieli has submitted a proposal to the Egyptian government to establish an integrated steel mill at a cost of $4 billion. The proposal includes a DRI facility and hydrogen plant to produce low-emissions steel for the EU market (Basirat 2024). In November 2024, German SMS Group also announced plans for a 2.5 million tonnes DRI facility in the Suez Canal Economic Zone, with an investment of $1.06 billion (Arab Finance 2024).

Algeria and Libya have also announced iron and steel projects, though mostly using DRI with natural gas. According to data collected by Basirat (2024), Turkish steelmaker Tosyali, in collaboration with the Libya United Steel Company for Iron and Steel Industry (SULB), plans to establish the world's largest DRI facility to produce hot briquetted iron (HBI) for markets including the EU. Similarly, Libyan Iron and Steel Company (LISCO) signed a memorandum of understanding (MoU) with Danieli to produce 2 million tonnes per annum DRI/HBI both for domestic use and export to Italy via offtake agreements with steelmakers. In Algeria, the Tosyali Algerie plant, built in 2007, is a large DRI-EAF investment project with plans to increase the proportion of hydrogen used in the production process. Most of the announced H2-DRI projects are geared towards the EU market, while other new DRI/HBI plans generally include plans for moving to green hydrogen use.

2.3. De-risking European decarbonisation with green iron imports

Iron and steel is a highly trade intensive sector. The EU imported 26 million tonnes of finished steel products in 2023, 16 million tonnes of which came from Asia, led by South Korea, India, Taiwan and China (EUROFER 2024). Safeguard measures have been in place since 2018, introducing an import quota and 25% tariff on anything above that, yet these measures are set to expire in 2026. While direct imports from China are relatively limited, the industry is facing pressure from a significant increase in cheap Chinese exports to other markets in recent years, as well as imports of Chinese steel containing products like EVs (Pfeifer et al. 2024).

By partially disaggregating iron and steel production, and importing green iron (HBI) from neighbouring countries, European industries can achieve multiple goals:

1. Safeguarding European (finished) steel output, including for exports, by bringing down energy costs of overall production, which ultimately preserves jobs and advances the EU's own decarbonisation process.
2. Limiting the need for unsustainable subsidies to scale up DRI production in Europe before low-cost imports of green hydrogen become available.
3. Creating a CBAM compliant green iron and steel trading ecosystem that includes European industries and facilities in neighbouring countries.
4. Displacing existing imports of finished steel products from Asian countries and other high-emitting countries of origin.

Investing in imported green hydrogen-based DRI does not need to be a disruptive process or a zero-sum game. In fact, apart from the above benefits to the EU, nearshoring part of this energy-intensive value chain also serves Europe's long-term geopolitical interests, by creating stable interdependencies and a shared green hydrogen economy with neighbouring countries. In the mid-to long term, European industries need those countries, not just as suppliers, but also as growth markets to achieve the scale it needs to be competitive with China and the US. North African countries, in turn, need the European single market for emerging green industries to be viable.

The European iron and steel sector today is also already highly import dependent, not only for coal but also iron ore, the early processing of which happens outside of the EU before shipping. Shifting from BF to imported HBI would shift the moment when this import dependence kicks in, which in the case of HBI is further downstream. While this means more value will be added outside, it does not entail a full relocation of industries.

While on paper, there is a clear geopolitical, and indeed business case for an integrated green iron and steel value chain, this is easier said than done. The following section looks at the different actors and factors that may affect the design and implementation of such industrial partnerships along the lines discussed above, focusing on (1) the complexity of decarbonising steel production, and the political economy of (2) European decarbonisation, and (3) North African green industrialisation.

3. The political economy of green steel in Europe and (North) African countries

Decarbonising steel is a technologically complex, logistically difficult, highly capital-intensive, and politically sensitive process. Much of the backbone energy and hydrogen infrastructure, trade flows, policy systems that can enable a timely transition to green steel production still need to be established. While for European industries the main challenge is to shift from one production method to another, completely transforming the way in which iron and steel is produced, for most North African countries, the challenge is to industrialise, and raise productivity while limiting emissions and securing long-term access to global markets through affordable financing.

Transforming the iron and steel value chain in a way that leverages the respective strengths and assets of European and African countries requires an in-depth understanding of the political economy of both European steel decarbonisation and North African emerging hydrogen economies. This section looks at the technological barriers, and the interests and incentives on both sides. It builds on ECDPM's framework for analysing the political economy of green industrialisation in developing countries (Medinilla and Byiers 2023), ongoing analysis on emerging hydrogen economies (Dekeyser and Medinilla 2024), and a series of interviews with European and international experts.

3.1. Complexity of the H2-DRI-EAF route

As Figure 1 above shows, the primary method of steel production today is (1) smelting iron ore in a coal-fired blast furnace (BF), where carbon monoxide from the coal reacts with iron oxide to separate pig iron, releasing carbon dioxide (CO2) as a byproduct, followed by (2) conversion to steel in a basic oxygen furnace (BOF), which uses fossil fuels for heating and releases carbon dioxide (IEA 2020).

The reduction process accounts for nearly 80% of the overall emissions associated with the steel sector (Hieminga et al. 2023). Currently, each tonne of steel produced releases almost twice as much carbon dioxide (1.87 tonnes) into the atmosphere. Annual steel turnover of 2 billion tonnes is expected to rise by 30% by 2050 driven by growth in developing countries and simply by the ubiquity of steel in all materials used in society (Wenban-Smith 2021).

While there are several potential technological pathways to lower emissions in the sector, including Carbon Capture, Usage and Storage (CCUS), and more experimental forms of direct electrification (see annex 1), most experts agree that the primary route for iron and steel decarbonisation in Europe will be the H2-DRI-EAF route. In H2-DRI, hydrogen reacts with iron oxide to produce sponge iron with water as a byproduct (see Figure 1). EAF, as the name suggests, uses electricity.

DRI itself is unstable (highly reactive and potentially igniting), but it can be compressed into HBI for transport, making it into an exportable hydrogen-derived product. HBI can then be further processed in EAF to produce steel products.

Currently, DRI with natural gas is more widely used. This emits CO2, although less than a coal-fired blast furnace. EAFs are also widely used, though the grid powering them may use fossil fuels. The full H2-DRI-EAF process, only when *completely* powered with renewable electricity, would make a feasible pathway to produce green, or net-zero, steel (see annex 2). While both DRI and EAF are established technologies, the green pathway comes from the use of green hydrogen (in the case of DRI) and full use of renewable energy (for green hydrogen as well as for EAF).[6] DRI-EAF entails lower direct (Scope 1) carbon emissions than the traditional BF-BOF process and using green H2 also reduces indirect (Scope 2) emissions.

Within the spectrum of current BF-BOF process and the (integrated) H2-DRI-EAF option, there are several decarbonisation pathways which firms are exploring such as:

- Constructing new (greenfield), or converting existing BOF to (brownfield), EAF to use pig iron from existing BF plants (EAF is the most flexible smelter for ferrous production accepting scrap, hot BF metal, DRI, HBI, Firsbach et al. 2023) and adapt BF plants to inject hydrogen directly or indirectly.
- Constructing new (greenfield), or converting existing BOF to (brownfield), EAF to use green DRI from a separate facility in Europe (e.g., Stegra in Sweden or GravitHy in France) or imported HBI (from outside Europe, for instance from North Africa).
- Constructing new (greenfield), or converting existing BOF to (brownfield), EAF and adding a DRI facility using natural gas prior to eventual conversion to hydrogen.
- Constructing new (greenfield), or converting existing BOF to (brownfield), EAF and adding DRI plant using imported green hydrogen (from outside Europe, for instance from North Africa).

[6] EAFs in 2023 accounted for close to 30% of global steel output, the majority for processing scrap (Aboura and Riva 2024). DRI adoption is rising more slowly in comparison – it is expected to rise to 13% of the total iron production by 2030 (Eurometal 2024).

While part of the technology exists, there are a number of technological constraints[7] that have, and may continue to delay a rapid scaling up of green H2-DRI-EAF production:

1. Green hydrogen production and price parity with natural gas for DRI remains in its infancy, with most green hydrogen production facilities set to come online after 2040 (Dekeyser and Medinilla 2024).
2. Extremely large requirement of green electricity which far exceeds the capacity of private players to generate it through captive power plants.
3. On-grid electricity in most industrial centres is insufficiently green which may create challenges in combining with green electricity from other facilities.
4. New plants that intend to sequence natural gas DRI to H2-DRI need to carefully manage process leakage, in addition to methane leakage linked to natural gas extraction and transport.

The biggest bottleneck is arguably the costs and availability of green hydrogen and renewable electricity. It takes about 55 kilowatt-hour of electricity to produce one kilogramme of hydrogen, and 50 kilograms of hydrogen to make one tonne of steel (Kurrer 2020). Including losses in electrolysers it is estimated that it takes about 4 megawatt-hour of electricity to produce 1 tonne of green steel (Ritchie 2024a). Greening the global steel sector with green hydrogen would add around one quarter to the world's overall electricity demand (Ibid.). To qualify for green steel production all this electricity must be from renewable sources. This in turn means construction of large scale renewable energy (e.g., solar, wind, hydro etc.) plants to produce electricity for hydrogen (that can then feed into steel production).

The scale of capital investments in the industry is vast - for an average steel company producing 5 million tons of steel per year, decarbonisation could entail approximately $6 billion in capital expenditures (Morgan Stanley 2023). This is close to 4% of the EU steel industry's gross revenue in 2022, which is significant given that margins in the sector are thin (EUROFER 2024).[8]

Steel plants also have long life cycles, implying sunk costs for incumbents - a single blast furnace, a technology that would need to be replaced for steel decarbonisation, runs for 40 years whereas the average age of furnaces in 2020 was 13 years (IEA 2020). As much as 62% of the worldwide steel capacity in 2020 was using BOF and just 29% used EAF (Copley 2024). In 2023, planned capacity for new coal-based blast furnaces was two-and-a-half times greater than planned new green iron and steel capacity, led mainly by China and India (GEM 2023). At the same time, 43% of planned steelmaking capacity is based on EAF technology to recycle scrap steel (Lempriere 2023).

According to Agora Industry and Wuppertal Institute (2023), 70% of blast furnaces worldwide will reach their end of campaign life by 2030 and operators face a choice of relining their blast

[7] An additional factor that is often cited is that DRI requires DR-grade iron ore with a higher iron (Fe) content than what is needed for BF-BOF (Nicholas and Basirat 2022). Yet new mining projects and refining technology appear to have eased initial concerns around bottlenecks (Kuykendall 2024).

[8] The global steel industry's margins are 8%-10% which is below the 15%-17% margin necessary for long term sustainability (McKinsey & Company n.d.).

furnaces and locking in high emissions for more than a decade or substituting these blast furnaces with low-carbon technologies. With the latter option, by 2040, 90% or more of existing blast furnaces can be phased out without needing a premature shutdown (Ibid.).

Many firms in the EU are adopting a two-pronged strategy to decarbonise the sector, namely conversion of existing BOF facilities to EAF by 2030 (brownfield EAF conversion), while looking to add H2-DRI facilities in the longer term, when commercial viability improves. This was recently also seen in the case of large firms such as ArcelorMittal and Thyssenkrupp, though there have been delays in their plans for DRI facilities, even if large-scale subsidies for both companies have been announced (Parkes 2024a; Pfeifer and Alim 2024; IndustriAll 2024).

3.2. Political economy of European steel transformation: technically possible but economically and politically challenging?

Steel sector transformation through a historical lens

Understanding the history of Europe's energy-intensive industries is key to grasping today's decarbonisation challenges. These industries were built on an abundant supply of (imported) fossil fuels and inputs. Heavy industries such as iron and steel flourished in Europe even if local availability of these resources was limited (Hausmann 2021). This reliance on easily transportable fossil fuels has shaped the geography of industrial production, and is difficult to transition away from today where the economics of renewable energy has a different logic and may necessitate the relocation of the most energy intensive parts of the production closer to the source of renewables.

At the same time, a historical perspective, as presented by Copley (2024), shows that industrial change is an inherently disruptive and conflictual process. While technological revolutions in the steel industry have delivered large productivity gains, their diffusion (1) has been slow and uneven due to associated costs; (2) is intimately bound with the industry's numerous crises of overaccumulation, and (3) has resulted in traumatic reorganisation of production.

Historically, as Copley (2024) highlights, every technological revolution in steel-making, while hugely productivity-enhancing, has seen a new steel power emerge - Britain followed by the US, then Japan and South Korea; currently China is the world's largest producer of steel accounting for over half of the global steel production (Worldsteel 2024). Part of the reason behind the emergence of new players was that they were able to adopt the newest technology and secure large profits, while for incumbents, writing-off existing infrastructure to make way for new technologies was not an attractive proposition given large sunk costs.

The industry is also troubled by continuous cycles of overaccumulation - in terms of overproduction and/or overcapacity - impacting profits and investments, which in turn affect the diffusion of technology. At the same time, without these technological upgrades, existing market share was typically lost to cheaper foreign steel, placing the steel sector at the middle of trade tensions (Copley 2024).

New technologies also change (reduce) the labour-intensity of production processes, fundamentally altering labour relations.[9] This makes the entire process of technological upgrading politically sensitive and consequently restructuring of the steel industry has often been state guided. This has political and economic concerns overriding corporate decisions in steel industry takeovers, exemplified by the blocked acquisition of U.S. Steel by Nippon Steel due to fears of job losses and national security risks (Pollard and Fontanella-Khan 2024). Thus, far from smooth transitions to leading technologies, the industry has been associated with "violent reorderings of the geography, geopolitics, and relations of production" (Copley 2024:978).

Challenges for 'European' green steel

While decarbonising the steel industry is essential for reducing emissions, it is unclear that green steel technologies would bring the radical productivity gains of past innovations. This may make firms hesitant to bear the high costs, even with the promise of significant government subsidies. Moreover, the fact that the need for large amounts of green hydrogen and renewable energy – resources in short supply in Europe – may require the relocation of energy-intensive parts of the industry (to regions like North Africa), is difficult to reconcile with the current political climate in the EU and pressures for a *Just* Transition, reshoring industrial production, and protecting vulnerable industries.

The energy inputs required for green steel are enormous as shown in Box 1. This large energy demand poses a bottleneck to finding decarbonisation solutions within Europe alone, where green hydrogen projects are also hindered by high costs and regulatory issues (Chu et al. 2024). Though green hydrogen imports from North Africa are appealing due to lower costs of production there (Wolf et al. 2024), its transportation to Europe remains expensive.[10] According to one estimate, "Green hydrogen [from North Africa] could cost as much as 11 times more than natural gas per unit of energy at prices before the 2022 energy crisis [...], even before storage and transportation" (Barnard 2022:1).

[9] According to Copley (2024) US steel employment fell from 521,000 in 1974 to 204,000 in 1990. In France and the United Kingdom (UK) it fell by more than 70% during the same time. In Japan it fell by almost half in 1974-1996, and in Germany much more.

[10] While the International Energy Agency estimates show that pipeline delivery of hydrogen, and shipping of ammonia for direct use from North Africa can compete with domestic production in the EU, liquefied hydrogen or reconversion of carriers are necessary for importing hydrogen which can more than double the final cost, making it commercially less attractive in the long term (Dekeyser and Medinilla 2024).

Box 1: Renewable electricity and green hydrogen requirements for green iron and steel production in Europe

60% of European steel production is through primary process, i.e. smelting iron into steel, using the conventional integrated BF-BOF process; the rest is through secondary process, i.e. recycling steel using scrap, with EAF (Correa Laguna et al. 2021; Eurofer 2023; Boldrini et al. 2024). Converting 30% of EU-based primary steel production to H2-DRI-EAF plants by 2030 in line with the REPowerEU plan would require 135 terawatt-hour (TWh) of renewable electricity, equivalent to the annual electricity consumption of Sweden, and around 19% of the policy target for domestic renewable hydrogen production under REPowerEU (Torres Morales and Maltais 2024).

As highlighted above, this electricity needs to be renewable to significantly reduce emissions. According to a briefing provided to the European Parliament, Germany alone would need an additional 100 TWh to decarbonize its steel sector (Kurrer 2020), which is equal to 40% of its total renewable electricity production in 2023 (Burger 2024). In Italy, the Netherlands, Belgium, Romania and Finland switching current steel facilities to H2-DRI-EAF processes would even require more wind electricity than is currently generated (Keßler and Lovisolo 2023). Only having an EAF, before adding H2-DRI, is also energy-intensive – the EAF plant at Georgsmarienhütte in Germany's Osnabrück district requires as much energy as the entire city of Osnabrück (Wermke et al. 2024). In addition, the relatively high price of electricity in the bloc raises concerns about the competitiveness of the EU's heavy industry as highlighted in the Draghi report. This refers to not just the amount of renewable electricity but also the steadiness of its supply in light of intermittency which requires a synchronisation of industrial activity to the availability of renewable energy (Zaccaro 2024).

The financial investments required to produce green steel are substantial. Decarbonizing 30% of the largest firms' European production with the H2-DRI-EAF route would exceed their typical annual investments by up to twice as much (Hüttel and Lehner 2024). According to EUROFER, the European steel industry needs €30 billion by 2030 and €50 billion by 2050 to meet decarbonization goals.[11] According to Agora Industry and Wuppertal Institute (2023), operational costs for green steel production remain significantly higher than conventional methods (30%-60% depending on the cost of hydrogen),[12] cutting into the already-thin industry profit margins. It is important to note that European steelmakers' margins have consistently been below the global average (Hüttel and Lehner 2024). Reduced profits on the one hand and significant capital and operating expenditures on the other risk making the business case for producing green steel in Europe a challenge (Copley 2024; Hüttel and Lehner 2024).

Global steel overproduction, expected to reach 630 million tonnes by 2026 according to the Global Forum on Steel Excess Capacity, further depresses prices, which are already low due to

[11] Hüttel and Lehner (2024) calculate the overall investment needs at €750 per tonne of green steelmaking capacity. This is significantly more compared to the cost of production with the conventional BF-BOF process at €400 per tonne (Kurrer 2020).

[12] As a result, green steel is likely to be more expensive - early assessments suggest a 20-30% higher price than conventional steel (Koch Blank 2019). While a carbon price will go some way in reducing this gap, it is unlikely to close it (Jäger 2024b).

slowed demand from China. This, combined with weak demand for green steel in lead markets and industries where steel is used as input (e.g. automotive), weakens incentives for decarbonisation.[13]

Politically, job preservation remains a critical issue. Energy prices in Europe, reeling from the fallout of Russian invasion of Ukraine, are high compared to competitors such as the US and China, already putting a strain on European competitiveness (Alkasabreh and Kreidelmeyer 2023). German steelmaker ThyssenKrupp in November 2024, announced plans to cut no less than 11,000 jobs and reduce capacity from 11.5 tonnes to 9 tonnes by 2030, citing cheap Asian imports (DW 2024).

Currently, the prospect of job loss, or relocation of industrial jobs is looked at primarily through a lens of unfair competition with China leading to European deindustrialisation fueled by traumatic memories of past waves of industrial restructuring in the twentieth century. With existing steel jobs on the line, the 'jobs versus environment' narrative pushed by European conservatives and the extreme right also gets a further boost, making job retention a major political priority for centrist incumbents across Europe. While some analysts argue that claims of European deindustrialisation are overblown (Palesh 2024; Agora Industry and Wuppertal Institute 2023), energy and trade intensive sectors are generally seen as more vulnerable. Further, even modest job loss in the steel industry will likely have outsized political repercussions, both directly, through large-scale union action, and indirectly by fuelling anti-green sentiments and creating opportunities for far right political capture. Consultations with companies, workers and communities will be essential (Ibid; Button 2024) and policymakers could draw on past transition experiences, such as in the UK, where workers were offered financial support and retraining, to smooth the transition for, and avoid opposition from, steel industry employees (Harris 2024).

HBI imports as both a necessity and a threat

Disaggregating green iron and steel production, and importing green HBI is seen as a solution to moderate the short-term costs and retain the decarbonisation targets for the sector under pressure. Experts as well as some industry representatives have suggested that HBI imports in the short run can help create breathing space for the sector, while increasing long-term capital efficiency of European steel decarbonisation (Wilmoth et al. 2024; Parkes 2024a).

Analysis by the Energy Transitions Commission (ETC) for UK steel industry suggests that separate iron and steel operations with imported HBI will entail lower capital expenditure outlay than a greenfield H2-DRI-EAF facility or a brownfield conversion i.e. retrofitting existing BF-BOF facility with DRI-EAF facility (Graham et al. 2023). Green iron corridors, which split ironmaking

[13] A 25% increase in the cost of low carbon steel would translate to only about 1% increase in the price of a car (Ritchie 2024b). However, in sectors like construction where steel makes up a significant proportion of input costs, prices are likely to increase by more. A recent report by Deloitte (2024) cites a construction company which suggests a large effect of decarbonising steel on the construction sector, where up to 85% of total emissions in the sector are Scope 3 emissions, the bulk of which originates from steel production. More of this is needed to raise awareness and create demand among lead markets and industries.

and steelmaking geographically, could benefit both regions with abundant renewable energy and those with advanced steel manufacturing capacities (Wilmoth et al. 2024). However, there are also risks - this approach requires restructuring of the current BF-BOF facilities, whereas the small number of DRI technology providers may hold significant pricing power over green iron, posing risks to cost of green steel production, and importing HBI would still require reheating after importing into Europe (Agora Industry and Wuppertal Institute 2023). Finally, profit margins with this option still remain low compared to conventional iron- and steel-making according to analyses by ETC in the UK, France and Southern Europe (Graham et al. 2023).

For all the commercial arguments for HBI imports, it also requires significant reform of the sector, and calls into question the logic behind European DRI facilities running on imported green hydrogen. Opponents, while acknowledging imported HBI will play a role, see overreliance on it as a 'bankruptcy declaration', or high-risk strategy (Parkes 2024b). They therefore see it rather as a last resort strategy, and instead call for stricter tariff and CBAM measures along with more ambitious subsidies for green hydrogen consumption (e.g., through the EU hydrogen bank). This comes with its own risks of higher prices for steel products.

Companies appear to be hedging their bets as the EU's own industrial strategy, state aid framework, and steel action plan are being re-formulated. Arcelor-Mittal for example announced in November 2024 that in the short term it does not see a commercially viable way to produce DRI in Europe, citing high energy and hydrogen costs, and insufficient assurances offered by the CBAM (ABVV Metaal 2024; Peverieri and Kacher 2024) and has delayed the Final Investment Decisions on its 5 DRI facilities across Europe (ArcelorMittal 2024). This is despite being in line for no less than €3 billion in subsidies. Critics see it as a move to secure further concessions and subsidies, or a strategic delay until the terms of the new EU industrial policies (Clean Industrial Deal, state aid framework, steel action plan, trade defence policies) are clearer.

In keeping with the earlier technological revolutions, real change towards decarbonisation may not come from steel majors but from disruptive new entrants (Hieminga et al. 2023). Stegra is Europe's most advanced green steel project, which aims to double its production to 5 million tonnes by 2030 (Jones 2023; Metingil 2024). However, this represents only 2% of EU forecasted demand (Lutter and Schmidt 2024).

Overall, the potential for HBI imports and green steel partnerships with third countries very much depend on the line that the European Union, its member states and the steel industry will take in the coming months, as the EU develops its new industrial policy framework, with the Clean Industrial Deal, a new State Aid Framework, and a Steel Action Plan. Industries are issuing a clear call for a more ambitious, but possibly also more inward-looking industrial deal, focused on protecting existing industries and onshoring through subsidies and trade and tariff measures. While this can shore up industrial outputs and cement the EU's first-mover role in green steel, it may also result in an expensive and uncompetitive decarbonisation process.

It's important to note that not all iron and steel imports should be seen as the same. The EU's iron and steel sector is under pressure from high energy prices and cheap imports from Asia, and European competitiveness concerns are compounded by greater support to the industry in competitor markets such as China and the US. Yet imports of green HBI from North African countries can feed into, and complement, EU green steel production, while creating a basis of regional trade in green industrial goods. This makes them qualitatively different from Chinese steel imports, which can directly or indirectly substitute EU production.

To conclude, international trade and investment partnerships with Southern Neighbours can play an important role in the decarbonisation of European steel through the import of HBI. Rather than deindustrialising Europe, this option preserves jobs, majority of which are in the steel industry rather than iron-making while moving the most energy-intensive parts of iron-making to places where it can be more cheaply produced. Similarly, rather than creating new dependencies, involving Southern Neighbours into the European supply chains can create synergies offering mutual benefits of fostering resilience of European supply chains and supporting North African green industrialisation. However, such partnerships would also require careful coordination and strategic planning to address the investments and other constraints in partner countries.

3.3. Political economy of African economic development: new opportunities faced with old challenges

African nations are striving to industrialise using their rich natural resources. As decarbonisation potentially alters the geography of industrial production in Europe, it provides unique opportunities to some countries to participate in the supply chains around energy intensive industries through their hydrogen economies and the production of intermediate goods. For instance, Mauritania, Africa's second-largest iron ore producer, plans to double its output to make high-quality iron pellets, and eventually produce green steel powered by green hydrogen (AISU 2024). Similarly, Egypt, Africa's largest steel producer, already operates DRI facilities that could support decarbonisation efforts if powered by green hydrogen. Morocco, on the other hand, has substantial renewable energy potential, and among the most advanced hydrogen economy plans on the continent.

All North African countries, including Egypt, Libya, Tunisia, Algeria, Morocco and Mauritania, have signed memoranda of understanding (MoUs) to advance green hydrogen megaprojects that could transform their economies, yet these plans are first and foremost export-oriented, in anticipation of large-scale demand from European industries and the shipping industry (Dekeyser and Medinilla 2024). This focus mirrors the historical cycle of raw material exports to earn foreign currency, which, when combined with falling raw material prices and rising interest payments, raises concerns of debt distress (Amouzai 2023). Indeed, recent investments in energy infrastructure have not translated to greater industrial integration which can foster an ecosystem to sustain long term economic growth and create much needed jobs in the region (Berahab 2024). Industrialisation and industrial policy also do not feature prominently in broader Africa-Europe cooperation which instead focuses on trade with the assumption that this will lead to industrial development (Chitonge 2024).

Low-carbon industrial production has the potential to break this pattern, allowing these nations to produce energy and hydrogen intensive products like green iron (and green steel) (Egypt, Mauritania, Algeria, Libya) or green fertilisers (Morocco and Egypt) instead of focusing solely on hydrogen exports. Producing green steel for export may indeed make more commercial sense than transporting green hydrogen from North Africa to Europe (Medinilla and Dekeyser 2024; Basirat and Nicholas 2023).

Despite these ambitions, hydrogen economy plans tend to face multiple challenges. For instance, Morocco's projected green ammonia exports far exceed (2x-9x) its domestic demand, even with its large fertiliser industry suggesting limited absorptive capacity (Amouzai 2023). Additionally, while numerous MoUs on green hydrogen signal official enthusiasm in Egypt, prior experience shows that most subsequently 'fall through' due to unclear financing and regulatory challenges (Tanchum et al. 2024). Similarly, Mauritania's recent MoU with ArcelorMittal (ArcelorMittal 2022) has captured the attention of many, but it is only to evaluate the scope of iron pelletising and DRI production in the country rather than an investment commitment at this stage.

Infrastructure and reliable power are significant hurdles. Inadequate energy has limited these countries' capacity to add value to iron-ore production (e.g., Mauritania, Mitchell 2024), become competitive green hydrogen suppliers to the EU (e.g., Morocco, Barnard 2022), and could jeopardise previously robust steel production (e.g., Egypt, Enterprise 2024). Although North Africa has great renewable potential, actual solar and wind installations remain five times less than France and twenty times less than Germany (Tanchum et al. 2024).

The above also reflects the difficulty in attracting investments, which is compounded by high financing costs: in Egypt, solar or wind projects cost nearly seven times more to finance than similar projects in Germany (IRENA 2023).[14] This sets the bankability bar for projects much higher (IEA 2023). While public financing is necessary to support such investments, all countries have constrained fiscal capacity and vast and competing development needs.

The political economy of early stage hydrogen consumption also illustrates the paradox faced by developing countries. While North African countries may hold a geographical advantage for hydrogen production, in the short term industrial demand will likely be structured by subsidies and policy incentives there. European subsidies for hydrogen consumption, including dual auctions through Germany's H2Global and the EU's hydrogen bank are seen as essential to enable the commercial viability of H2-DRI in Europe. Coupled with other incentives for decarbonisation, like the Emissions Trading System (ETS),[15] this means that even if on a

[14] According to calculations by IRENA (2023), the cost of financing a solar or wind power project in Egypt is as high as 8.8% while in Germany it is 1.3%. In Morocco, where the macroeconomic situation is better than in Egypt, these costs still remain high at 6.7%.

[15] The ETS will raise the costs of emissions, which is meant to create a competitiveness gap between high emitting and decarbonised production facilities.

technical level it would be more efficient to produce green iron in North African countries and then import into Europe, in the short term at least, the focus will be on imports of hydrogen and derivatives from these countries.

Benefitting from opportunities of changing industrial geography will require significant coordination and reform which are likely to show results only in a medium to long term. However, leaders in the region, much like in the EU, often prioritise short-term political survival and economic stability over long-term socioeconomic development, even when they are confronted with challenging policy dilemmas. The reluctance to implement reforms that, while necessary, may also be socially and politically contentious, leads to a preference for maintaining the status quo or diluting reforms, to avoid alienating their constituencies, but further exacerbating existing challenges (Arafeh and Meddeb 2024).

Industrial policy coordination

Successful production of green iron or steel in North Africa requires significant coordination and faces numerous technical and practical challenges, spanning renewable energy and green hydrogen production, and green iron or steel manufacturing capacity. Historically, such coordination for an industrial ecosystem has been limited, raising questions about the viability of these ambitious green projects which require even more coordination. Large (and complementary) investments are required for the numerous processes for green steel - all of which are capital-intensive (see Figure 3 above).

Renewable energy, in particular, is likely to constitute the bulk of these investments. For example, scaling up the power facilities to produce enough green hydrogen to create one million tonnes of crude steel in Australia would cost approximately $3.5 billion, exceeding investments needed for other critical green steel infrastructure like pelletising facility, DRI plant, EAF, and hydrogen electrolysers (Basirat and Nicholas 2023). Final investment decisions on green hydrogen worldwide are delayed due to higher than anticipated production costs and uncertainty around offtakers (Basirat 2024; Arroniz Velasco et al. 2024). Only about 17% of global hydrogen projects scheduled for 2030 have secured offtakers (IEA 2023). Projects to produce green iron or steel are even rarer. Not only do debt-laden North African countries lack public support to drive these investments unlike some of their counterparts in the EU, private investments too remain limited, or prove difficult to secure, due to high cost of financing as mentioned above (Tanchum et al. 2024; Agora Industry 2024b).

Similarly, aspiring green iron or steel producing countries in North Africa would require using green hydrogen to feed into local industries, rather than focusing solely on exports. Yet, there are uncertainties around domestic offtakers, as they themselves face challenges of insufficient infrastructure, financing gaps, and limited policy frameworks to drive demand for green hydrogen-based iron and steel. Furthermore, demand for HBI *from North Africa* remains unclear, given development in the EU described above. Where green hydrogen projects do target local industries, the emphasis is generally on fertiliser production, where domestic demand is more established, as seen in Morocco and Egypt (Tanchum et al. 2024). In fact, in

Morocco, green hydrogen today "does not offer much viable potential for other envisaged uses" other than fertilisers (Barnard 2022:11). One exception to this trend is in Mauritania, where developer CWP Global has announced plans to use green hydrogen from its upcoming project to produce green HBI for export to Europe (Basirat 2024). However, such initiatives are rare. Additionally, successful establishment of new green iron and steel production in the region will depend on an integrated industrial ecosystem, including raw materials supply chain, industrial facilities, workforce, and supportive policies. Obtaining organisational capabilities and knowledge to run a successful business requires learning by doing during which time firms typically require support in the form of industrial policies. It is unclear whether these exist and more research is required to map out the kind of support North African economies require given their specific sociopolitical and economic development contexts.

Whereas the above refers to coordination *within* North African states, cooperation *between* states in the region - as a way to overcome some of the structural challenges of small market size and seek complementarity with others through own specialisation - remains very limited. For example, even though Morocco is Mauritania's largest African trading partner, this only accounts for 1.3% of Mauritania's total trade (Fakir and Zeglam 2023). Political tensions between Morocco and Algeria, and persistent instability in Libya complicate relations (Tamburini 2024).

All countries in the region are more economically integrated with Europe than with each other, and on energy and hydrogen partnerships with European countries they directly compete with one another. The potential for regional industrial cooperation and cross-border offtake of hydrogen and industrial goods, for example Mauritanian iron ore exports for regional H2-DRI, or green steel production in the region, as well as exploring links with Moroccan automotive manufacturing, is understudied, and has not been prioritised by any of the countries concerned.

Macroeconomic concerns and vested interests

'Green' economic development in North Africa requires broad policy reforms, particularly in macroeconomic management, as unresolved challenges such as exchange rate volatility and other liabilities could jeopardise green hydrogen projects in the region (Arezki 2023). Additional structural issues, including ongoing food, energy, and debt crises, influence domestic power dynamics, pushing leaders into difficult policy dilemmas (Arafeh and Meddeb 2024).

Egypt exemplifies these challenges. The country is grappling with persistent internal challenges of large fiscal deficits, limited foreign investments, and battered by external shocks COVID-19, conflicts in Ukraine and Gaza, and Red Sea attacks. The government's reliance on debt-fueled growth has led to unsustainable debt levels, with external debt rising from 15% of gross domestic product (GDP) in 2013 to 42.4% in 2023 (Kaldas 2023a; Tanchum et al. 2024). Egypt's piecemeal approach to economic reform has stifled long-term growth, requiring periodic interventions of the International Monetary Fund (IMF), with the country being the IMF's second-largest borrower (Hussein et al. 2024).

In Mauritania, iron ore exports are key, but earnings remain vulnerable to volatile international prices with limited employment opportunities (BTI 2024).[16] Similar to Egypt, Mauritania faces economic instability due to external shocks, requiring IMF support (Castaner 2023). Economic growth is more volatile than in neighbouring countries, making investment decisions difficult with large swings in public revenues (BTI 2024).

For hydrogen projects, these challenges translate to in some cases prohibitively high cost of capital, which can significantly reduce the technical advantage of developing countries. For instance, applying the country-specific risk premium increases the projected Levelised Cost of Hydrogen in Morocco by more than 20%, and in Mauritania by more than 50% (Agora Industry 2024b). Countries in the region are unable to derisk these investments on their own, which is leading to significant delays in hydrogen project development. Today, only 5% of African project investment is at the front-end engineering design stage, compared to 20% globally, while a mere 1% has passed the final investment decision (FID) compared to 7% globally (Hydrogen Council 2024).

Government involvement is essential for low-carbon industry development in these countries. However, state-administered economies in the region, with large state-owned enterprises, have in the past crowded out private investment, while a crony capitalist class has captured wealth and limited competition. Reforms in this area need to be sequenced and informed by political astuteness to minimise political backlash.

Egypt's approach in this regard contrasts with Morocco's: while both nations have focused on megaprojects for economic growth, Egypt has avoided critical reforms needed to attract private investment, prioritising political considerations (Tanchum et al. 2024). Morocco, on the other hand, has combined megaprojects with institutional reforms, and global competitiveness of its SOEs, creating a more stable environment for private investment. Egypt's economic structure, dominated by regime-owned enterprises, restricts private-sector participation (Kaldas 2020), while Mauritania's oligopolistic economy means that influential families and tribal conglomerates dominate key sectors, effectively creating informal barriers to new private investment (BTI 2024).[17]

Sociopolitical and governance challenges

Large-scale hydrogen and industrial development projects in the region also face a number of unique, or outsized socio-political and governance challenges, including:

- **Shortage of water and electricity -** rolling blackouts in Egypt (Scotto di Clemente 2024) as debt services crowd out social spending (Kaldas 2023b), concerns in all countries over

[16] The mining sector - copper, gold, iron ore - constitutes 30% of GDP and over 70% of exports in the country (Castaner 2023).

[17] Mauritania's state-owned iron ore producer, SNIM, is the country's largest company and second-largest employer with around 5,000 workers (BTI 2024).

capital-intensive projects not benefitting local communities (Amouzai 2023) and exacerbating tensions due to water scarcity (OECD 2024; Mahmoud 2024; Desmidt 2021).

- **Lack of transparency -** Limited public debate can undermine effective energy and industrial policy across the region, from Egypt's military-economic continuum to Morocco's centralized elite economy to Mauritania's political persecution (Kaldas 2020; Colombo 2023; Weisenthal and Alloway 2024; BTI 2024; Arezki 2023).
- **Risk of resource capture** - Without reforms, green energy megaprojects risk being exploited for rent-seeking, widening inequality, but also potentially stifling competition and innovation. For instance, Mauritania's iron ore ports previously served private interests under past regimes (BTI 2024).
- **Regional instability -** Insecurity from conflicts—like the Gaza war affecting Egypt or Sahel violence impacting Mauritania—further hampers the region's viability for long-term investments (Tanchum et al. 2024).[18]

All of these factors combined create a highly uneven and in some cases deeply challenging business environment for large-scale investments in new technologies. Countries seek to improve this through dedicated investment promotion for hydrogen projects, offering favourable conditions for large-scale hydrogen investments. Egypt for example is positioning the Suez Canal Economic Zone as a hydrogen cluster, including for DRI, and is offering privileged access to land and incentives though its 'golden licence' or comprehensive approval scheme (Gadelhak and El Harmy 2024). Morocco in turn launched its Hydrogen offer in 2024, a call for proposals that will grant projects access to land, shared infrastructure and a range of investment and fiscal incentives (MASEN 2024; Kingdom of Morocco 2024). These measures are meant to shield foreign investors from some of the old challenges of North African industrial development and offer a compelling and competitive investment climate for new technologies, but at the same time they also risk creating new forms of inequality, conflict, and regional competition.

Finally, tensions in relations with the EU – which stem from perceived power imbalance rather than that of equal partnerships (McNair 2024), excessive focus on short-term migration and energy security while overlooking North African concerns of movement of people and market access (de Larramendi and Piazza 2024) – have meant that despite stronger economic, technical, and infrastructural ties with North Africa compared to the US, China, and Russia, the EU lacks equivalent political influence (Grieveson and Weiss 2023).

To conclude, North African ambitions to industrialise by leveraging on its renewable energy and green hydrogen potential will require significant coordination, investments while ensuring broader socioeconomic benefits in terms of job creation and industrial linkages. While it may be more ambitious, inclusion of North African countries in European supply chains can create mutually beneficial interdependencies which on the one hand can further the EU's

[18] Houthi attacks on the Red Sea resulted in a significant drop in the 12-15% of global trade that normally passing through the Suez Canal, affecting revenues for Egypt normally amounting to over $700 million per month or 2.2% of GDP in balance-of-payment receipts and 1.2% of GDP in fiscal revenue (IMF 2024).

decarbonisation efforts while providing a viable pathway for North African countries to industrialise without falling into 'green-or-development' trap (Byiers et al. 2023).

4. Conclusions and recommendations

Decarbonisation of energy intensive industries is necessary for the EU's path towards climate neutrality. However, the green transition also puts into focus the question of the geography of energy intensive industries given the need for vast amounts of renewables energy and hydrogen needed to power green production which may not be most cost-effectively produced within the EU and that transporting them remains expensive.

The progress towards decarbonising the iron and steel industry in Europe is slow, further compounded by geopolitical concerns and political climate in the bloc. However, decarbonisation also presents an opportunity to rethink the industrial partnerships as part of the next phase of the European green deal.

Imports of HBI into European steel production can relieve some of the stress on European steel from high energy prices and cheap Chinese exports, while contributing to new, more mutually beneficial industrial partnerships with North African countries.

- For Europe, HBI imports can complement (but not necessarily replace) efforts towards DRI and expansion in EAFs based in Europe, while creating a more secure and diverse integrated supply chain with neighboring countries. In doing so it can preserve a majority of direct jobs in the industry while ensuring long-term competitiveness.
- For North African countries HBI production can be a driver of local hydrogen consumption and cement its industrial development through linkages with other industries including steel production that can be geared towards growth markets in the wider region.
- For both, it can be a vector for a new Euro-Mediterranean energy and industrial partnership based on a shared commitment to decarbonisation and an intensification of regional trade in low-carbon industrial goods.

Yet this is also a politically and economically highly sensitive issue. Imports are seen as a sign of deindustrialisation in the EU. Some players bank on these fears to secure more concessions (subsidies) and protections (tariffs) and assurances (CBAM) against imports (mainly from Asia). Politicians fear further far-right, and anti-green agenda capture in case of job loss in the sector.

H2-DRI projects in Europe, despite billion euro subsidies, are facing significant delays and an uncertain future. On the other hand, North African H2-DRI in turn is struggling to move from announcements to Front-End Engineering Design (FEED) and Final Investmentl Decision (FID), facing high cost of capital and offtake insecurity in a difficult market without close collaboration and coordination with European partners.

As the EU reformulates its industrial policy in response to the multitude of challenges it faces, its energy intensive industries, especially iron and steel, are hanging in the balance. The dilemma is between:

- A short-term, inward-looking perspective, which in essence will be an expensive decarbonisation process built on subsidies and aggressive tariff measures.
- A longer-term perspective built on a more integrated industrial geography between European countries, and with Europe's neighbours, with an ambition to scale up the markets for green industrial products beyond Europe.

The latter may be a more disruptive strategy, but it can enhance the resilience of Europe's decarbonisation, increase capital (subsidy) efficiency by focusing on higher tech manufacturing and more downstream production.

- Doing so with neighbouring countries in North Africa will also pay geopolitical dividends by creating long term integration and more secure interdependencies with key regional allies, and construct the basis for an ambitious nearshoring strategy in some of the most promising hydrogen economy hubs close to the EU.

Box 2: Recommendations

For Europe

1. Actively engage North African countries through Clean Trade and Investment Partnerships, emphasising support for political, economic, regulatory, and societal conditions to facilitate large-scale production and export of (green) HBI to Europe.
2. Prioritise derisking investments in a select number of green iron projects where HBI exports directly align with European steel plants by enhancing their financial viability, thus making the case that HBI can in fact support, rather than supplant, European steel industry and jobs.
3. Learn from initial international experiences of derisking H2/NH3 with dual auctions (H2Global; H2 bank) and consider options for applying this to HBI.
4. Be transparent with North African countries about projected EU hydrogen demand, underlining that weaker-than-expected demand projections mean planned exporters should prioritise exporting green goods made using green hydrogen over raw hydrogen.
5. Incorporate a green industry roadmap into all hydrogen partnerships, focusing on potential uses beyond EU exports. Link green hydrogen/iron/steel planning to priorities like migration and energy security, highlighting how North African industrialisation can create jobs and mitigate future migration pressures.

For North African countries

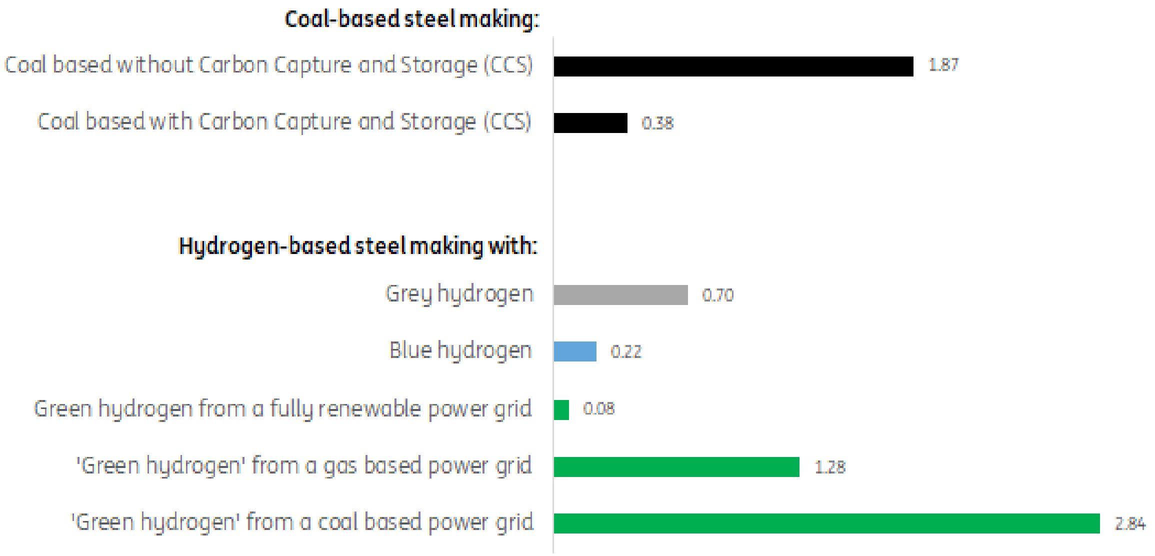
1. Focus on domestic offtake of H2 and international off-takers for HBI.
2. Prioritise industrial policy coordination for low-carbon energy intensive industries.
3. Ensure green hydrogen, iron, and steel projects provide substantial local benefits, such as renewable energy for nearby communities, to promote social harmony and maximize positive socioeconomic impacts.
4. Design investment promotion strategies for green iron and steel.
5. Foster regional cooperation among North African countries, encouraging collaboration between their industries, including, presenting a united front in negotiations with the EU on hydrogen and related projects to better leverage and align with North African priorities.

Annex 1: Pathways to low-carbon iron and steel production

METHOD	PROCESS	ADVANTAGE	DISADVANTAGE
Carbon capture and storage (CCS).	Outfitting current steel plants with carbon capture technologies.	Least disruptive pathway from the perspective of the status quo; may reduce emissions by 75-90% (Hieminga et al. 2023).	Not climate-effective because it is difficult to capture all emissions (80% stored underground, 20% enters atmosphere; Hieminga et al 2023); marred by underperformance (Nicholas and Basirat 2024a) and failure (Nicholas and Basirat 2024b); unlikely to play a significant role in steel decarbonisation (Agora Industry and Wuppertal Institute 2023).
Renewables-powered electric arc furnace (EAF).	Relies of scrap steel and renewable energy.	Most suitable from a sustainability perspective.	Affects profitability as there is limited scope for substantial expansion which has the source of profits in the industry.
Direct electrification.	Produce the liquid metal from iron ore via molten oxide electrolysis.	Climate-friendly.	Early stages of development; combining with 24/7 operating model may reverse energy transition (Zaccaro 2024) as the renewables intermittency and constant daily peaks in consumption make backup thermal generation essential for grid reliability.
Direct reduction of iron-ore (DRI) using hydrogen and conversion with EAF.	Combining two techniques: • DRI using hydrogen that is produced by renewables-powered electrolysis. • Conversion of iron into steel in renewables powered EAFs.	Most optimism among industry observers, requires lower temperatures and so less energy-intensive and no emissions, greater flexibility (Hieminga et al. 2023) as easier to start/stop the process.	Large capital outlays, energy intensive.

Source: adapted from Copley 2024

Annex 2: CO2 emission with different steel-making processes:



Source: Hieminga et al. 2023

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