Full Report

Assessing Opportunities for Green Steel Development and Industrial Competitiveness in Thailand

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April 2026

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Executive Summary

Thailand's transition toward green steel is not constrained by a lack of technological options, but by structural trade-offs across energy systems, economic competitiveness, and institutional readiness. As global steel markets increasingly incorporate carbon intensity into trade, investment, and procurement decisions, the strategic question is no longer whether decarbonization will occur, but how countries can position themselves within emerging low-carbon steel value chains.

Globally, the steel sector remains one of the largest industrial sources of emissions, accounting for approximately 7% of energy-related CO_2 emissions. While established production routes such as blast furnace-basic oxygen furnace (BF-BOF) remain dominant, a range of lower-carbon alternatives has emerged, including scrap-based electric arc furnaces (EAF), natural gas-based direct reduced iron (DRI), hydrogen-based DRI, and carbon capture solutions. Each pathway presents distinct trade-offs in terms of cost, emissions, infrastructure requirements, and scalability. At the same time, policy developments such as the European Union's Carbon Border Adjustment Mechanism (CBAM) are transforming carbon emissions into a determinant of market access, reinforcing the need for credible decarbonization strategies.

Within this global context, Thailand's steel sector faces a distinct set of structural conditions. The industry is already predominantly based on EAF production and relies heavily on imported inputs, particularly for primary iron units. While this reduces the need for a full transition away from coal-based production, it also limits domestic control over upstream decarbonization pathways. More importantly, Thailand's energy system, characterized by continued reliance on fossil fuels, limited renewable energy availability, and constrained access mechanisms for industrial users, emerges as the primary bottleneck for green steel development.

The analysis shows that no single pathway simultaneously maximizes cost competitiveness, deep decarbonization, energy security, and domestic value capture under current conditions. Instead, viable strategies differ across time horizons and depend on how Thailand manages key system-level constraints.

In the near term, scrap-based EAF production and the import of pre-reduced iron (DRI/HBI) for domestic steelmaking represent the most immediately viable configurations. These pathways build on existing industrial capabilities while limiting exposure to high capital investment and energy system constraints. Importing HBI, in particular, allows Thailand to externalize the most energy-intensive stage of production to regions with more abundant and lower-cost renewable energy, while preserving domestic value creation in steelmaking and downstream industries.

Natural gas-based DRI may serve as a transitional option, provided that gas prices remain stable and that a credible pathway exists for future decarbonization. However, this pathway introduces exposure to fuel price volatility and risks locking in emissions if not carefully managed. In contrast, hydrogen-based DRI offers a long-term pathway toward near-zero emissions steel, but its feasibility in Thailand is contingent on substantial improvements in renewable electricity availability, cost competitiveness, and supporting infrastructure.

An alternative pathway, importing crude steel, may offer short-term cost advantages but risks weakening domestic industrial capabilities and increasing long-term dependence on external supply chains. As global carbon regulations tighten, this approach may also expose Thailand to increasing trade and carbon-related risks.

The findings further highlight a structural shift in global steel supply chains. As production becomes more electricity- and hydrogen-intensive, comparative advantage is increasingly determined by access to low-cost, low-carbon energy rather than traditional factors such as raw material availability. This shift creates opportunities for geographically fragmented value chains, where energy-intensive processes such as ironmaking are located in resource-rich regions, while steelmaking and downstream manufacturing remain in industrial economies. For Thailand, this implies that maintaining competitiveness will depend less on achieving full domestic production and more on strategic positioning within these emerging supply chains.

Across these pathways, the transition to green steel carries broader socio-economic implications across multiple dimensions. At the macro level, decarbonization pathways will shape Thailand's industrial competitiveness, trade exposure, and ability to attract investment within emerging low-carbon supply chains. Different configurations imply varying degrees of domestic value capture and integration into global markets. At the same time, the transition will affect cost structures and their distribution across firms, consumers, and society, with implications for affordability and social acceptance. Environmental co-benefits, particularly reductions in air pollution and associated health impacts, represent an important but often under-recognized dimension of the transition. While large-scale employment losses are not expected, changes in skill requirements and job quality will require proactive workforce development to ensure an inclusive and just transition.

Overall, the analysis suggests that Thailand's green steel transition should be approached as a process of sequencing and coordination rather than a binary technological choice. In the near term, priority should be given to pathways that align with existing industrial structures and minimize system constraints. In parallel, structural reforms, particularly in the power sector, will be critical to expanding renewable energy availability, improving grid access, and enabling industrial decarbonization. Over the longer term, as energy systems evolve, more ambitious pathways such as hydrogen-based steelmaking may become viable.

Chapter 1

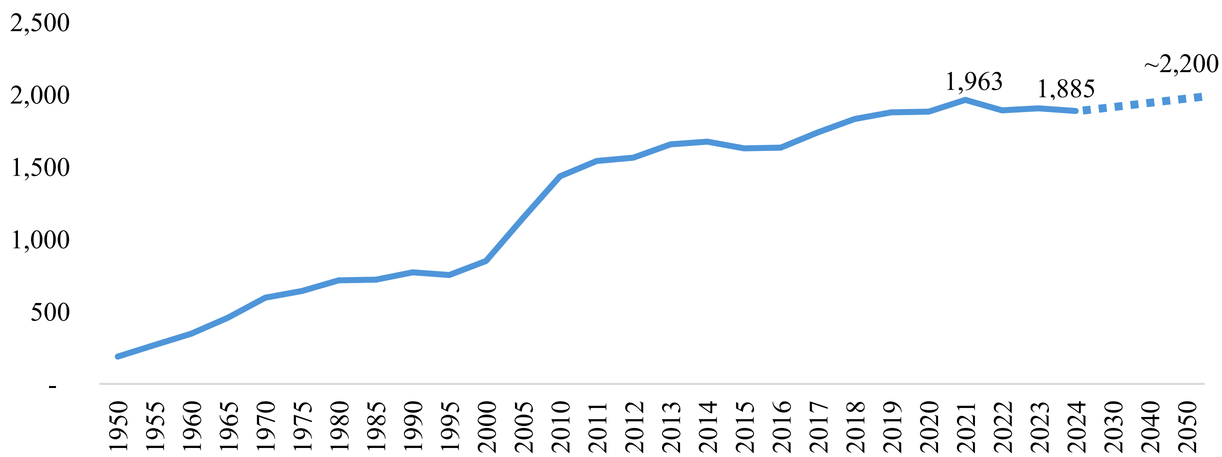
Global Overview in Steel Decarbonization

Steel is a cornerstone of modern economies, yet it is also among the most challenging sectors to decarbonize. As global demand for steel continues to grow, driven by urbanization, infrastructure expansion, and industrial development, the sector's emissions profiles has become increasingly central to global climate challenge. This chapter provides a necessary foundation for understanding the trend of steel industry, strategic choices, and constraints facing countries seeking to transition their steel industries in a carbon-constrained global economy.

1.1. Global Steel Production Trends & Overviews

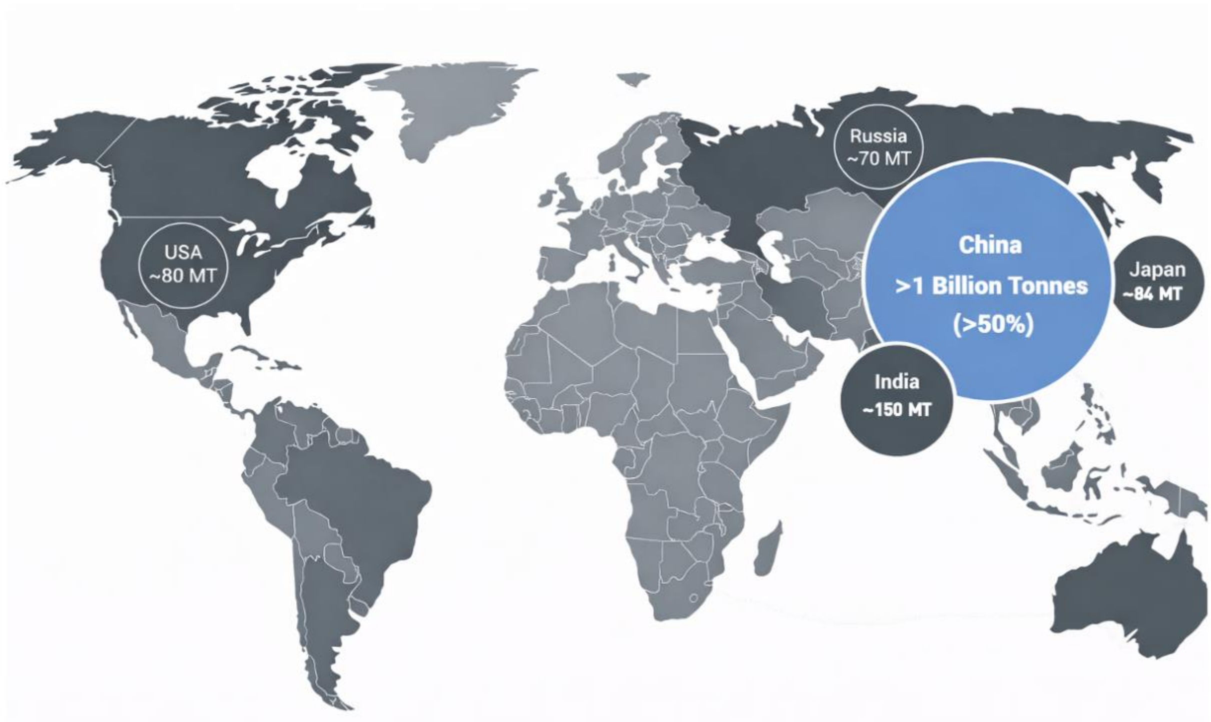
Global crude steel production reached 1.89 billion tonnes in 2024. Output has roughly doubled since 2000, driven largely by Asia's rapid development. China alone produces over half of the world's steel or around 1 billion tonnes in 2023/24 (Figure 1.1 and Figure 1.2) (Worldsteel Association, 2025), far surpassing the next-largest producer like India, Japan, the United States, and Russia. According to World Steel Association, steel production is expected to reach around 2.16-2.20 billion tonnes. At the same time, steel demand is projected to rise up to 30% by 2050. Besides China, most regions, particularly India, Africa and South-East Asia, will see an increase in demand, where urbanization and infrastructure development drive steel use (World Economic Forum, 2022).

Figure 1.1 Global production growth



Source: (Worldsteel Association, 2025)

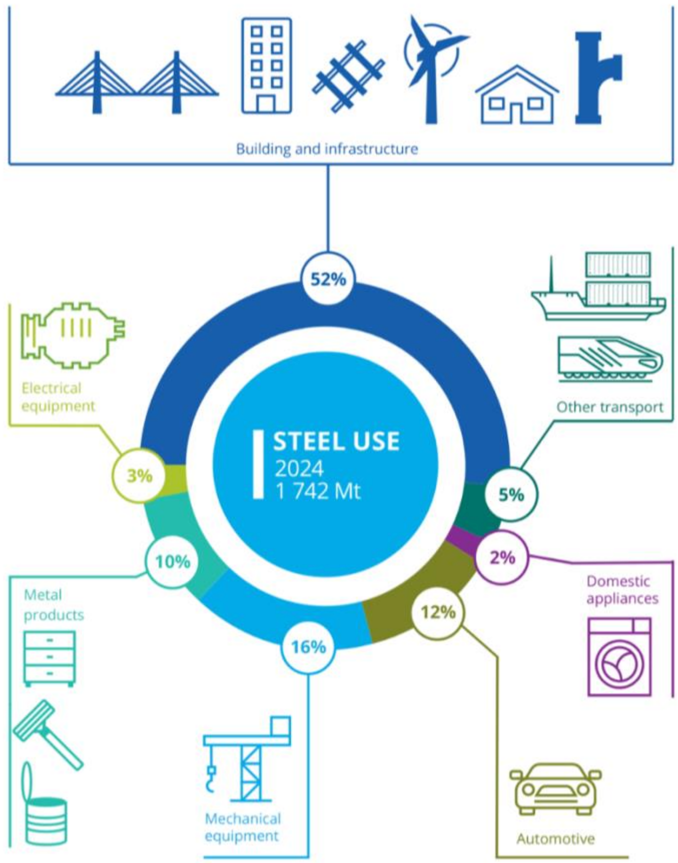
Figure 1.2 Production concentration, 2024



Source: (Center on Global Energy Policy, 2021)

Steel is fundamentally important to modern economies (Figure 1.3). It underpins construction (building and infrastructure) (52%), machinery (mechanical & electrical equipment) (19%), transportation (automative and other transport) (17%), and consumer goods (10%), reflecting steel's role as a backbone of industrial development (Worldsteel Association, 2025) (Center on Global Energy Policy, 2021).

Figure 1.3 Steel use by sector



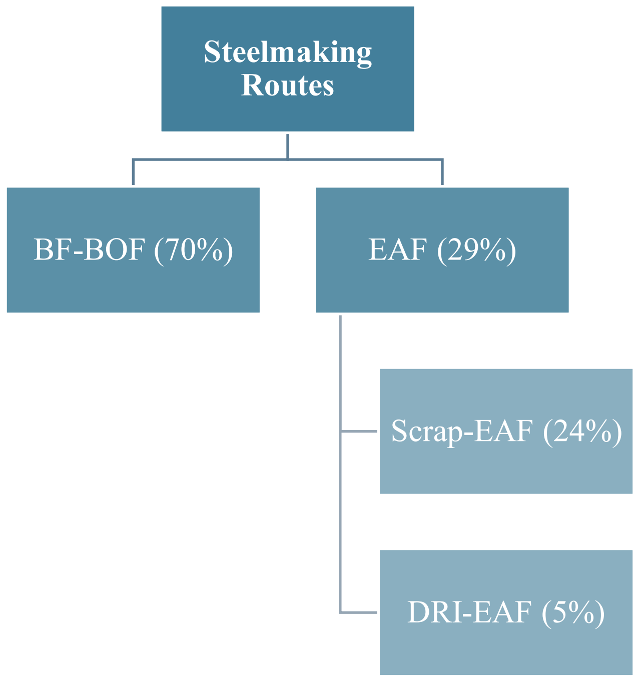
Source: (Worldsteel Association, 2025)

There are, however, no easy substitutes for steel's characteristics of strength, toughness, and recyclability. This combination is why every nation's infrastructure and manufacturing supply chains rely on it—and why it is so challenging to decarbonize.

Steel is made via two primary routes: (1) **the integrated route (BF-BOF)** and (2) **the electric arc furnace route (EAF)**. In the integrated route, iron ore is reduced to pig in a blast furnace (BF) using coke (derived from coal) and then converted to steel in a basic oxygen furnace (BOF). This method currently produces about 71% of crude steel production globally and it prevalent in China, Japan, and Europe.

Alternatively, steel can be made by melting scarp and/or direct reduced iron in an electric arc furnace, which account for the remaining 29% of production (24% Scrap-EAF and 5% DRI-EAF) (Figure 1.4). EAF mills dominate in the U.S. and some other regions. They rely on recycled steel scrap or direct reduced iron (DRI) as feedstock instead of raw iron ore. DRI itself is often made by reducing iron ore with natural gas in a shaft furnace and then fed into an EAF.

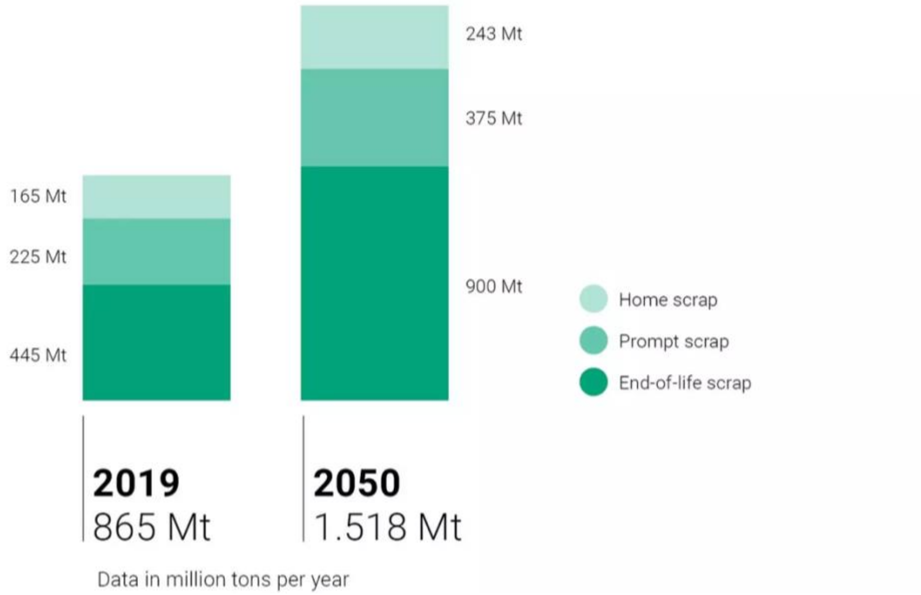
Figure 1.4 Steel making routes



Source: (Worldsteel Association, 2025)

The scrap-EAF route has much lower energy needs and carbon emissions per tonnes than the coal-based BF route, but it is constrained by scrap availability. However, a share is expected to increase as more scrap becomes available. Steel industry outlooks anticipate a greater role for scrap recycling: end-of-life scrap supply is expected to roughly double from 445 Mt in 2019 to 900 Mt in 2050, which could enable recycled material to supply 40% of future steel production (Figure 1.5) (SMS group, 2024).

Figure 1.5 Scrap availability (2019) and growth (2050)



Source: (SMS group, 2024)

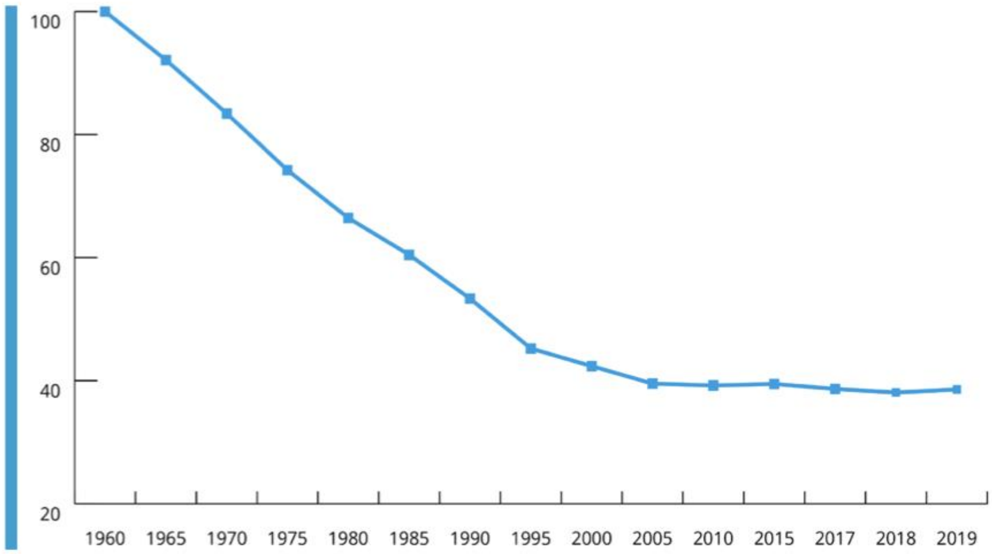
Given this scale and continued demand, including its importance to economies in dimensions of national security and labor, how the world decarbonizes steel will have major implications for emissions, trade, and industrial competitiveness.

1.2. Emissions Profile of the Global Steel Industry

1.2.1) Energy consumption in steel production

Steelmaking is highly energy-intensive, accounting for around 20% of total industrial energy use. Since 1960, the sector has achieved significant efficiency improvements, reducing the energy required to produce one tonne of crude steel by roughly 60%, driven by technological advancements and increased plant scale (Figure 1.6) (Worldsteel Association, 2021). Despite these gains, steel production still consumes substantial amounts of fuel and electricity. On average, producing one tonne of crude steel requires approximately 19-20 GJ of energy (equivalent to about 5.3-5.6 MWh).

Figure 1.6 Indexed Global Energy Consumption/tonne of crude steel production

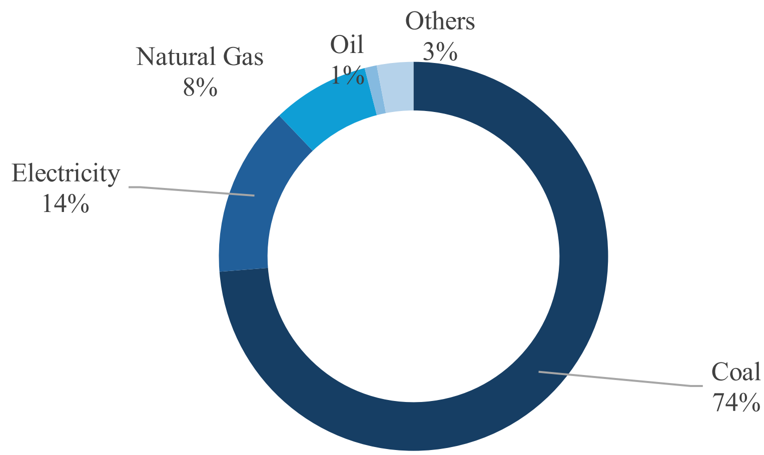


Source: (Worldsteel Association, 2021)

Energy intensity varies significantly across production routes. Primary steelmaking methods, BF-BOF and DRI-EAF, can require up to 25 GJ per tonne of steel. In contrast, the scrap-based EAF route is substantially less energy-intensive, consuming around 10 GJ per tonne, or roughly 2.5 times less than primary production routes (World Economic Forum, 2023).

Looking at the sector's energy mix, fossil fuel dependence remains a central challenge. Globally, approximately 74% of energy used in steel production is derived from coal, largely reflecting the dominance of coal-based blast furnace operations. Natural gas contributes a smaller share, while the remainder comes from electricity and other minor energy sources (Figure 1.7) (World Economic Forum, 2023). This composition also differs by process route. In BF-BOF production, about 89% of energy input comes from coal, 7% from electricity, 3% from natural gas, and 1% from other sources. In contrast, the EAF route relies more on electricity (around 50%) and natural gas (38%), with coal accounting for only 11% and other sources for 1% (Worldsteel Association, 2021).

Figure 1.7 Steel production energy mix



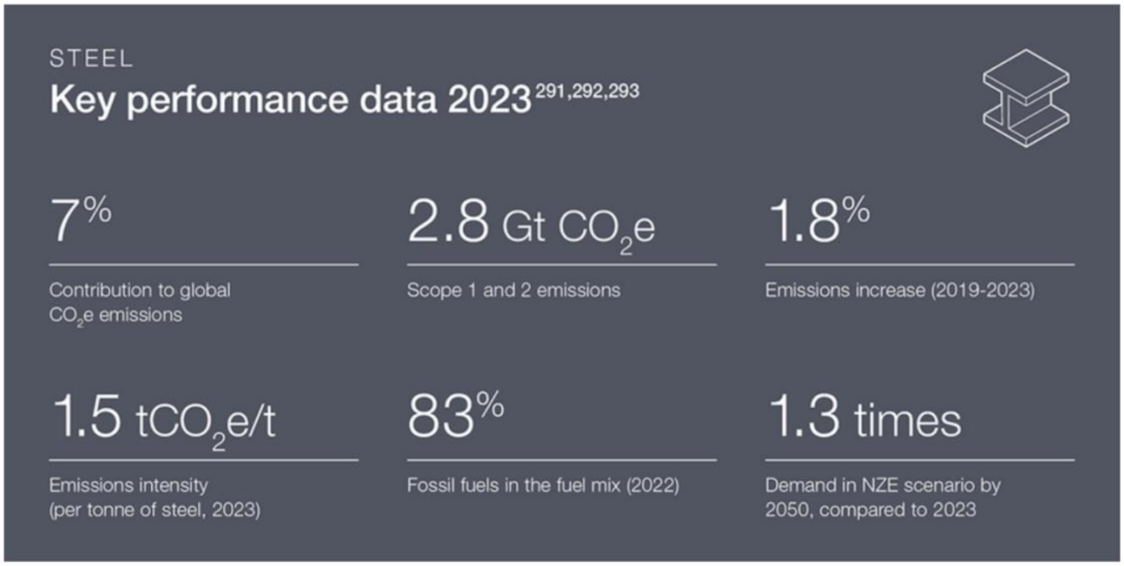
Source: (World Economic Forum, 2023)

Many integrated mills do practical energy recycling, for example, using blast furnace gas (a by-product rich in CO and CO_2) to fuel on-site power plants or boilers, and recovering waste heat from hot stoves or coke ovens. This improves overall efficiency; however, these measures do not change the fossil origin of the energy. They only make better use of the coal's energy content. Some benchmark integrated mills already operate near theoretical efficiency limits. In the EAF route, the electricity source is crucial. For EAF-based production, the carbon intensity of electricity becomes the key determinant of emissions: EAF powered by renewable electricity can significantly reduce emissions, whereas reliance on coal-based grid electricity results in persistently high emissions.

1.2.2) Environmental impact & decarbonization imperative

The iron and steel industry is a major contributor to climate change and local pollution. Globally, steel production is responsible for roughly 7% of energy-related CO_2 emissions, making it one of the largest emitting manufacturing sectors. This translates to about 2.8 gigatonnes of CO_2 emissions per year (out of about 50 Gt greenhouse gases worldwide) Key data shown in Figure 1.8. (World Economic Forum, 2023). If one includes indirect emission, some estimates put steel's emissions closer to 8-10% of global CO_2 (Breakthrough Energy, 2025). This emissions profiles means that meeting international climate targets (especially Paris Agreement) is practically impossible without addressing steel. The IPCC's 1.5°C pathways require heavy industry like steel to reach net-zero emissions by 2050, so the pressure is on this sector to fundamentally transform.

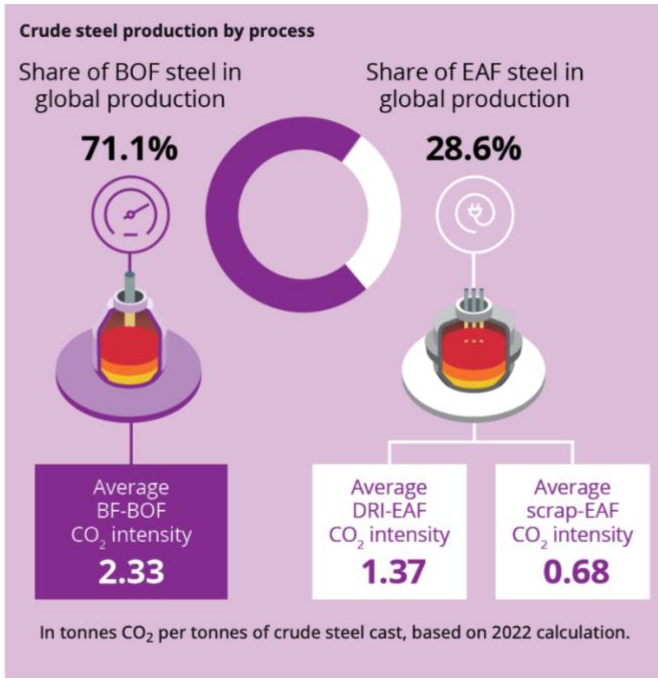
Figure 1.8 Key performance data of steel' carbon emission profile, 2023



Source: (World Economic Forum, 2023)

Like energy intensity, the emissions intensity is closely linked to the production routes, as illustrated in Figure 1.9. The production via the BF-BOF route has an average emissions intensity of approximately 2.33 tCO_2 per tonne of crude steel. In contrast, the EAF route is significantly less carbon-intensive, particularly when based on scrap. Scrap-based EAF steel has an average emission of only 0.68 tCO_2 per tonne, while DRI-EAF production averages around 1.37 tCO_2 per tonne, depending on the fuel and electricity mix.

Figure 1.9 Steel production's carbon emission profile by process



Source: (Worldsteel Association, 2025)

Beyond climate change, steel production has significant environmental and health externalities. Steel mills, especially integrated coke- and coal-based plant, emit large quantities of air pollutants: sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter (PM2.5 and dust), and toxic compound like heavy metals. These emissions harm local air quality and public health. For example, in the United States, the just 17 coal-based steel and coke plants were estimated to cause around 892 premature deaths and over 250,000 cases of asthma symptoms per year due to their pollution, with annual health cost on the order of USD 13 billion (Industrious Labs, 2024). Similar stories play out around the world, whether in Europe's Ruhr Valley or China's Hebei province, making steel decarbonization not just a climate issue but also a public health imperative.

Recognizing these impacts, there is increasing stakeholder pressure on the steel industry to decarbonize.

- Policymakers are tightening environmental regulations. For example, the EU's Industrial Emissions Directive, Carbon Border Adjustment Mechanism or CBAM (discussed in 1.4), etc.

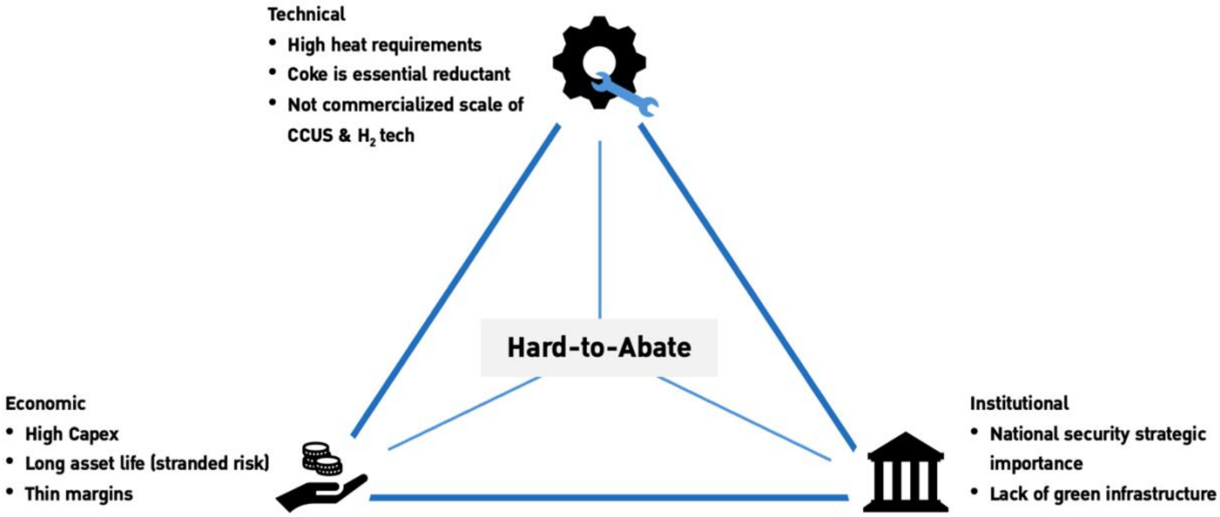
- Investors and shareholders are pushing under their ESG or climate commitments. Many large steelmakers (ArcelorMittal, Thyssenkrupp, Nippon Steel, POSCO, etc.) have now announce net-zero by 2050, at least for scope 1 and 2 emissions.
- Customers are playing a role. Automakers, construction firms, and appliance manufactures are increasingly interested in green or low-carbon steel to meet their own sustainability goals.
- International climate commitments drive the decarbonization imperative. Under the Paris Agreement, almost all major steel-producing countries have National Determined Contributions (NDCs) to reduce emission. Even China has pledged carbon neutrality by 2060 and specifically aimed to peak steel sector emission before 2025 (Climate Action Tracker, 2026).
- Global sectoral initiatives are also emerging. The Net-Zero Steel Initiative and Mission Possible Partnership have developed roadmaps for near-zero steel by 2050.

All these pressures add up to a strong decarbonization mandate for steel. In other words, there is an expectation that the industry must innovate and invest to drastically lower its carbon footprint in the upcoming decades.

1.2.3) Why is steel a "hard-to-abate" sector?

Steel is often labeled as a "hard-to-abate" sector, meaning that reducing emissions is technically, economically, and institutionally challenging compared to other industries. These challenges stem not from a single constraint, but from a combination of deeply embedded production processes, cost structures, and governance arrangements.

Figure 1.10 Triple constraint of steel decarbonization



Source: Authors

1. **Technical Barriers:** Steelmaking requires extremely high temperatures and complex chemical reaction to convert iron ore into steel. In conventional blast furnace production, coal-based coke plays a dual role: it acts both as a fuel to generate heat and as a reducing agent to remove oxygen from iron ore. This dual function makes direct substitution with low-carbon alternatives particularly difficult. While low-carbon technologies, such as hydrogen-based direct reduced iron (H_2-DRI) and carbon capture, offer promising pathways, they are not yet at the commercialized scale.
2. **Economic Barriers:** Steel production is highly capital-intensive, with large plants designed to operate over several decades. Those long investment cycles limit the ability of producers to rapidly shift technologies without risking stranded assets. At the same time, profit margins in the steel sector are typically thin, leaving limited cost headroom to absorb higher capital expenditures or operating cost associated with cleaner technologies. As a result, green or low-carbon steel production remains more expensive than conventional processes in most market, raising concerns about competitiveness.
3. **Institutional Barriers:** The supporting ecosystem required for green or low-carbon steel, such as reliable access to renewable electricity, hydrogen infrastructure, and carbon capture and storage, remains underdeveloped in many countries. Moreover, steel is often treated as a strategic industry due to its link to national security,

employment, and broader industrial development. This status can reduce governments' willingness to pursue deep structural reforms that may disrupt existing production models or impose short-term economic costs.

Taken together, these technical, economic, and institutional constraints explain why steel has emerged as a central focus of global industrial decarbonization efforts. Achieving deep emission reductions in this sector will require not only technology innovation, but also coordinated changes in market structure, energy systems, and policy frameworks.

1.3. Emerging Low-Carbon Steel Technologies

Decarbonizing steel fundamentally means finding ways to produce iron and steel without fossil carbon or with carbon capture. Broadly, the technological pathways fall into a few categories: increasing electrification (including recycling scrap), using alternative reductants like hydrogen, deploying carbon capture, utilization, and storage (CCUS) on existing processes, and other innovative processes.

1.3.1) Electrification and increased scrap recycling

The most straightforward way to decarbonize steel is to use more recycled scrap in electric arc furnaces, and power those EAFs with clean electricity. As mentioned above, recycling scrap is inherently low carbon as it avoids the ore reduction step entirely. Today, about 29% of steel come from scrap, which already saves a huge amount of energy and emissions. Many countries are trying to promote scrap use. For example, China has a target to increase scrap utilization as its steel stock matures (Climate Action Tracker, 2026).

However, scrap alone cannot meet all demand. The availability of scrap depends on past steel consumption, and emerging economies building new infrastructure simply do not have enough scrap yet. Also, certain steel grades, like ultra-low alloy or very clean steels, cannot use 100% scrap due to residual element. They still need some primary iron.

Beyond scrap-EAF, full electrification of ironmaking is being explored through novel processes like molten oxide electrolysis (MOE). This is similar to aluminum smelting, where electricity is used to directly reduce metal from ore. In MOE for iron is dissolved in a high-temperature electrolyte and an electric current split the iron from oxygen. The appeal is that it uses only electricity and no carbon-based reductant at all. However, it runs at around 1600°C and requires specialized inert anodes. Moreover, it is still in R&D and not expected to be commercially viable before 2035 (World Economic Forum, 2022). If successful, though, it could allow steelmakers to essentially electrowin iron like aluminum, which when paired with renewable power would be near-zero carbon.

1.3.2) Hydrogen-based direct reduction (H_2-DRI)

This is one of the most promising and talked-about routes to near-zero carbon steel. The concept is to use green hydrogen in a direct reduced iron furnace to replace natural gas or coal. In DRI, hydrogen gas can act as reducing agent as it reacts with iron ore to remove oxygen, producing metallic/sponge iron and water vapor (instead of CO_2) (SteelWatch, 2025). The metallic iron is then melted in an electric arc furnace to produce steel. This process eradicates the need for coal/coke/natural gas, so it can be virtually carbon-free if the hydrogen and electricity are green.

Several demonstration projects are underway. Notably, the HYBRIT project in Sweden which in 2021 produced the world first batch of sponge iron reduced using 100% hydrogen, and has since delivered trial green steel to automakers. The technology is near commercial viability. The main barriers are scale and cost of hydrogen. Hydrogen reduction can theoretically achieve the same iron output as a blast furnace with zero CO_2, but it requires huge supply of H_2. Producing that via electrolysis takes on 2,500-3,000 kWh of electricity per tonne of steel. As a result, widespread adoption of H_2-DRI hinges on abundant cheap renewable electricity to make hydrogen.

1.3.3) Carbon Capture, Utilization, and Storage (CCUS)

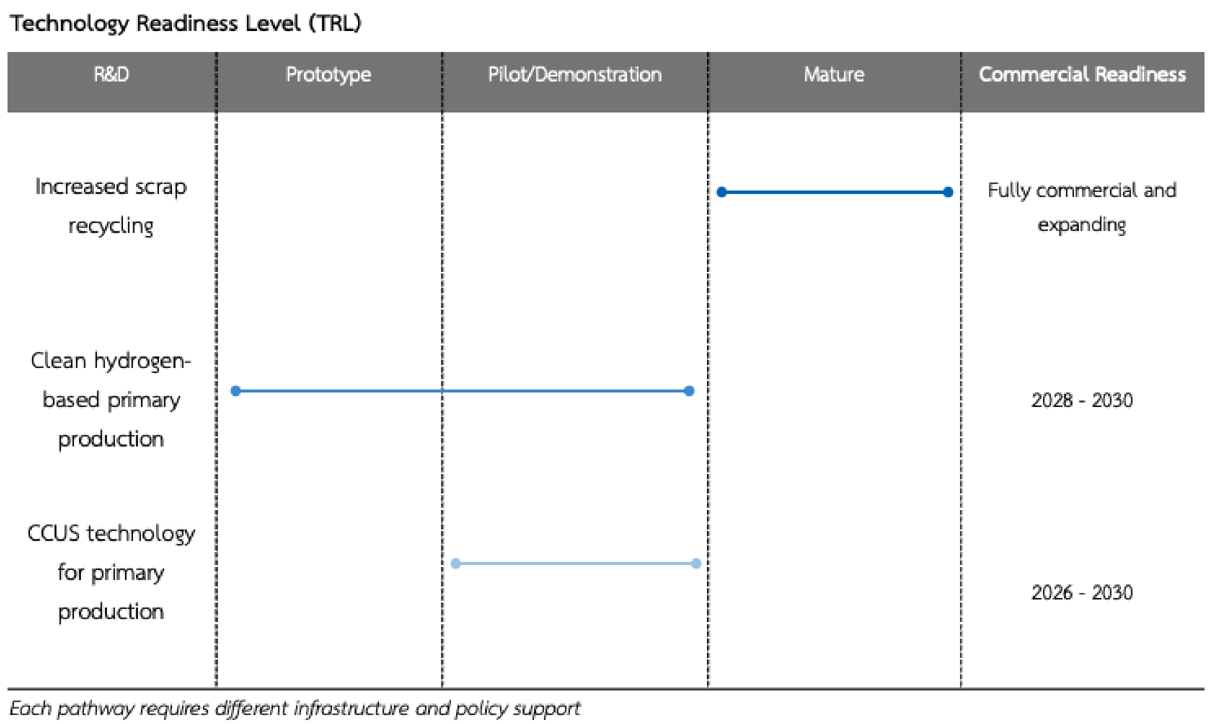
CCUS is a retrofit-oriented pathway. Instead of changing the fundamental process, capture the CO_2 that is produced and store it or use it, so it does not enter atmosphere. In steel, CCUS can be applied to a few places. The most obvious is the blast furnace gas. Also, steel plants often have their own power plants burning blast furnace gas, coke oven gas, etc., which have CO_2 that can be capture. Studies show that by deploying capture on the main emission points, it is technically possible to capture about 60-80% of a steel plant's CO_2 emissions (Ramboll, 2025).

The advantages of CCUS are that it can be retrofitted to existing plants and can achieve large emission reductions without fundamentally changing the steelmaking chemistry. However, the disadvantages are also significant. It is energy-intensive and costly to capture CO_2, and it also needs infrastructure to transport and store or utilize it. According to analyses, applying CCUS could add 65-120% cost premium to steel, making it one of the most expensive options (World

Economic Forum, 2023). In addition, it will not be able to reach 100% capture rate. Still, CCUS could play a big role as a transition strategy, especially for newer blast furnaces that cannot be shut down soon.

Regions with good CO_2 storage sites are exploring CCUS hubs where clusters of industries, including steel mills, pipe their CO_2 for storage. For example, ArcelorMittal's plant in France is part of the North Lights project to ship captured CO_2 to offshore storage. In the UAE, Emirate Steel has already implemented a CCUS project, capturing about 0.8 $MtCO_2$/year from its DRI plants and injecting it into oil fields for enhanced oil recovery.

Figure 1.11 Technology Readiness Level of steel decarbonization



Source: (World Economic Forum, 2022)

Shifting to green or low carbon steel is as much an energy challenge as a technological one. All the low carbon steel pathways are far more electricity-intensive (either directly or via hydrogen production) than the current coal-based route. This implies that decarbonizing steel will require a massive expansion of carbon-free energy, both power grid and new energy carriers like hydrogen, and significant upgrades to industrial infrastructure.

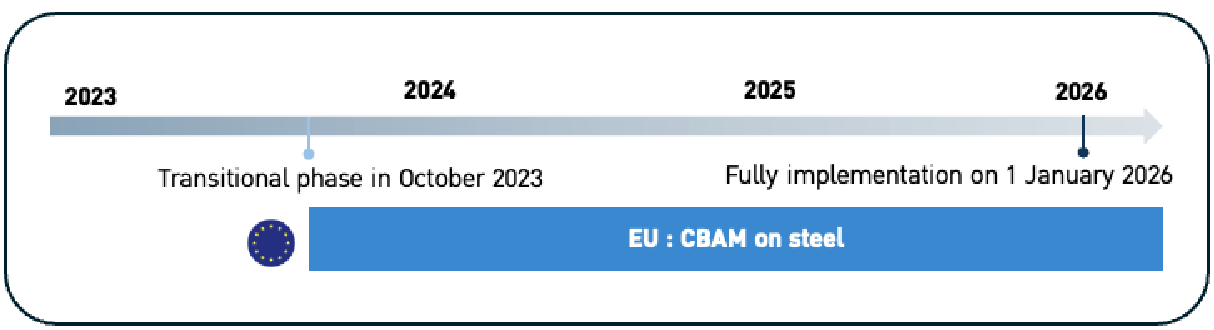
1.4. International Policy Drivers

One prominent policy development affecting the steel industry is the EU's Carbon Border Adjustment Mechanism (CBAM). It is a carbon tariff on imports of carbon-intensive goods. CBAM is being implemented by the European Union (EU) to put a fair price on the carbon emissions of imported products like steel, cement, aluminum, fertilizers, electricity, and hydrogen (European Commission, 2026).

The goal is to prevent carbon leakage, where EU companies subject to carbon costs (through the EU Emissions Trading System or ETS) could be undercut by foreign producers with the lack of climate policies. Under CBAM, importers will have to report and pay for CO_2 emissions embedded in certain products entering the EU, so that imported steel faces a similar carbon cost as steel made in Europe.

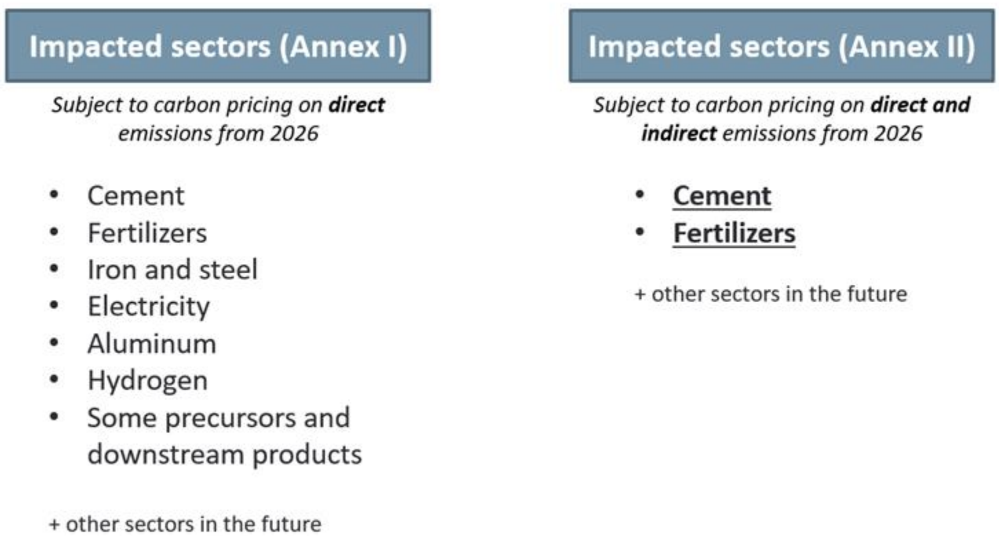
The EU's CBAM entered a transitional phase in October 2023, where importer must begin reporting the embedded emissions of covered products. No financial payments are due during this phase. It is primarily for data collection and to allow companies to adjust. Starting from 1 January 2026, CBAM is fully implemented (Figure 1.12). At this point, importers of covered steel products will be required to purchase CBAM certificates equal to the tons of CO_2 emitted in producing those goods, at a price pegged to the EU ETS allowance price. CBAM will progressively replace the free allowance under the EU ETS by 2030 in parallel. This alignment ensures EU producers and foreign producers are on equal standard.

Figure 1.12 CBAM Timeline and Milestones



In the steel sector, CBAM initially covers key steel products such as raw iron, crude and semi-finished steel, certain finished steel items, and ferroalloys. It accounts for direct emissions from production of those goods, while indirect emissions from electricity are not initially included for steel, but the importers must still report them (it will be included at a future date determined by the European Parliament) (see Figure 1.13) (European Commission, 2026). Importers can report the actual emissions intensity of their steel, verified by accredited experts. If they do not, a default value (likely high) is assigned to prevent under-reporting.

Figure 1.13 Impacted sectors by CBAM under Annex I and Annex II



Source: (European Commission, 2026)

CBAM has raised concerns among steel exporters, especially in developing countries, about competitiveness and market access. Many developing countries' steel sector have higher CO_2 intensities than EU benchmarks often because they use coal-based methods. For example, a country like Russia, Türkiye, or India that export a lot of basic steel to Europe could face significant fees if their production is carbon heavy. This, however, gives an incentive for exporters to adopt cleaner processes to maintain access to EU markets.

CBAM introduction has already prompted some adjustments. Countries like Türkiye and China have started developing systems to track and reduce the carbon intensity of their steel, partly to mitigate CBAM effects.

Besides CBAM, other countries are also considering similar mechanisms to shield their industries and encourage cleaner production. For example, The United States is currently considering a Clean Competition Act (CCA), which is expected to cover 10 product categories, including iron/steel; The United Kingdom is considering a UK CBAM, which is expected to cover products such as aluminum, cement, ceramics, fertilizers, glass, hydrogen, and iron/steel; and Australia is expected to initially cover two main product categories: iron/steel and cement. These efforts suggest a future where carbon intensity becomes a factor in trade flows of steel, especially for export-oriented producers in emerging economies.

Figure 1.14 Other upcoming carbon border adjustment mechanisms

Other (upcoming) pressures

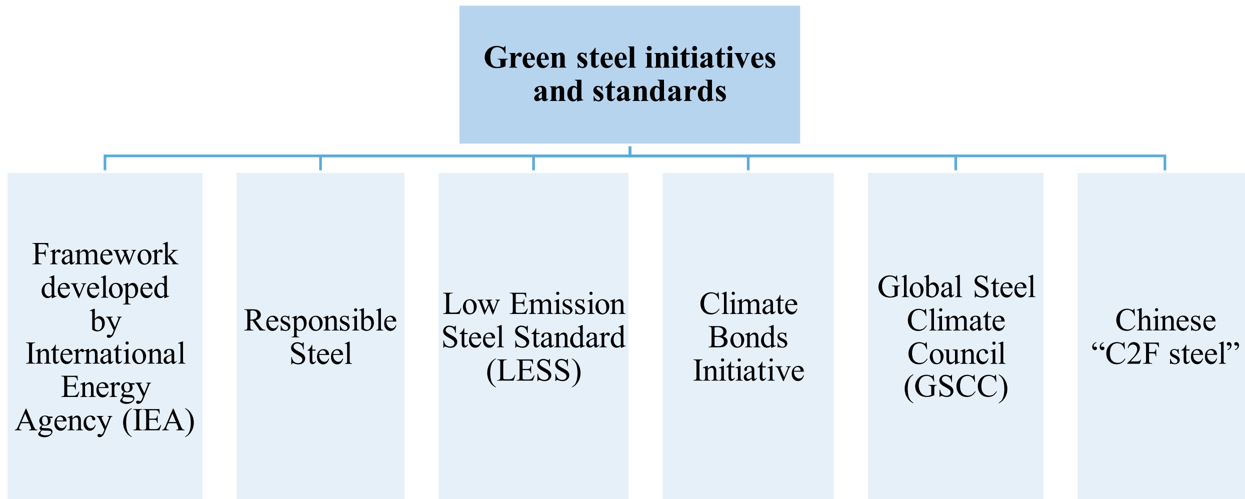
United States	Considering the Clean Competition Act , which is expected to cover ten product categories, including steel.
United Kingdom	Planning to introduce a BCA under the name UK CBAM, covering steel.
Australia	Proposing a BCA that will initially apply to two product categories: iron/steel and cement.

1.5. Emerging Green Steel Standards and the Role of Carbon Accounting

As governments, investors, and downstream industries increase pressure on heavy industry to reduce emissions, the need for credible and comparable methods to measure the carbon footprint of steel has become increasingly important. In response, a number of international initiatives and certification systems have emerged to define, measure, and verify what constitutes "low-carbon" or "green" steel. These frameworks are gradually shaping the emerging market architecture for low-carbon steel by standardizing carbon accounting methodologies and enabling the differentiation of steel products based on their emissions intensity.

Several initiatives are currently developing standards for low-carbon steel. Among the most prominent are the frameworks developed by organizations such as the **International Energy Agency (IEA), ResponsibleSteel,** the **Low Emission Steel Standard (LESS)**, the **Global Steel Climate Council (GSCC),** the **Climate Bonds Initiative**, and the **Chinese "C2F steel"** (European Commission, 2025). While these initiatives differ in scope and methodology, they share a common objective: establishing transparent and verifiable metrics for measuring the greenhouse gas emissions associated with steel production. Most standards rely on lifecycle-based accounting approaches that assess emissions across defined system boundaries, typically ranging from plant-level ("gate-to-gate") emissions to broader "cradle-to-gate" assessments that include upstream mining, energy production, and material inputs.

Figure 1.15 Green steel initiatives and standards



Source: (European Commission, 2025)

Steel production involves multiple processes and inputs, including iron ore mining, reduction processes, electricity consumption, and downstream processing. Without standardized accounting methods, comparing emissions across production routes or across countries becomes extremely difficult. Green steel standards therefore define consistent methodologies for calculating emissions intensity. These metrics allow policymakers, investors, and buyers to evaluate the relative carbon performance of different production routes.

This emergence of green steel standards represents a critical institutional development in the global steel transition. Together, they transform carbon emissions from an external environmental concern into a measurable product attribute that directly influences trade, investment, and industrial competitiveness. As these frameworks continue to evolve and converge, they are likely to play a central role in shaping the global market for low-carbon steel in the coming decades.

1.6. Conclusion

This global overview establishes the analytical foundation for the subsequent chapters. Understanding production trends, emissions structures, technological options, and policy drivers is essential before assessing how individual countries, such as Thailand, can navigate the transition. The key question is no longer whether steel must decarbonize, but how different national contexts can align technological pathways, energy systems, and industrial strategies in a carbon-constrained global economy.

Steel lies at the core of the global decarbonization challenge due to its scale, structural importance, and dependence on carbon-intensive processes. While global demand continues to rise, the sector remains heavily reliant on coal-based production, making it a major contributor to industrial emissions.

Although multiple low-carbon pathways are emerging—including scrap-based EAF, hydrogen-based DRI, and CCUS—none offer a standalone solution. Each involves trade-offs across cost, technological maturity, and infrastructure requirements. This reinforces the characterization of steel as a “hard-to-abate” sector, where progress depends on coordinated transformation across energy systems, industrial processes, and policy frameworks.

At the same time, the global policy landscape is shifting rapidly. Mechanisms such as CBAM and the emergence of green steel standards are redefining competitiveness by embedding carbon intensity into trade. As a result, decarbonization is no longer optional but a prerequisite for market access.

Three implications follow. First, transition pathways will be uneven and context-specific. Second, access to low-carbon energy will become the primary constraint. Third, global steel value chains will become increasingly fragmented and strategic. These dynamics set the stage for assessing Thailand’s position within the emerging low-carbon steel economy.

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Chapter 2

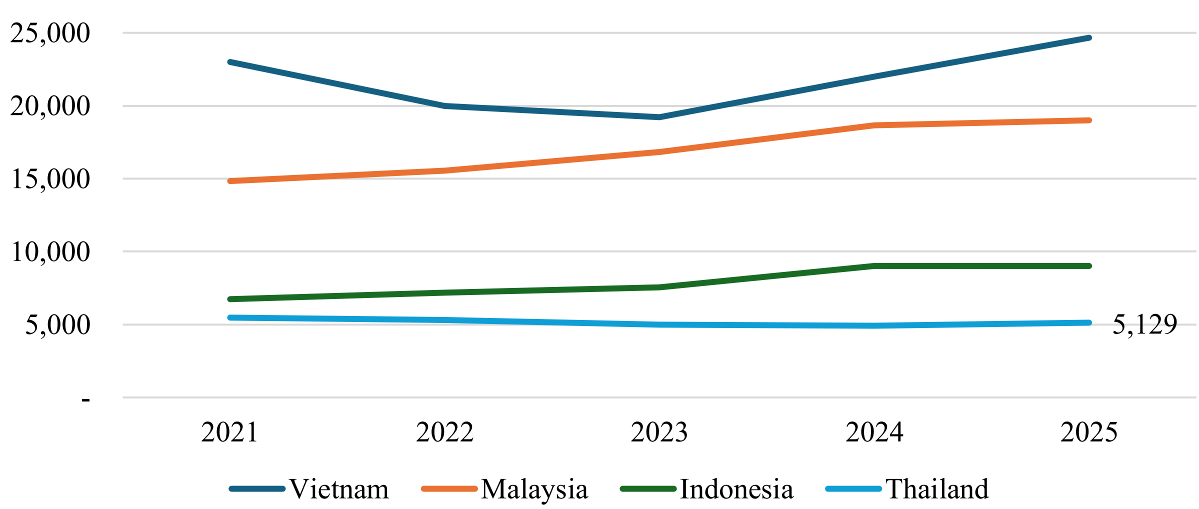
Thailand’s Steel Sector

The steel industry is a fundamental and strategically important sector of Thailand’s economy, serving as a critical input for downstream industries along the value chain, including construction, automotive manufacturing, and national infrastructure development. As global market conditions become increasingly shaped by cost pressures, technological shifts, and emerging climate-related trade measures, understanding the underlying structure of Thailand’s steel sector has become critical. This chapter examines the production landscape, demand structure, cost competitiveness, and exposure to external pressures, providing the necessary foundation for assessing the strategic choices available to Thailand in a changing global steel economy.

2.1. Production, Capacity Utilization, and Import Dependence

Thailand’s steel production scale is currently at a medium level within the Association of Southeast Asian Nations (ASEAN) region. Thailand’s crude steel production amounted to 5.13 million tonnes, ranking fourth in the region after Indonesia, Vietnam, and Malaysia (Shanghai Metals Market, 2025; Worldsteel Association, 2026) (Figure 2.1).

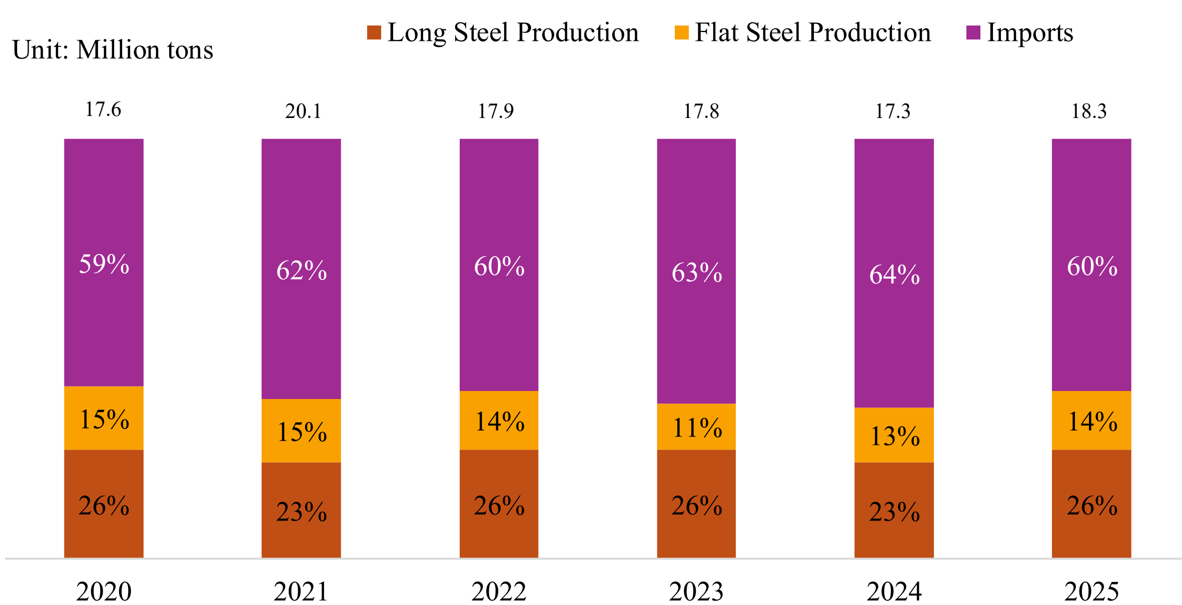
Figure 2.1 Production of crude steel



Source: (Worldsteel Association, 2026)

In 2025, Thailand's steel consumption was estimated at approximately 16-18 million tonnes per year, while domestic production stood at around 5-6 million tonnes. This resulted in import dependency of roughly 11 million tonnes, accounting for around 60 percent of total steel consumption (SCB EIC, 2025; ISIT, 2025) (Figure 2.2). This situation reflects fundamental structural limitations within Thailand's steel industry; these are not only driven by short-term economic fluctuations but rather stem from the characteristics of the production structure and domestic manufacturing capabilities that are misaligned with evolving domestic consumption patterns.

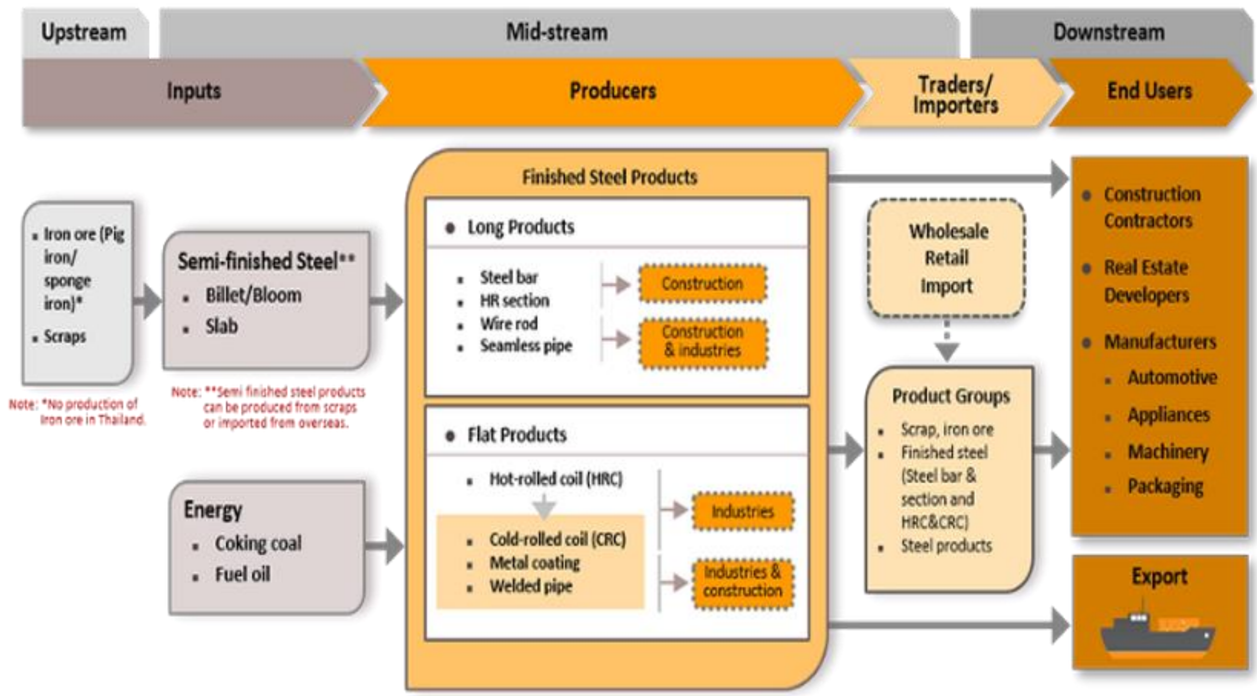
Figure 2.2 Thailand's steel consumption, 2025



Source: (SCB EIC, 2025; ISIT, 2025)

Structurally, Thailand's steel industry comprises upstream, midstream, and downstream segments (Figure 2.3). Within the midstream segment, which involves primary steelmaking processes, Thailand relies predominantly on electric-based steelmaking technologies, as there is currently no large-scale commercial production of upstream production from iron ore. The melting process primarily utilizes pig iron, sponge iron, and steel scrap, processed through two main types of furnaces: induction furnaces (IF) and electric arc furnaces (EAF). These technologies are critical in determining the types, quality, and range of steel products manufactured domestically.

Figure 2.3 Thailand steel supply chain



Source: (Krungsri Research, 2019)

While Thailand's prevailing production technologies offer greater operational flexibility and require lower initial capital investment than conventional primary steelmaking, both furnace types are inherently better suited for manufacturing long products and construction-grade steel than for flat products or higher-quality steel. Consequently, the domestic steel industry faces significant limitations in meeting the stringent requirements of higher value-added downstream sectors, such as automotive manufacturing and advanced machinery production.

In recent years, domestic steel producers have increasingly shifted toward EAF technology due to its greater flexibility in raw material selection. Nevertheless, this predominantly scrap-based production structure faces significant constraints regarding the quantity and quality of domestically available scrap. Such limitations not only affect the quality of finished steel products but also hinder Thailand's ability to fully substitute imports.

Trends in scrap availability further illustrate these structural. In 2023, Thailand's total scrap demand for steel production was 5.5 million tonnes. Domestic scrap supply amounted to 4.7

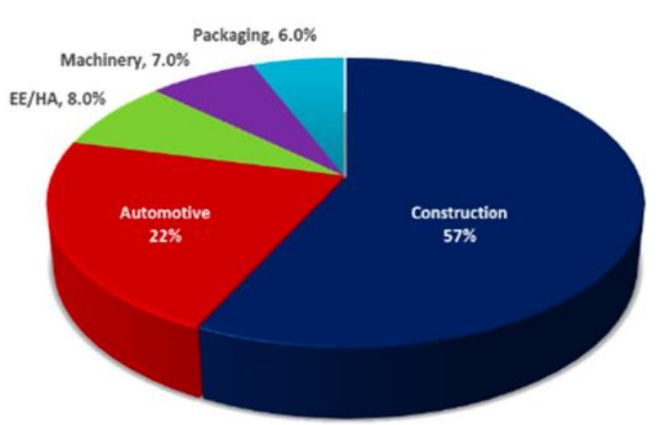
million tonnes, while scrap imports were recorded at 1.3 million tonnes. Major import sources included the United States, Australia, Japan, and Panama. (SEAISI, 2024).

This production structure also affects capacity utilization within Thailand's steel industry. Despite the installed production capacity, the mismatch between domestic production capabilities and actual market demand results in uneven utilization rates. In recent years, capacity utilization has remained relatively low, at around 30 percent. Consequently, operational levels fall below potential, particularly when domestic demand shifts toward high-grade products that local producers are unable to supply (Steel Radar, 2024; Shanghai Metals Market, 2025).

2.2. Domestic Demand Structure

Thailand's domestic steel demand structure is driven primarily by the construction sector in terms of volume, whereas high value-added downstream industries, such as the automotive and machinery, have played an increasingly important role regarding quality standards and value-added consumption (Figure 2.4). This demand structure directly affects the ability of Thailand's steel industry to meet domestic needs and is closely linked to the structural constraints on the production side.

Figure 2.4 Share of steel consuming sector by demand



Source: (FTI, 2024)

The construction sector is the key driver of steel consumption in Thailand, with demand concentrated mainly in long products and structural steel. Since these products can be manufactured domestically using existing production technologies, the demand structure of the construction sector broadly aligns with current production capacity of Thai steel producers and constitutes an important base for domestic capacity utilization. However, heavy reliance on the construction sector alone could make the steel industry vulnerable to economic cycles and fluctuations in public investment.

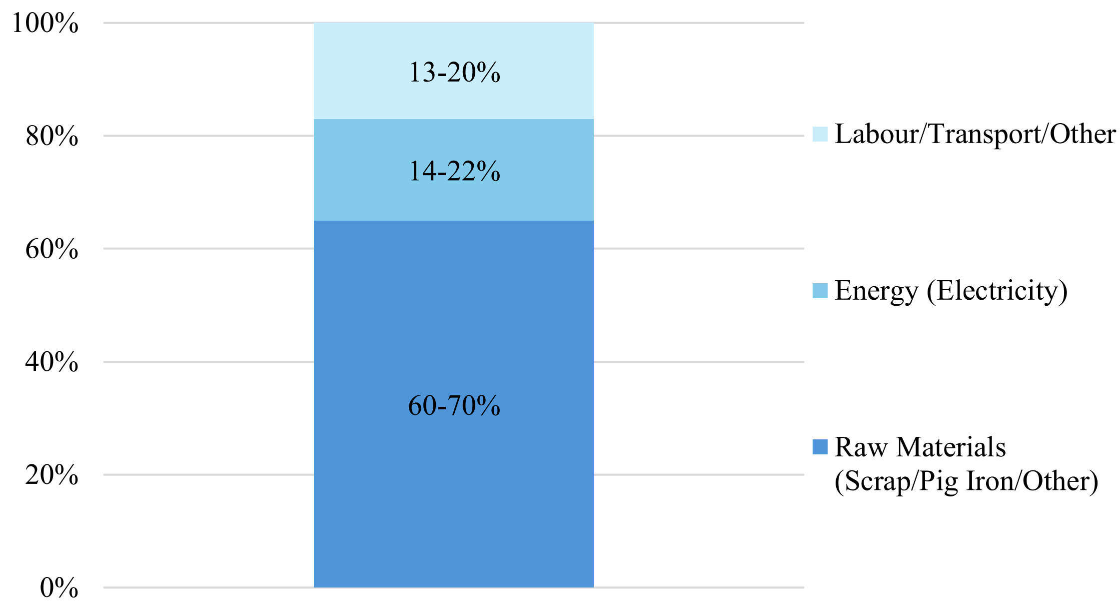
In contrast, the automotive and machinery industries, while accounting for a smaller share of steel consumption in volume terms, require steel products with higher quality, stringent production standards, and consistent material properties. Steel demanded by these sectors is predominantly of high-grade flat products, for which domestic production capabilities remain limited in meeting downstream industry specifications.

Thailand's steel demand structure shows how different sectors use steel, and it also highlights the limitations of domestic producers in meeting that demand. This mismatch between what is needed and what can be produced locally explains why Thailand continues to rely on steel imports.

2.3. Cost Structure and Competitiveness of Local Production

The cost structure of Thailand's steel industry is largely driven by input costs, with raw materials accounting for the largest share at approximately 60-70 percent of total production costs. Energy, particularly electricity, represents the second-largest component at around 14-22 percent, followed by labour, transportation, and other, which together account for about 13-20 percent. This structure, domestic producers are highly exposed to fluctuations in raw material and energy prices, while operating with relatively low profit margins. As a result, the industry's cost structure is shaped not only by persistently high production costs but also by structural constraints that limit flexibility and the ability to adapt to changing market conditions (Figure 2.5).

Figure 2.5 Production cost structure, 2025



Source: (steelonthenet, 2025)

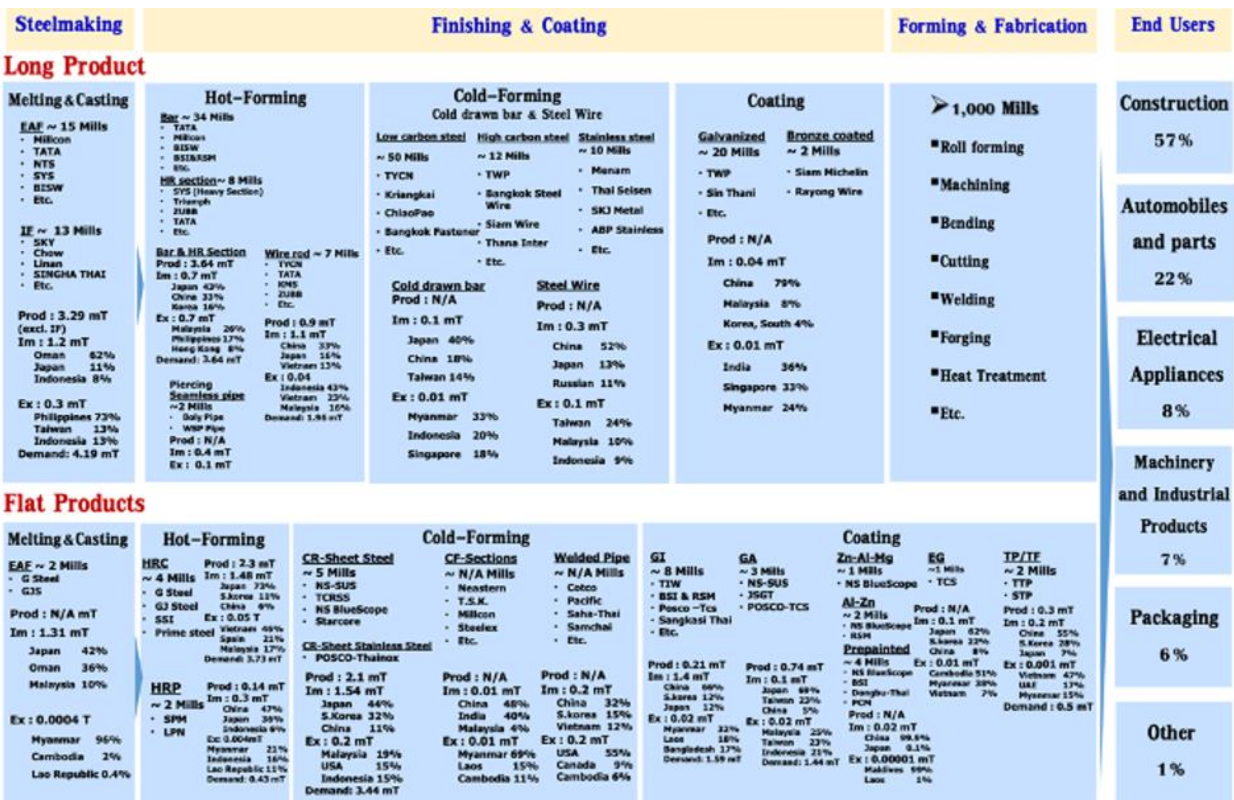
Dependence on imported inputs, including semi-finished steel and key raw materials, exposes domestic producers to fluctuations in global prices and exchange rates, limiting their ability to control or predict production costs. This external cost exposure weakens their capacity to compete on price, particularly during periods of intensified import competition. As a result, cost competitiveness in Thailand's steel industry is driven less by improvements in domestic production efficiency and more by changes in external market conditions.

2.3.1) Technology choice and cost implications

Midstream production technologies play a critical role in shaping cost structures and market accessibility within Thailand's steel industry. In particular, the choice between conventional furnace technologies and electric arc furnaces (EAF) has direct implications for raw material flexibility, product quality, and environmental performance. For example, induction furnaces (IF) operate as open systems and contribute to higher levels of dust and toxic gas emissions compared to more modern production methods (The Nation, 2025).

Production using conventional furnace technologies is generally associated with lower capital investment and simpler operating processes, making it more accessible to smaller producers. However, this route is constrained by limited raw material flexibility and challenges in maintaining consistent product quality. In contrast, EAF based production offers greater flexibility in raw material use including steel scrap, pig iron, and direct reduced iron enabling the production of higher quality steel suitable for a wider range of end uses. Nevertheless, EAF based production faces increased exposure to volatility in scrap availability (Recyglo Thailand, 2024) and electricity costs, both of which constitute major cost components for EAF operators, particularly as the share of EAF production in Thailand continues to increase.

Figure 2.6 Thailand steel industry, 2022



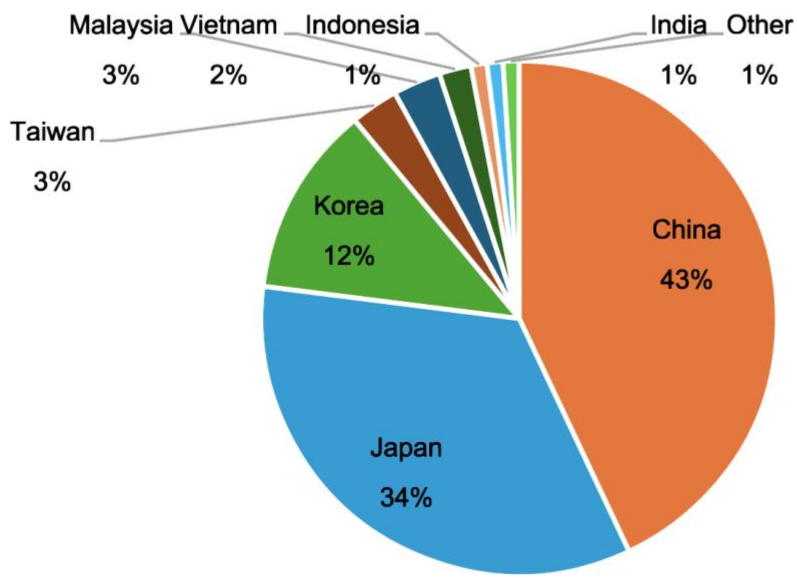
Source: (Iron and Steel Institute of Thailand, 2024)

Energy costs, especially electricity, may further intensify cost pressures in the steel industry. Electricity represents a significant share of overall production costs. While conventional production routes may involve lower electricity consumption, limiting its flexibility in adjusting energy use or passing higher costs on to end users further constrain producers' ability to maintain long-term competitiveness.

2.3.2) Competitiveness

The competitiveness of Thailand's steel sector varies across product segments and end market. Domestic producers have competitive advantage in segments with less stringent requirements, particularly construction related steel products. In contrast, competitiveness in high-grade segments, those serving the automotive and machinery industries are more limited due to stricter quality standards and the need for metallurgical consistency. Consequently, these industries continue to rely on either specialized imports or high-specification domestic steel (Figure 2.7).

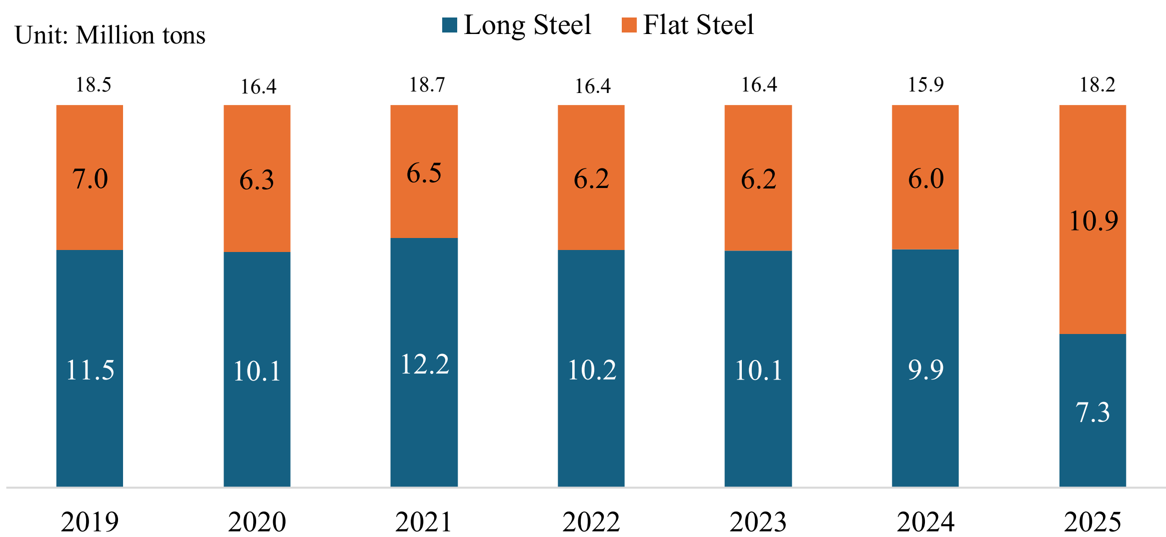
Figure 2.7 Share of imported steel to Thailand (Jan-May 2024)



Source: (FTI, 2024)

Structurally, the competitiveness of domestic producers is therefore concentrated on long steel products, such as reinforcing bars and structural steel for construction. In contrast, flat steel and higher-quality steel products required by the automotive and machinery industries remain largely import dependent.

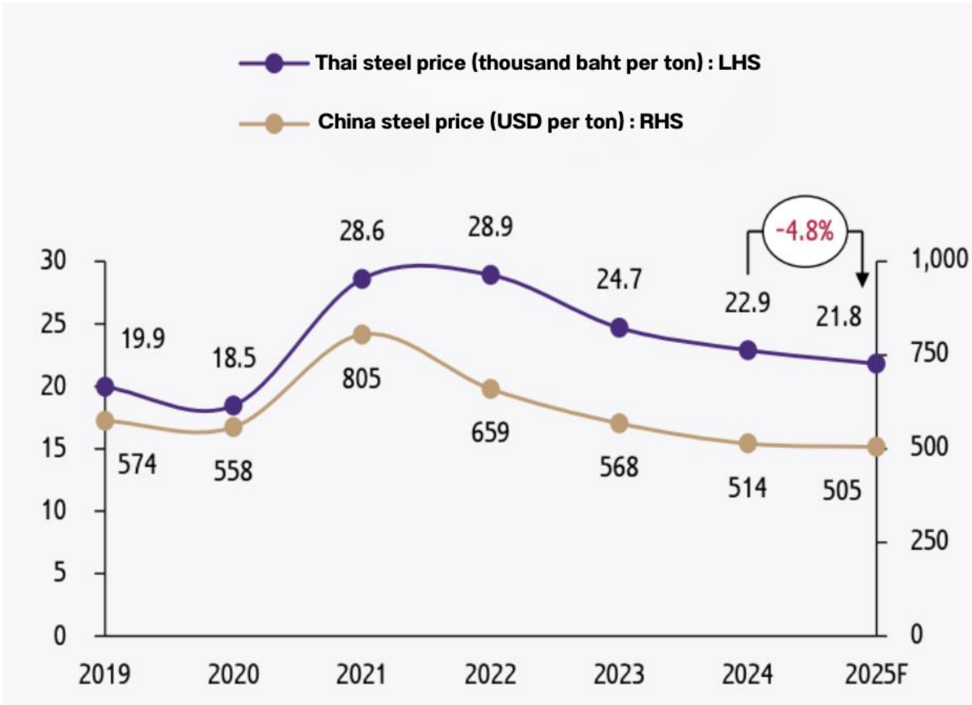
Figure 2.8 Domestic demand for steels in Thailand



Source: (SCB EIC, 2025; ISIT, 2025)

Beyond high quality steel segments, domestic producers also face sustained pressure from imports arising from global oversupply or trade distortions, particularly from China (Figure 2.9). These imports are often produced at large scale with lower unit costs, exert downward pressure on domestic prices and compress profit margins. As a result, Thai producers face limited capacity to respond, leading to production cutbacks that further constrain competitiveness.

Figure 2.9 Trend of steel price (Thailand vs. China)



Source: (SCB EIC, 2025)

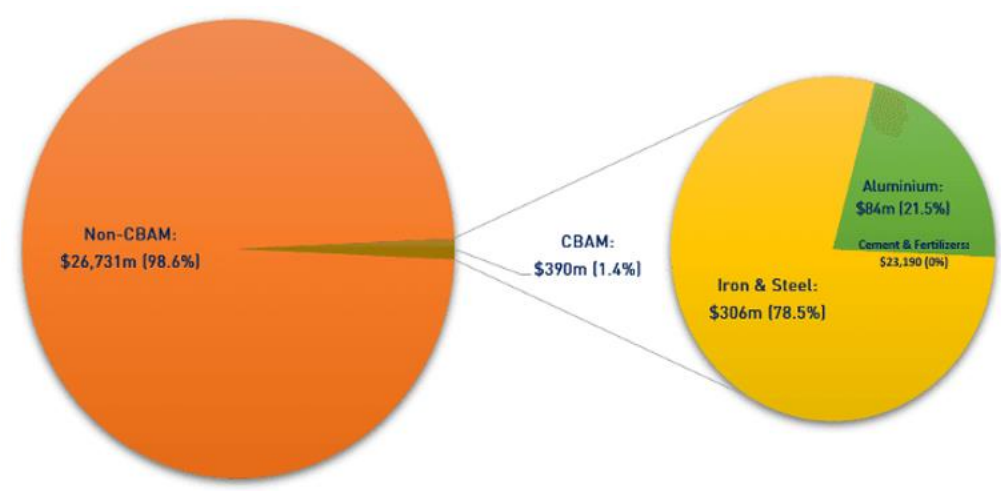
In summary, cost structures, production technologies, and the composition of domestic demand collectively shape the competitive position of Thailand's steel industry. Against the backdrop of shifting global market dynamics, these structural vulnerabilities expose the sector to heightened risks from international trade pressures and climate-related trade measures, which will be discussed in the following section.

2.4. Exposure to Global Market Pressures

Thailand's steel industry is facing increasing external pressures arising from both climate-related trade measures and trade protectionist policies. These pressures cannot be viewed in isolation; instead, they interact with the existing structural constraints in Thailand's steel sector, particularly those related to production structures, cost competitiveness, and domestic demand patterns. This interaction elevating systemic risks for domestic producers.

The European Union's Carbon Border Adjustment Mechanism (CBAM) is a primary example of trade measures linked to greenhouse gas emission reductions, carrying direct implications for steel exporters from non-EU countries, including Thailand. Although iron and steel exports account for only about 1.1 percent of Thailand's total exports to EU (Figure 2.10). CBAM introduces significant qualitative impacts on Thai producer. These impacts include substantial compliance costs, carbon emissions reporting requirements, and long-term financial risks as the mechanism now enter its full implementation phase in 2026 (PIER, 2024).

Figure 2.10 Share of Thailand's steel export to EU



Source: (PIER, 2024)

Within the context of Thailand's steel industry, the impact of CBAM is especially significant because most producers operate under thin profit margins and rely heavily on imported raw materials, as previously discussed in Section 2.3. The additional financial burden imposed by CBAM not only affects price competitiveness in the European market but also increases risks related to investment decisions and market accessibility within global value chains, particularly for export-oriented downstream industries.

Thailand's steel exports to the EU are estimated to incur CBAM certificate costs of at least 1.5-1.7 percent of the total export value under mechanism's product coverage. This is equivalent to approximately THB 167-193 million, implying that Thai steel exporters to the EU may face an additional cost burden of around THB 1,338-1,545 per tonne of steel (Bangkok Bank, 2023). These costs, effective as of the full implementation phase in 2026, represent a significant financial challenge for producers operating with narrow profit margins.

Beyond the direct financial burden, the impact of CBAM is also shaped by the ability of producers to measure and verify emissions at the plant level. Under CBAM rules, if verified emissions data are not available, importers are required to apply default values determined by the European Commission. These default values are often conservative and may exceed actual emissions, particularly for electric arc furnace (EAF)-based producers.

Figure 2.11 Examples of default values under CBAM

Semifinished slab/billet

Steel Product	CN Code	Origin	Year	Default Prod. Route	Default BM (t CO2e/t)	Default Value (t Co2e/t)	CBAM cost (Eur/t)
Semifinished	72071210	Algeria	2026	Carbon Steel - BF/BOF	1.364	3.3	€ 157.61
(slab/billet)	72071210	Brazil	2026	Carbon Steel - BF/BOF	1.364	1.771	€ 35.29
	72071210	China	2026	Carbon Steel - BF/BOF	1.364	3.485663842	€ 172.46
	72071210	India	2026	Carbon Steel - BF/BOF	1.364	4.697	€ 269.37
	72071210	Russia	2026	Carbon Steel - BF/BOF	1.364	3.531	€ 176.09
	72071210	Turkey	2026	Carbon Steel - BF/BOF	1.364	2.540638498	€ 96.86
	72071210	Ukraine	2026	Carbon Steel - BF/BOF	1.364	2.63723394	€ 104.59
	72071210	Vietnam	2026	Carbon Steel - BF/BOF	1.364	2.585	€ 100.41

Source: McCloskey by OPIS []

Hot-rolled Coil (HRC)/Heavy Plate

Steel Product	CN Code	Origin	Year	Default Prod. Route	Default BM (t CO2e/t)	Default Value (t Co2e/t)	CBAM cost (Eur/t)
HR	72083900	Algeria	2026	Carbon Steel - BF/BOF	1.37	3.3	€ 157.14
(Coil/Plate)	72083900	India	2026	Carbon Steel - BF/BOF	1.37	4.708	€ 269.78
	72083900	Indonesia	2026	Carbon Steel - BF/BOF	1.37	9.053	€ 617.38
	72083900	Japan	2026	Carbon Steel - BF/BOF	1.37	2.31	€ 77.94
	72083900	Serbia	2026	Carbon Steel - BF/BOF	1.37	2.651	€ 105.22
	72083900	South_Korea	2026	Carbon Steel - BF/BOF	1.37	2.330323809	€ 79.57
	72083900	Taiwan_China	2026	Carbon Steel - BF/BOF	1.37	2.54050804	€ 96.38
	72083900	Thailand	2026	Carbon Steel - Scrap-EAF	0.072	2.11145	€ 163.30
	72083900	Turkey	2026	Carbon Steel - BF/BOF	1.37	2.670262911	€ 106.76
	72083900	Vietnam	2026	Carbon Steel - BF/BOF	1.37	2.585	€ 99.94
	72083900	Ukraine	2026	Carbon Steel - BF/BOF	1.37	2.730942761	€ 111.62

Source: McCloskey by OPIS []

Source: (McCloskey, 2025)

For Thailand, this introduces an additional layer of competitiveness risk. Without a robust measurement, reporting, and verification (MRV) system, Thai exporters may face higher effective carbon costs than their actual emissions would imply. At the same time, as MRV systems improve and plant-level emissions are disclosed, Thailand's structural reliance on imported inputs, especially from carbon-intensive BF-BOF production routes, may become more visible. This suggests that competitiveness under emerging trade policies depends not only on reducing emissions but also on the ability to measure them accurately and manage emissions across the supply chain.

2.5. Conclusion

Thailand’s steel sector is structurally constrained not by demand, but by a persistent mismatch between production capabilities and market requirements. While domestic demand is substantial and increasingly oriented toward higher-value segments, local production remains concentrated in lower-grade, scrap-based steel, resulting in sustained reliance on imports.

This structural position weakens competitiveness on two fronts: cost competition against large-scale producers and quality competition in high-specification segments. At the same time, dependence on imported inputs exposes producers to external price volatility, limiting control over cost structures.

Emerging trade measures such as CBAM further amplify these challenges. Competitiveness will depend not only on emissions performance but also on the ability to measure and verify emissions credibly. Without robust MRV systems, Thai producers risk facing inflated carbon costs and reduced market access.

Overall, the sector faces a structural—not incremental—transition challenge. Future competitiveness will depend on how Thailand repositions itself within global steel value chains, rather than attempting to fully replicate upstream production domestically.

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Chapter 3

Thailand’s Energy and Infrastructure Readiness

Electricity systems play a central role in determining whether steel decarbonization pathways are viable. As low-carbon steelmaking increasingly relies on electricity-intensive processes, the availability, cost, and carbon intensity of power supply have become decisive factors shaping national transition options. This chapter provides a foundation for assessing Thailand’s readiness to support green steel development by examining the structure and performance of its energy system, associated infrastructure, and governing policy frameworks. By analyzing power system characteristics, renewable energy deployment, access constraints, and regional comparisons, the chapter identifies the energy-related conditions that enable or constrain green steel viability under current and foreseeable circumstances.

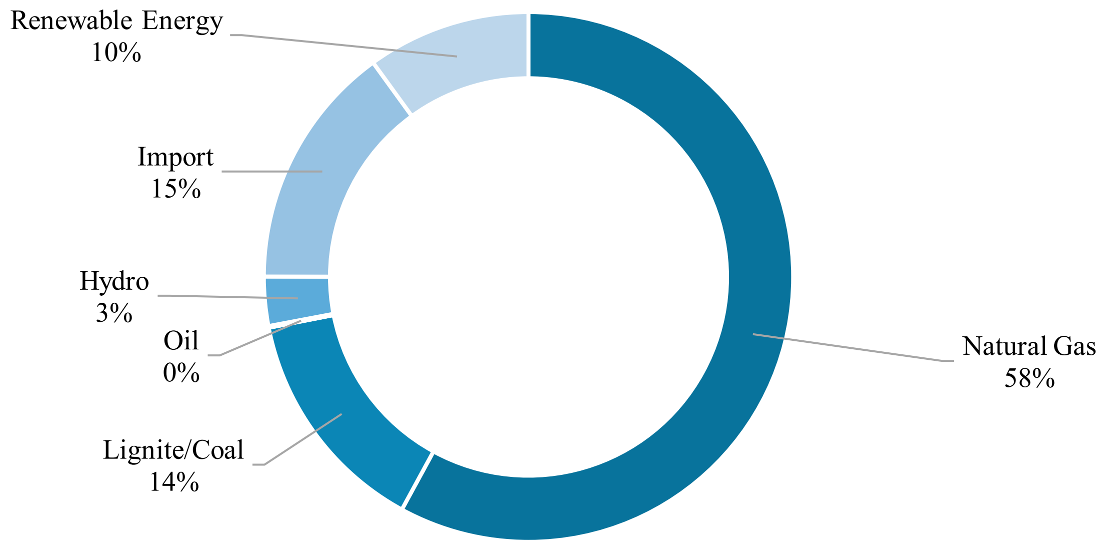
3.1. Overview of Thailand’s Power System

3.1.1) Thailand’s electricity generation and its constraints

Thailand’s power system is relatively large and reliable, with total installed generation capacity of around 50 GW serving peak electricity demand of approximately 30 GW (IEA, 2023). This excess capacity has historically supported supply security and economic growth. However, from the perspective of industrial decarbonization, green steel in particular, the key question is not only system reliability, but the carbon intensity, fuel structure, and exposure to external price risks embedded in the electricity system.

Electricity generation in Thailand remains heavily dominated by fossil fuels. In 2024, natural gas accounted for approximately 58% of total electricity generation, followed by coal at around 14%. Renewable energy, excluding large hydropower, contributed only about 10%, with electricity imports and hydropower accounting for the remainder (Figure 3.1). This generation mix implies that electricity supplied to industrial consumers is predominantly fossil-based, resulting in a relatively high emissions intensity.

Figure 3.1 Share of power generation by fuel type, 2024

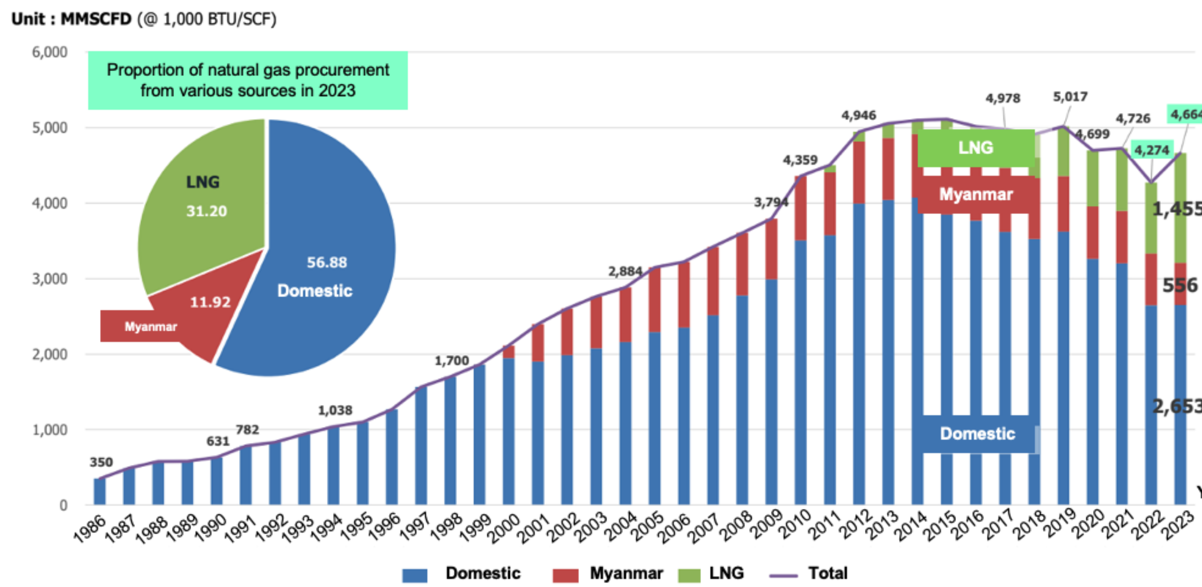


Source: (EPPO, 2025)

For electricity-intensive industries such as steel, particularly electric arc furnace (EAF)-based production, the carbon intensity of grid electricity is a critical determinant of whether production can be credibly classified as low-carbon. Under the current generation mix, EAF steel powered by grid electricity alone would still carry a significant indirect emissions footprint, limiting its alignment with emerging international definitions of green or near-zero-carbon steel.

Natural gas (or LNG) is the key input of electricity generation, accounting for over 65% of total gas use (EPPO, 2024). As domestic gas production from the Gulf of Thailand declines due to maturing fields, LNG imports have increasingly been used to bridge the supply gap. By 2023, imported LNG accounted for 1,455 MMSCFD, accounting for roughly 30% of the total gas supply as shown in Figure 3.2. As a result, power generation costs are increasingly exposed to global LNG price volatility. Recent shocks, including the COVID-19 pandemic and the Russia-Ukraine conflict, highlighted the vulnerability of Thailand's energy system to external supply disruptions and price spikes.

Figure 3.2 Natural gas sourcing (1986-2023)



Source: (EPPO, 2024)

For green steel development, this dependence translates into heightened cost uncertainty for electricity-based production pathways, even before accounting for carbon constraints.

3.1.2) Renewable energy supply

Thailand possesses a diverse portfolio of renewable energy resources, including biomass, solar, wind, biogas, hydropower, and municipal solid waste. As of 2023, total installed renewable generation capacity stood at approximately 12,810 MW, accounting for around 19% of total power generation capacity (DEDE, 2024). However, the scale, composition, and growth trajectory of renewable energy supply present important constraints for industrial decarbonization.

Biomass remains the dominant component of Thailand's renewable portfolio, accounting for about 30% of installed renewable capacity, followed by solar power (26%) and large hydropower (23%). Wind power represents only around 12%, while other sources such as biogas and waste contribute relatively small shares (Table 3.1). This composition reflects continued reliance on dispatchable bioenergy rather than large-scale expansion of modern variable renewables such as solar and wind, despite Thailand's strong solar resource potential.

More critically, renewable energy deployment has stagnated in recent years. Between 2022 and 2023, total installed renewable capacity increased by only 1.1%, with solar capacity expanding by just 0.11 GW.

Table 3.1 Thailand's RE installed capacity, 2023

Electricity from Renewable Energy	Installed Generation Capacity (MW)					% Change
	2019	2020	2021	2022	2023	2022-2023
Solar Power	2,982	2,979	3,060[1/]	3,180[2/]	3,294[2/]	3.6
Wind Power	1,506	1,506	1,545	1,545	1,543	-0.1
Small Hydropower	187	190	197	207	213	3.0
Biomass	3,410	3,517	3,646	3,759	3,869	2.9
Biogas	530	557	623	643	559	-13.1
Waste	314	333	388	411	411	-
Large Hydropower	2,918	2,918	2,918	2,918	2,918	-
Other RE	0.3	0.3	0.3	0.3	0.3	-
Total	**11,850**	**12,003**	**12,386**	**12,665**	**12,810**	**1.1**

[1/] Includes off-grid systems.

[2/] Includes Floating Solar.

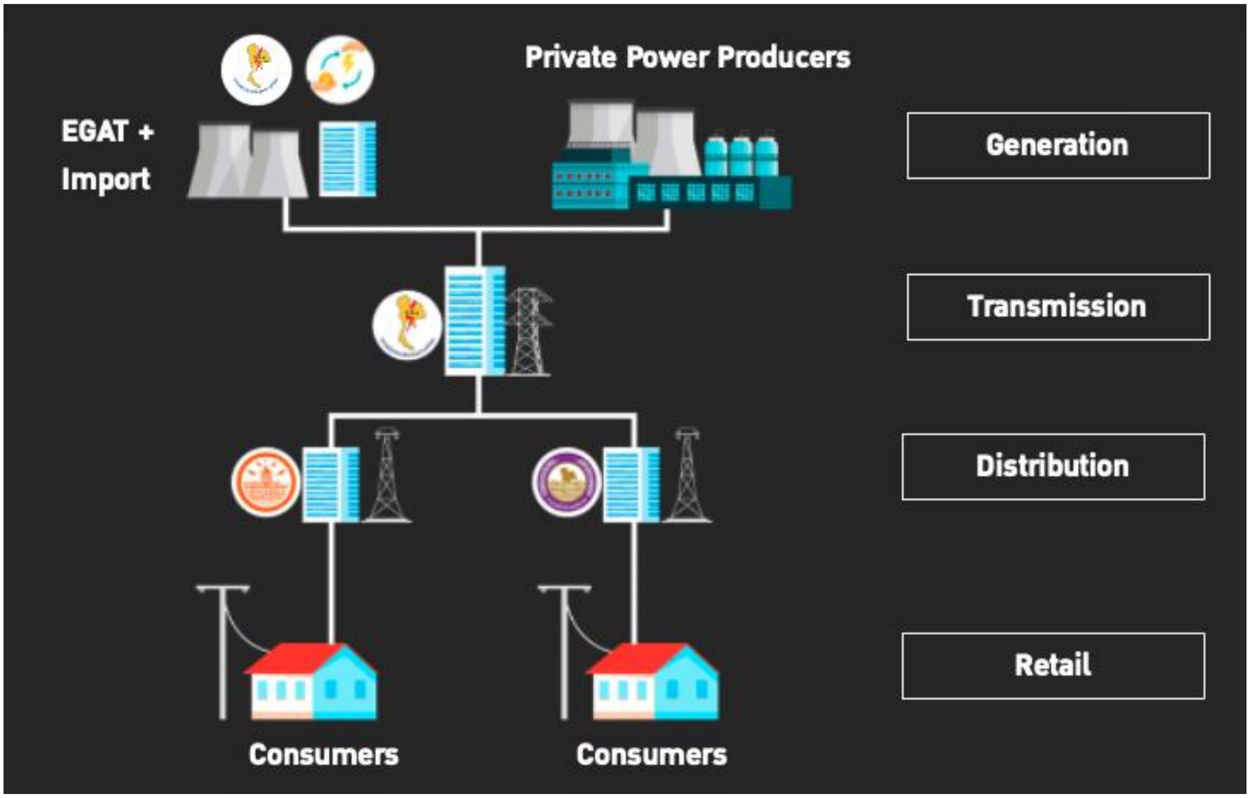
Source: (DEDE, 2024)

This limited growth suggests that, under current policies, renewable electricity supply may not be able to scale rapidly enough to materially reduce grid-wide carbon intensity or to meet the additional demand from new electricity-intensive industries such as green steel production.

3.1.3) Power system structure

Thailand's current power system operates under the Enhanced Single Buyer (ESB) model. Under this structure, the Electricity Generating Authority of Thailand (EGAT) purchases electricity from various power producers, including Independent Power Producers (IPPs) and Small Power Producers (SPPs). EGAT then sells this electricity to the two distribution utilities responsible for retail supply: the Metropolitan Electricity Authority (MEA) and the Provincial Electricity Authority (PEA). The ESB model allows for relatively centralized control of electricity generation and distribution, facilitating large-scale infrastructure investment, and enabling the system to respond to fluctuations in electricity demand.

Figure 3.3 Thailand's Enhanced Single Buyer (ESB) model



Source: Authors

The ESB system aims to strike a balance between efficiency and power system security, with EGAT responsible for managing the transmission network and ensuring security of electricity supply. However, this model faces several challenges, including limited competition, heavy reliance on natural gas (for security reason), high risk to non-transparent or inequitable pricing, inflexible power purchase agreements, and restricted access to transmission networks. These issues hinder Thailand's transition to clean energy, limiting consumers' choices for clean electricity and resulting in higher electricity costs due to sector management that does not fully reflect market mechanisms.

Taken together, Thailand's power system presents a mixed picture for green steel development. Electricity supply is generally reliable and supported by substantial installed capacity but remains carbon-intensive and increasingly exposed to fossil fuel price volatility due to heavy reliance on natural gas and imported LNG. Renewable energy resources exist, but deployment has slowed and remains tightly integrated into a centralized system. Under current conditions, these structural characteristics are likely to constrain both the emissions performance and cost competitiveness of electricity-intensive green steel pathways, particularly those reliant on renewable-powered electric arc furnaces.

3.2. Policy Constraints

While Thailand's power system is technically capable of supplying reliable electricity, policy and regulatory frameworks play a decisive role in shaping whether low-carbon electricity can be accessed by industrial users. For green steel development in particular, the key constraint is not generation potential, but the way electricity planning, procurement, and access are governed.

3.2.1) Power Development Plan (PDP)

3.2.1.1) Planning priorities and structural implications

Thailand's Power Development Plan (PDP) serves as the country's long-term blueprint for electricity sector development. Its primary objectives are to ensure supply security, maintain system reliability, and keep electricity prices stable while gradually increasing the share of clean energy in the generation mix. The draft PDP 2024 projects peak electricity demand to reach approximately 56,133 MW by 2037 and proposes significant new capacity additions to maintain high reserve margins. After accounting for planned retirements, total installed capacity is expected to increase to over 112,000 MW by 2037, nearly doubling current levels (International Rivers, 2024).

The draft PDP also signals a stronger role for clean energy, with renewable sources expected to account for roughly 51% of electricity generation by 2037. New capacity additions include solar, wind, biomass, imported hydropower, energy storage, and smaller shares of gas-fired generation and emerging technologies such as small modular reactors.

Overall, the PDP seeks to balance three core policy priorities (security, economy, and sustainability) while supporting Thailand's long-term climate commitments.

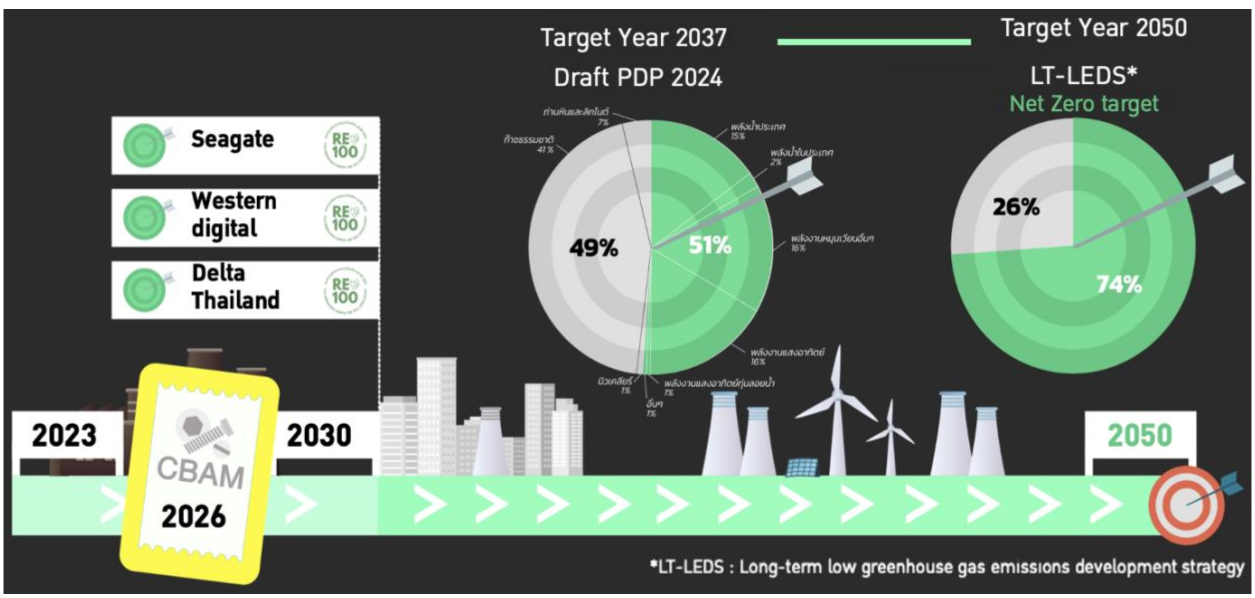
However, the PDP's planning logic prioritizes overall system reliability and capacity sufficiency but does not explicitly plan for differentiated electricity access based on attributes such as carbon intensity. As a result, while the plan may deliver sufficient electricity at the system level, it does not explicitly ensure that low-carbon electricity will be available, affordable, or accessible for specific industrial users such as green steel producers.

3.2.1.2) Misalignment between PDP timelines and industrial decarbonization pressures

A central concern for green steel viability is the temporal misalignment between the PDP's clean energy trajectory and the decarbonization timelines faced by Thailand's export-oriented industries. Although PDP 2024 raises the renewable share of electricity generation to 51% by 2037, major external policy and market drivers require much earlier access to low-carbon electricity.

From 2026 onward, the European Union's Carbon Border Adjustment Mechanism (CBAM) will impose carbon costs on steel and other carbon-intensive imports. At the same time, global corporate initiatives such as RE100, Thai Renewable Energy Association, require participating companies to source 100% renewable electricity by 2030. Together, these pressures imply that a substantial share of Thailand's industrial electricity demand, particularly among multinational manufacturers and export-oriented firms, will need access to renewable power well within this decade.

Figure 3.4. Misalignment between PDP timelines and industrial decarbonization pressures



Source: Authors

This mismatch raises uncertainty over whether Thailand's power system will be able to support low-carbon industrial production at the pace required by global markets. For green steel producers, whose competitiveness depends on both electricity emissions intensity and traceable clean power sourcing, delayed renewable deployment risks undermining market access, investment attractiveness, and participation in emerging green value chains.

3.2.1.3) Demand forecasting, overcapacity, and electricity cost implications

The draft PDP 2024 is also based on electricity demand projections that appear optimistic relative to more recent macroeconomic forecasts. Demand growth assumptions rely on economic projections developed in 2022 from the Office of the National Economic and Social Development Council (NESDC), which exceed updated estimates by other institutions such as the Bank of Thailand (BOT) (Table 3.2). This raises the risk of systematic overestimation of future electricity demand.

Overestimated demand projections can lead to excessive capacity expansion and persistently high reserve margins. In practice, this has resulted in underutilized generation assets and rising availability payments[1], which are ultimately passed through to consumers (both industries and households) via electricity tariffs. For example, in 2024, several large power plants were not operating despite receiving availability payments, contributing to higher system costs.

Table 3.2 GDP Estimation of NESDC and BOT (As of 25 June 2025)

GDP Estimation	2024	2025	2022-2037
PDP 2024 from NESDC (2022)	3.4%	3.3%	3.1%
BOT (2024)	2.6%	2.3%	

Source: (EPPO, 2024; BOT, 2025)

For electricity-intensive industries such as steel, elevated baseline electricity prices directly affect production costs and competitiveness. This is particularly relevant for green steel pathways that rely on electric arc furnaces, where electricity costs represent a substantial share of total

[1] Availability payments (APs) are guaranteed fees paid to private power producers (or other infrastructure operators) for ensuring their facilities are ready and able to supply electricity or service, regardless of whether the power is actually dispatched or used.

operating expenses. In this context, overcapacity driven by conservative planning assumptions may unintentionally weaken the economic viability of low-carbon industrial production.

The cancellation of the draft PDP 2024 introduces additional regulatory uncertainty at a time when long-lead investments, including green steel facilities, require stable policy signals. Without a credible and timely PDP, industry and investors face weaker incentives and higher risk premia, potentially delaying or deterring green steel deployment. However, the development of a new PDP also offers an opportunity to align electricity planning with emerging industrial decarbonization imperatives (such as CBAM and corporate RE targets).

3.2.2) Third Party Access (TPA)

Beyond system-level planning, the most immediate policy constraint for green steel development lies in the limited availability of market-based mechanisms for industrial access to renewable electricity. Historically, large industrial consumers in Thailand have not been permitted to directly procure off-site renewable power. Electricity has generally been purchased through regulated utility tariffs, reflecting the fossil-heavy system mix, regardless of individual firms' decarbonization objectives.

In 2023-2024, regulators began developing a Third-Party Access (TPA) framework to allow direct power purchase agreements (PPAs) between renewable generators and large consumers using the existing transmission network (Hunton, 2025). However, implementation remains at an early stage and is currently limited to pilot schemes, primarily targeting data centers. Steel producers are not yet explicitly included (but could possibly access to RE-based electricity through the same mechanism).

Until TPA regulations are fully implemented, expanded beyond narrow pilot sectors, industrial users cannot reliably secure large-scale, traceable renewable electricity. For green steel producers, this means that pathways dependent on renewable-powered electric arc furnaces remain institutionally constrained, regardless of technical feasibility or resource availability.

In summary, Thailand's current policy framework creates structural barriers to electricity access for green steel development. While the PDP ensures system reliability and gradual decarbonization at the aggregate level, its timelines and planning priorities are misaligned with the near-term decarbonization requirements faced by export-oriented industries. Conservative demand projections and resulting overcapacity place upward pressure on electricity costs, while the absence of mature market-based access mechanisms prevents industrial users from securing dedicated low-carbon power. Under current policy conditions, these factors collectively constrain the economic and energy viability of green steel pathways in Thailand.

3.3. Grid Constraints

Even if policies allow more renewables. Physical grid constraints could also pose challenges to powering green steel projects. A green steel plants, especially one using DRI and large EAFs, will be a significant electricity load. Potentially, they are on the order of hundreds of megawatts. Integrating such a load with a supply, that is largely variable renewables, requires a robust grid. Key considerations are listed in Table 3.3.

Table 3.3. Key considerations for grid constraints of green steel development

Key consideration	Detail
Transmission capacity	New renewable generation is often not located near industrial centers or existing grid backbones. Thailand will need transmission upgrades to carry power from high RE areas to demand centers, such as the Eastern Economic Corridor (EEC) where a steel plant may be located. If a steel plant relies on dedicated renewables, any bottleneck in transmission could limit the deliverable power.
Grid stability	Large EAFs draw fluctuating loads. Managing this alongside high levels of solar/wind, which cause supply fluctuations, is a technical challenge. The grid will need stronger frequency control and possibly energy storage to ensure stability. If a green steel mill is trying to use most RE, during periods of low renewable output, it either needs backup or storage.
Curtailment risks	In Vietnam, a solar and wind boom without synchronous grid expansion. By 2023, parts of Vietnam saw 10-15% of renewable energy output curtailed (wasted) due to grid congestion and

Key consideration	Detail
	oversupply at certain times (Market Research Vietnam, 2025). Thailand could face similar issues if renewables deployment outpaces grid enhancements. Curtailment is essentially lost opportunity. A steel plant, counting on renewable power, might find that some of its contracted solar/wind cannot be delivered at peak times due to grid limits.

The Thai grid operator, EGAT, is aware of these issues and has been working on a grid modernization roadmap (Smart Grid), including deploying smarter controls and possibly grid-scale batteries. The goal will be to ensure that by the time renewables reach, the grid can handle it with minimal curtailment and maintain power quality. But currently, these enhancements are in progress, not fully realized.

In conclusion, grid infrastructure poses a non-trivial challenge for green steel in Thailand. There is a risk of insufficient transmission or stability issues causing either energy shortages or inefficiencies like curtailment. This is not an insurmountable problem, but it requires forward planning, grid investments, and possibly new technologies.

3.4. Regional Comparison: Thailand's Energy Market and Implications for Green Steel

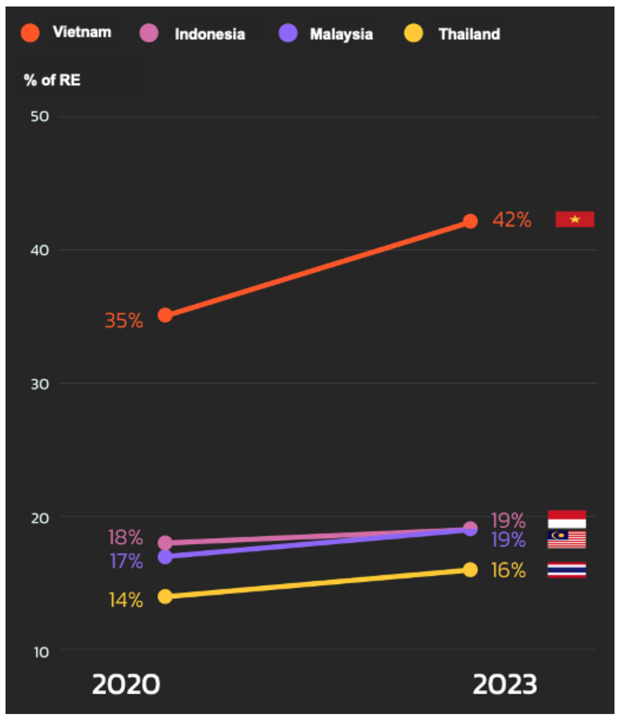
Assessing the viability of green steel development in Thailand requires situating the country's energy market conditions within a regional context. Steel production is increasingly shaped by global supply chains, cross-border investment decisions, and international carbon regulations. As a result, Thailand's relative performance in renewable energy deployment and electricity market design matters not only for domestic decarbonization, but also for its competitiveness as a potential host for electricity-intensive green industries.

3.4.1) Relative pace of renewable electricity deployment

Thailand has articulated a long-term objective to increase the share of renewable energy in electricity generation to approximately 51% by 2037. However, the pace of renewable deployment to date has been comparatively slow. In 2023, clean electricity accounted for around 16% of Thailand's generation mix[2], a modest increase from 14% in 2020.

By contrast, several regional peers have expanded renewable electricity at a significantly faster rate. Vietnam, in particular, increased its clean electricity share from approximately 35% in 2020 to 42% in 2023, supported by rapid solar and wind expansion. Vietnam has also set a target of around 47% clean electricity generation by 2030, reflecting a stronger near-term focus on renewable scale-up (IRENA, 2025).

Figure 3.5 Clean electricity share comparison in ASEAN (2020-2023)



Source: (IRENA, 2025)

From the perspective of green steel development, the speed of renewable deployment is as important as long-term targets. Electricity-intensive low-carbon steel pathways require access to substantial volumes of low-carbon power within the next decade, aligned with the implementation of carbon border measures and corporate decarbonization commitments. Slower renewable

[2] This number is different than section 3.1.1 because it included imported large hydropower and other smaller-scale projects.

expansion increases the risk that clean electricity will not be available when market demand materializes, placing Thailand at a relative disadvantage compared to faster-moving peers.

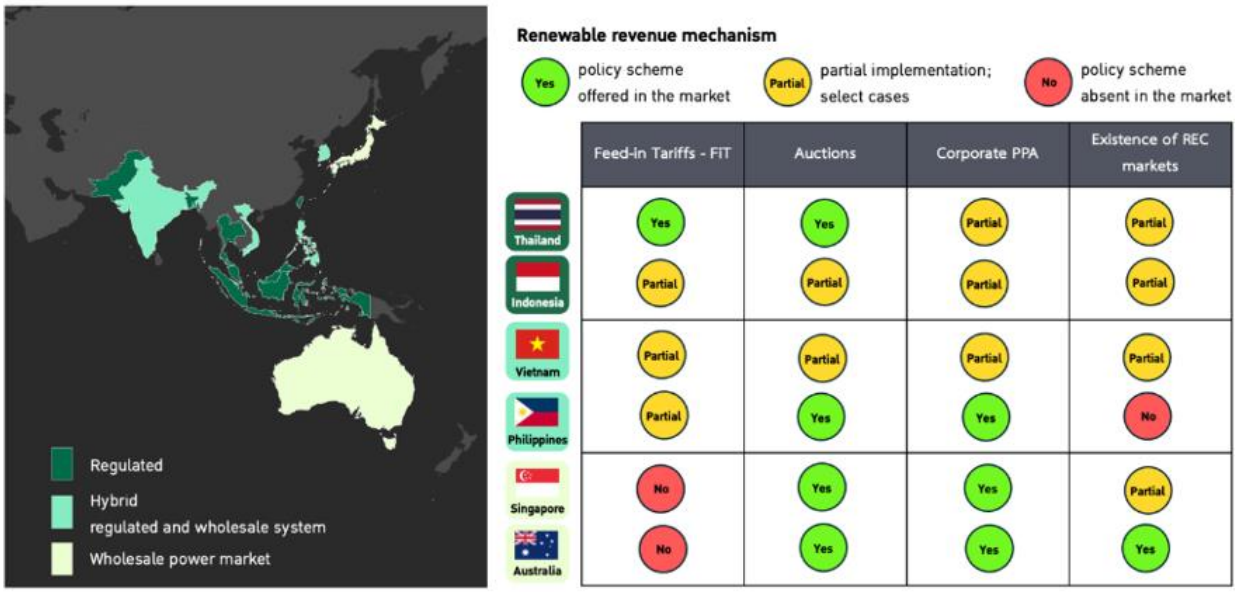
3.4.2) Energy market of Thailand and its regional peers

Renewable energy markets in the Asia-Pacific region can be categorized into three main groups based on the level of electricity market liberalization. The first group consists of countries where the market remains largely state-controlled, such as Thailand and Indonesia, which continue to operate under centralized single-buyer or state-dominated structures. The second group represents hybrid models, including Vietnam and the Philippines, where market mechanisms have gradually been introduced. The third group comprises fully liberalized markets, such as Singapore and Australia.

As illustrated in Figure 3.5, countries in the second and third groups tend to demonstrate significantly stronger growth in renewable energy deployment compared to the first group. This may suggest that allowing market mechanisms and private sector demand to play a larger role can accelerate clean energy capacity expansion more effectively than relying solely on centralized planning.

Compared to countries that continue to operate centralized electricity systems with limited private demand participation, such as Thailand and Indonesia, Vietnam presents a case of rapid renewable energy expansion. Within just a few years, Vietnam significantly increased its solar and wind capacity through attractive Feed-in Tariff (FiT) policies, followed by the introduction of Direct Power Purchase Agreements (DPPA), which enable large consumers to procure renewable electricity directly. The key difference lies not only in quantitative targets but in market design specifically, whether the structure enables the private sector to act as a primary driver of renewable capacity expansion. Vietnam's experience may demonstrate that market flexibility plays a more decisive role in the speed of energy transition than centralized planning only.

Figure 3.6 Energy market comparison in Asia-Pacific



Source: (Wood Mackenzie, 2024)

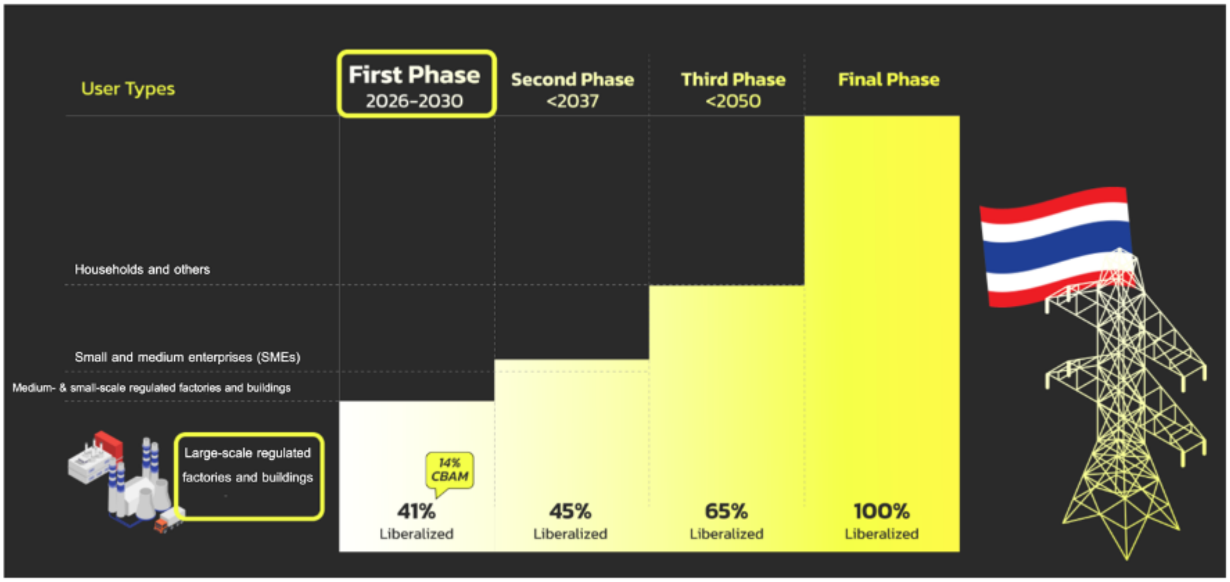
In Thailand's context, there are both electricity-intensive industrial consumers and renewable energy producers with the capacity to expand investment. However, electricity transmission continues to operate under a state-managed framework that limits direct private-to-private competition. This structural constraint reduces the ability of industrial users to procure flexible and traceable low-carbon electricity.

Therefore, genuinely enabling TPA and opening the grid to competition over shared infrastructure could serve as a key mechanism for significantly increasing renewable energy penetration. A more flexible market structure would not only respond to industrial demand but also enhance Thailand's competitiveness in the regional low-carbon economic transition.

3.4.3) Phased plan for Third-party Access (TPA)

A primary priority for Thailand's energy transition is increasing the share of renewable energy to meet the needs of the economy, particularly industries facing pressure from carbon regulations and green supply chain requirements. The design of TPA implementation should therefore follow a phased approach aligned with demand urgency.

Figure 3.7 Phased plan for electricity liberalization



Source: Authors

Phase 1: 2026-2030

Priority should be given to industries with immediate exposure to carbon constraints, particularly those affected by CBAM and companies participating in RE100. These are primarily large industrial users, accounting for approximately 40-41% of total electricity demand. Enabling TPA access for this group is critical to maintaining international competitiveness and ensuring timely access to renewable electricity by 2030.

Phase 2: before 2037

Under the draft Power Development Plan 2024, Thailand targets a 51% share of clean electricity. Achieving this requires expanding TPA access beyond large users to include medium- and small-sized industries. Together with CBAM- and RE100-related industries from Phase 1, this would cover approximately 45% of total electricity demand.

Phase 3: before 2050

In the longer term, Thailand's Net Zero 2050 target implies increasing the share of clean electricity to around 74%. This requires broader and more inclusive TPA implementation. Allowing industrial users representing approximately 65% of total electricity consumption to access renewable electricity would create strong demand-pull for renewable capacity expansion and support systemic decarbonization of the power sector.

Final Phase

The final stage should involve broader market liberalization, contingent on the readiness of infrastructure, regulatory frameworks, and system operation capabilities. A gradual approach is essential to avoid risks to grid stability, while ensuring that energy security is maintained alongside decarbonization objectives.

3.5. Conclusion

Thailand's current electricity system provides a reliable but structurally carbon-intensive foundation that is not yet fully aligned with the requirements of electricity-intensive industrial decarbonization.

Beyond carbon intensity, the growing reliance on imported LNG has tied domestic electricity prices to global fuel price volatility. This creates a dual constraint for green steel plants: a high carbon footprint paired with heightened cost uncertainty, both driven by fossil fuel dependence and import exposure.

Policy frameworks further exacerbate these challenges. The current PDP prioritizes system reliability over industrial decarbonization needs, while its timeline is misaligned with near-term pressures from global markets and climate policies. At the same time, limited progress on Third Party Access restricts direct procurement of clean energy.

Institutionally, the Enhanced Single Buyer (ESB) model has ensured reliability and centralized coordination but limits industrial users' ability to directly procure low-carbon electricity. While Third-Party Access (TPA) is under development, implementation remains limited and incomplete. Without a mature and scalable mechanism for traceable renewable electricity procurement, technically viable green steel pathways remain institutionally constrained.

Physical grid considerations add another layer of complexity. Large-scale green steel facilities would represent significant electricity loads, potentially requiring transmission upgrades, enhanced frequency control, and energy storage integration. These challenges are manageable with sufficient planning and investment.

Regional comparison further highlights Thailand's relative positioning. Compared to peers such as Vietnam, which has accelerated renewable deployment through more flexible market mechanisms, Thailand's centralized structure and slower renewable expansion may weaken its competitiveness as a host location for electricity-intensive green industries. Market design and regulatory openness appear to be as important as resource availability in determining transition speed.

The key implication is that green steel feasibility in Thailand is not constrained primarily by technical resource scarcity, but by structural and institutional conditions. Accelerating renewable deployment, aligning power planning with industrial decarbonization timelines, operationalizing Third-Party Access at scale, and investing in grid modernization will be decisive in determining whether Thailand can position itself competitively within emerging low-carbon steel value chains.

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Chapter 4

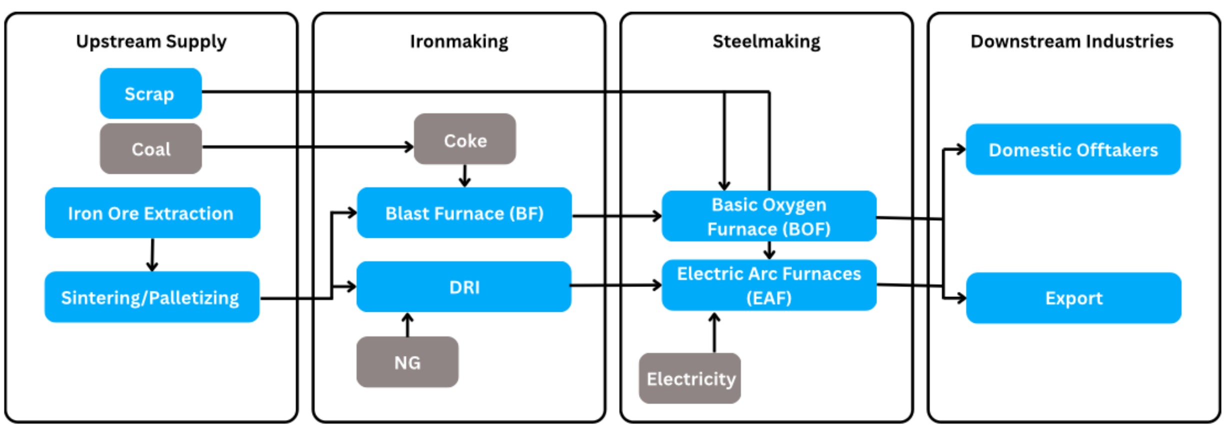
Steel Supply Chain and Emerging Configurations

Steel production is not only an industrial process but a complex value chain that connects natural resources, energy systems, heavy industry, and downstream manufacturing. As the global steel sector moves toward decarbonization, this value chain is undergoing structural reconfiguration. The shift from coal-based blast furnace systems to electricity- and hydrogen-based processes does more than reduce emissions. It alters the physical, economic, and geographic logic of steel production. Renewable electricity and hydrogen introduce new inputs, new cost drivers, and new possibilities for separating ironmaking from steelmaking. This chapter examines how these structural changes reshape global steel configurations and explores the strategic positioning options available to Thailand within an emerging green steel landscape.

4.1. Structure of Steel Supply Chain

The steel supply chain spans four major stages: upstream supply, ironmaking, steelmaking, and downstream industries as shown in Figure 4.1.

Figure 4.1 A simplified traditional steel supply chain from upstream to downstream



Source: Adjusted from Agora Industry and Wuppertal Institute (2024)

i) Upstream supply

This involves obtaining the inputs for steel. The primary input is iron ore, mined from the earth and often processed into concentrated forms like pellets or sinter. Another key input is coking coal, which is converted to coke for fueling traditional blast furnaces. In addition, scrap steel from recycled metal is an important raw material, used especially in electric arc furnaces. Upstream facilities include iron ore mines, pelletizing/sintering plants, coke ovens, and scrap collection and processing yards.

ii) Ironmaking

In this stage, iron ore is converted into metallic iron. Traditionally, ironmaking is done in a blast furnace (BF), where iron ore is combined with coke (from coal) at high temperatures to produce molten pig iron (hot metal). An alternative ironmaking route is direct reduction, where iron ore is reduced to solid iron (called direct reduced iron or DRI) using a reducing gas (commonly natural gas). The DRI can also be compacted into hot briquetted iron (HBI) for easier handling and shipping.

iii) Steelmaking

Iron from the previous stage is transformed into steel. In integrated plants, molten pig iron from the blast furnace is transferred to a basic oxygen furnace (BOF), where it is refined into steel by blowing oxygen and adding alloying elements. BOF steelmaking is fast and handles large batches, often mixing some scrap steel with pig iron. In the electric route, steelmaking is done in an electric arc furnace (EAF), which melts scrap steel and/or DRI using electric energy. EAFs are smaller and more modular. EAFs are versatile, they can make steel using 100% scrap, or a mix of scrap and DRI if high-quality steel or additional iron units are needed.

iv) Downstream (processing and manufacturing)

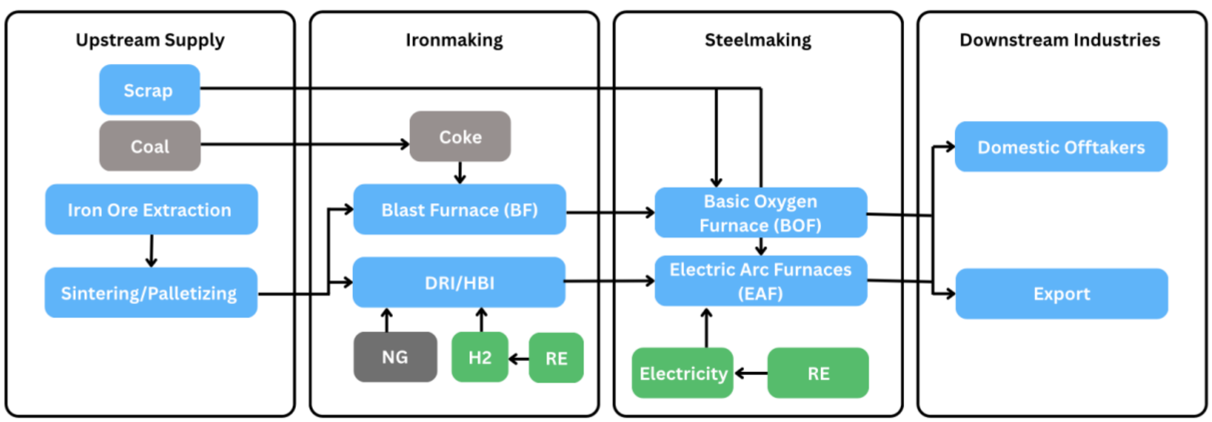
Once steel is made, it is cast into basic shapes (slabs, billets, blooms) and then rolled or processed into finished products (like flat, long, tubular or wire). These steel products feed into downstream industries such as construction, automotive manufacturing, appliances, machinery, and so on. This segment also includes finishing processes (galvanizing, cutting) and the distribution network to deliver steel to end-users or export markets.

In the traditional BF-BOF route, ironmaking and steelmaking are typically integrated at one site, where the blast furnace's continuous output of molten iron feeds directly into the BOF. This means large integrated mills are often located near ports (for importing iron ore and coal) and must operate at high capacity to be efficient. By contrast, the EAF route can be smaller and spread out, since they primarily melt scrap which is widely collected.

4.2. Structural Change under Renewable Energy and Hydrogen

Recent literature argues that access to renewable electricity and hydrogen fundamentally alters the steel supply chain. Moving toward "green steel" fundamentally changes what energy sources are used in these segments, and this in turn changes how the supply chain can be configured. Renewable electricity (RE) and green hydrogen (H_2) allow iron to be made with far lower carbon emissions, but they also introduce new inputs and more flexibility in location of facilities (Figure 4.2).

Fig 4.2 A simplified steel supply chain with renewable electricity and hydrogen



Source: Adjusted from Agora Industry and Wuppertal Institute (2024)

i) Upstream inputs shift

Instead of consuming large quantities of coal and coke, a green steel system consumes large quantities of clean energy. Renewable electricity becomes a direct input (to run electric furnaces and electrolyzers), and hydrogen (made from renewable electricity via electrolysis) becomes the new reducing agent to replace coal. Iron ore (Fe) itself may need to be higher grade (DRI-grade pellets with Fe content around 67%) suitable for direct reduction (Midrex, 2022). Traditional mining and pelletizing remain, but the supply of hydrogen and electric grid capacity are now part of the upstream considerations. Countries rich in renewable resources effectively become potential suppliers of energy or even processed iron, not just raw materials. Scrap steel remains important in a green steel pathway. In fact, maximizing scrap recycling is a low-carbon strategy in any scenario, but green hydrogen enables production of new iron with minimal emissions when scrap is insufficient.

ii) Ironmaking with natural gas and H_2

The big innovation is using hydrogen (H_2) to reduce iron ore. In a hydrogen direct reduction (H_2-DRI) process, hydrogen gas reacts with iron ore to remove oxygen, producing solid sponge iron (DRI) and H_2O (water vapor) as the byproduct instead of CO_2. This DRI can be briquetted into hot briquetted iron (HBI) for storage and transport or fed directly into an electric arc furnace. Importantly, the production of solid DRI or HBI allows ironmaking and steelmaking to be geographically separated (Trollip, 2025). However, this modularity is not entirely new as natural gas-based DRI has long produced transportable HBI that is traded internationally. What hydrogen changes is not the physical form of the product, but the energy basis of comparative advantage.

Under hydrogen-based DRI, the key input becomes low-cost renewable electricity (for hydrogen production) rather than natural gas. This potentially shifts ironmaking toward regions with abundant renewable energy resources rather than fossil fuel endowment. As a result, a renewable-rich country can produce green HBI/low-carbon for export, while another country with established steelmaking capacity can import that HBI and perform steel production domestically. In this sense, hydrogen-based DRI deepens the possibility of value chain modularization while enabling substantially lower lifecycle emissions, provided that hydrogen is produced from low-carbon electricity. It does, however, require reliable cheap electricity (for H_2) and could benefit from locating near iron ore sources or ports (to bring in iron ore).

iii) Steelmaking (EAF) with clean power

In green pathways, steelmaking will predominantly use electric arc furnaces, since they can be powered by renewable electricity and handle solid inputs (Solid DRI/HBI). EAFs will melt the H_2-reduced iron together with scrap steel to produce liquid steel. Because EAFs are electricity-driven and not dependent on coal, they can theoretically be located anywhere there is a grid or power supply, potentially closer to markets or sources of scrap. This opens the possibility of siting steel mills based on logistic or market needs rather than having to be adjacent to ironmaking. (For instance, an EAF could be in a manufacturing hub or port city, even if the ironmaking (DRI) occurred in a different region or country.) The main requirements are a supply of DRI or scrap and affordable electricity. If the electricity is renewable (from the grid or captive sources), the steelmaking emits very little CO_2. One consideration is that EAFs have somewhat smaller scale than giant blast furnaces, which could allow a more distributed network of steel producers.

iv) Downstream and overall supply chain

The downstream processing of steel (rolling, fabrication) does not fundamentally change with green steel. Those facilities will still be located near industrial centers or consumers. From a supply-chain perspective, international trade is likely to evolve toward new intermediate products. Rather than just importing iron ore and coal for domestic steelmaking, nations may increasingly trade in hydrogen or, more likely, HBI and green iron. Essentially, the supply chain might split. Some countries specialize in energy-intensive iron production (using their renewable energy to make HBI), while others specialize in steel production and manufacturing, importing low-carbon iron as input. This could improve efficiency, as each step happens where it is most cost-effective. It also means policymakers must consider new dependencies (e.g. reliance on imported hydrogen or HBI vs. domestic production).

In summary, renewables and hydrogen allow a more flexible and low-carbon steel supply chain. Iron production no longer needs to be closed to steelmaking on the same site. The comparative advantages in steelmaking may shift. Countries or regions with abundant cheap low carbon/renewable power (sunny, windy areas) could become key locations for iron production (DRI/HBI). Meanwhile, countries with established manufacturing and demand (but maybe higher energy costs) could import green iron and focus on steelmaking and downstream industries. This reconfiguration creates several possible global supply chain setups for green steel.

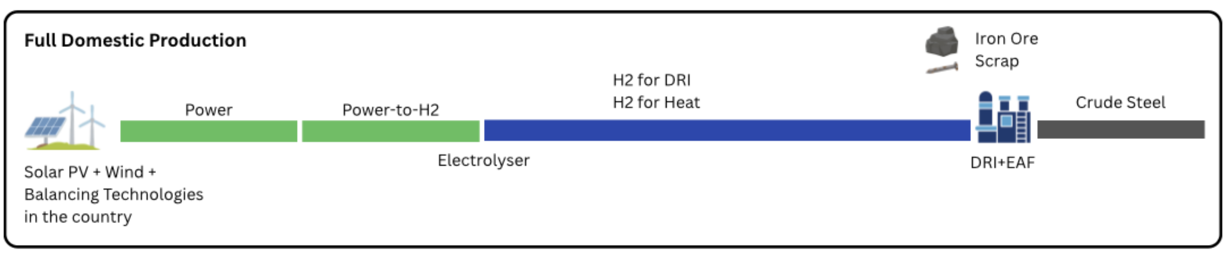
4.3. Global Configuration Options for Green Steel Supply Chains

Considering the changing of the steel supply chain, there are four potential global green steel supply chain models. Each representing a different distribution of activities between domestic and international locations.

Model A: Full domestic green steel production (all stages in-country)

In this configuration (Figure 4.3), a country handles the entire green value chain from energy generation to the finished product. By producing its own renewable electricity (e.g. via local solar or/and wind farm), the country generates green hydrogen on-site through electrolysis. That hydrogen feeds a direct reduction plant to reduce iron ore (which can be imported as pellets if the country lacks domestic ore) into DRI. The DRI is then melted in a domestic EAF, mixed with scrap metal, to produce steel, then casted and supplied to domestic users or exported. Essentially, the entire green steel value chain is domestic: energy, hydrogen, ironmaking, and steelmaking are done within the nation's borders. This requires significant investment in renewable energy and electrolyzer capacity, as well as steel plant infrastructure, but gives the producing country full control over steel production and potential self-sufficiency.

Figure 4.3 Model A: Full domestic green steel production

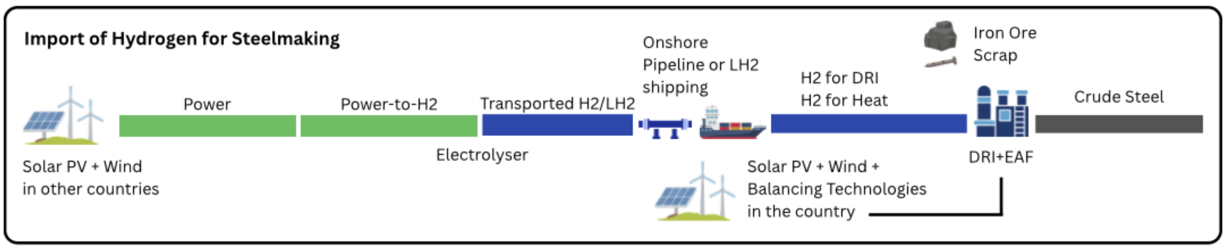


Source: Adjusted from Lopes et al. (2023)

Model B: Import hydrogen for domestic iron & steelmaking

In this model (Figure 4.4), the country retains the ironmaking and steelmaking stages domestically but outsources the hydrogen production from a partner country with a low-cost renewable resource. The domestic steel industry still performs DRI reduction and operates EAFs, but instead of producing hydrogen itself (which needs a lot of cheap power), it imports hydrogen or hydrogen-derived fuels from abroad. For example, a partner country with vast renewables could produce green hydrogen and ship via tankers or pipeline. The receiving country would take the imported hydrogen and feed a local DRI plant to produce iron, which is then processed in an EAF for steel. The advantage of this model is that the steelmaking country does not need to devote as much land or investment to renewable energy; it can leverage cheaper foreign hydrogen. However, the downsides include added complexity and cost in transporting hydrogen, which is physically difficult and costly to move over long distances combined with the energy loss during conversion. This model can drive up quite expensive final cost of steel.

Figure 4.4 Model B: Import hydrogen for domestic iron & steelmaking

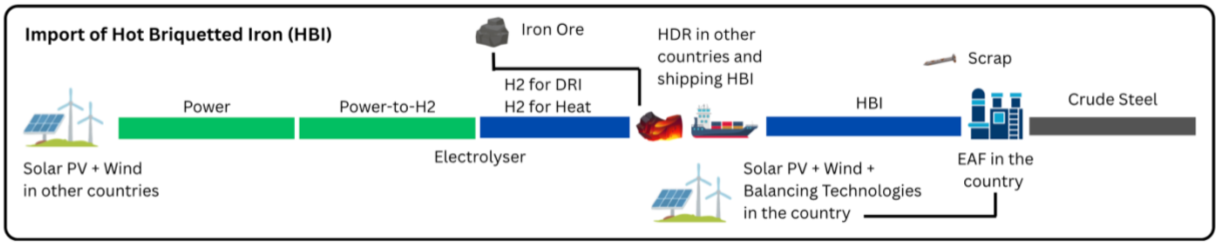


Source: Adjusted from Lopes et al. (2023)

Model C: Import pre-reduced iron (HBI) for domestic steelmaking

This configuration (Figure 4.5), the ironmaking stage is shifted to regions with abundant renewable energy. Instead of making iron domestically (via BF or DRI), the country imports solid iron in the form of HBI from overseas. In other words, another country performs the direct reduction of iron ore and compresses it into briquettes. These HBI briquettes, which are stable and easy to ship, are then transported to the steelmaking country. The receiving country then feeds the imported HBI into its electric arc furnaces, often mixed with scrap, to make steel. This model splits the value chain: the upstream, energy-intensive reduction process occurs where green energy is cheapest, while the midstream steelmaking remains close to the end-market. The benefits are efficiency and cost. It also simplifies logistics compared to shipping hydrogen. For the steelmaking country, it secures a low-carbon iron supply without needing to build massive hydrogen infrastructure domestically.

Figure 4.5 Model C: Import pre-reduced iron (HBI) for domestic steelmaking

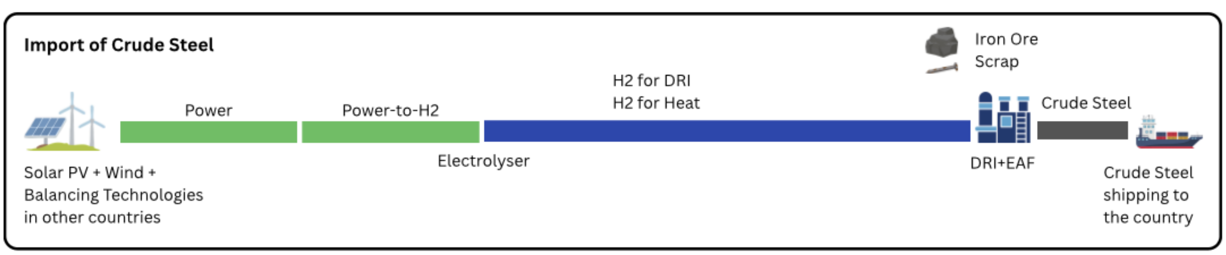


Source: Adjusted from Lopes et al. (2023)

Model D: Import green steel (crude steel) and focus on downstream

In the final configuration (Figure 4.6), the country chooses not to perform ironmaking and primary steelmaking locally, relying instead on imported crude or semi-finished steel (such as slabs or billets). In a decarbonized future, these imports would presumably originate from low-carbon producers to comply with climate regulations. The point is the entire heavy production process is done elsewhere. The local industry might then simply do downstream activities such as importing steel slabs or billets and rolling them into finished products or importing finished steel directly for manufacturing. However, this creates a high level of import dependency and shifts the majority of the industrial value-add to other nations.

Figure 4.6 Model D: Import green steel (crude steel) and focus on downstream



Source: Adjusted from Lopes et al. (2023)

Each configuration presents distinct trade-offs for a country's energy security, industrial development, and cost-competitiveness. Models A and D represent the opposite ends of the spectrum

- Model A (full localization) maximize self-reliance and domestic value-add but requires highly competitive local renewable energy and massive capital.
- Model D (full import) is essentially an exit from the steel production.

Model B and C are in the middle ground. Model B maintains domestic ironmaking but with noted cost challenges (due to hydrogen transport). Meanwhile, Model C leverages the world's cheapest energy sources to keep steelmaking sector jobs within the country, though it increases import dependency.

4.4. Findings Across Literatures

A review of recent academic and policy literature reveals a consistent conclusion: the global steel transition will not occur uniformly. Instead, low-carbon/hydrogen-based direct reduced iron (H_2-DRI) enables new supply chain configurations that allow countries to specialize based on energy endowment, industrial structure, and development stage.

i) Energy endowment becomes the primary driver of comparative advantage

The transition from coal-based reduction to hydrogen-based reduction fundamentally shifts comparative advantage. Historically, steel production location was anchored in proximity to coal reserves, iron ore, and integrated industrial complexes. Under a green steel supply chain system, the critical cost drivers move from commodity prices (coal/iron ore) to infrastructure and energy inputs:

- Cost and availability of renewable electricity
- Cost and availability of hydrogen
- Scrap availability for EAF production

Recent techno-economic analyses indicate that certain "sweetspot" regions, such as parts of North Africa, the Middle East, Australia, and Latin America, can produce green HBI at significantly lower cost than industrialized European locations, even when accounting for shipping costs. In some cases, imported HBI reduces overall steelmaking costs by approximately 15-20% compared to fully domestic green iron production (Trollip, 2025). As a result, access to low-cost renewable energy and hydrogen increasingly determines where ironmaking can occur competitively.

ii) Importing HBI may be more economically rational than importing hydrogen

The literature consistently finds that importing hydrogen for domestic ironmaking is technically feasible but economically and logistically challenging. Hydrogen transport requires either liquefaction (LH_2), conversion to carriers such as ammonia and reconversion at destination, or long-distance pipelines (Lopez, et al., 2023) (Bataille, 2019) (Trollip, et al., 2022). Each introduces cost, infrastructure requirements, and geopolitical vulnerability.

By contrast, HBI is a stable, solid product that can be shipped via conventional bulk vessels and stockpiled at ambient conditions. For many industrialized countries, importing green HBI may therefore be more cost-effective and lower risk than importing hydrogen directly. This distinction has important implications for countries without abundant low-cost renewable energy.

iii) Structural transition is asymmetric across countries

Countries will not follow a single green steel pathway. Comparative modelling in Europe (e.g., Lopez et al., 2023) shows that cost-optimal configurations differ significantly across countries under scenarios with and without carbon pricing. Industrial structure, renewable energy costs, scrap availability, fiscal capacity, and domestic steel demand influence which pathway emerges.

1. **Relocation of ironmaking:** In countries where domestic hydrogen production remains relatively costly, hydrogen-based ironmaking may shift to renewable-rich regions. Industrialized economies may retain EAF steelmaking and downstream processing while importing green HBI. Modelling suggests that economies such as Germany could adopt such configurations under certain cost assumptions.
2. **Partial import:** Some countries may become importers of specific green steel inputs (e.g., hydrogen, HBI, or crude steel) rather than retaining full domestic production. Finland, for example, shows cost sensitivity between domestic hydrogen production and imports, particularly under varying carbon pricing scenarios.
3. **Full retention of the value chain:** Countries with abundant low-cost renewable energy and established industrial infrastructure may retain the full H_2-DR-EAF supply chain domestically. Spain is often cited as comparatively well-positioned for such a configuration due to strong renewable resources.

Taken together, the literature suggests that the green steel transition is not merely a technological upgrade within existing plants. It is a restructuring of the global steel value chain.

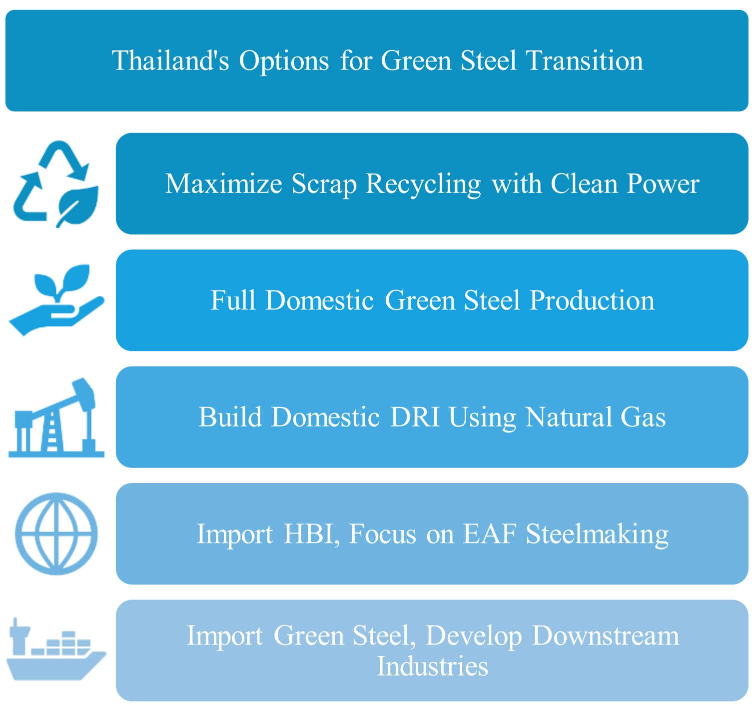
The key strategic question for each country becomes: Which segment of the modular green steel supply chain should it specialize in?

Countries with low-cost renewable resources may specialize in hydrogen production or green iron exports. Countries with strong downstream industries but limited renewable endowment may specialize in EAF steelmaking and manufacturing. Others may transition toward greater import dependence.

4.5. Implications and Strategies for Thailand

Considering the global configurations above, Thailand has a range of strategic options for its steel sector in the transition to green steel. There are five possible strategies for Thailand's supply chain, each corresponding to how Thailand might specialize in one or more segments of the green steel value chain.

Figure 4.7 Thailand's strategy options for green steel transition



Source: Authors

Option 1: Maximize scrap recycling with grid power (BAU)

In this scenario, Thailand leans heavily on its existing EAF-based industry, focusing on melting scrap steel using electric arc furnaces powered by grid (possibly renewable or low-carbon) electricity. This is the most straightforward decarbonization path: increase scrap collection and utilization, improve EAF efficiency, and decarbonize the electricity supply. It does not involve hydrogen or new ironmaking; it simply makes the most of secondary (recycled) steel. This strategy corresponds to Thailand specializing mainly in the steelmaking segment (and downstream) using domestic and import scrap. It is a low-capital approach and can significantly cut emissions, but it is limited by scrap availability. As a developing economy, Thailand's in-use steel stock per capita is still growing (meaning scrap supply is relatively low compared to demand). Moreover, crucial, scrap-based production alone cannot meet all future steel needs, especially for high-quality grades.

Option 2: Import green steel, develop downstream industries

This corresponds to **Model D**. In this strategy, Thailand would rely on importing most or all its primary steel from foreign producers. Ideally, those producing green steel with low carbon footprints to meet future standards. Thailand's domestic industry would then focus on downstream segments: rolling, forming, and manufacturing with that imported steel. Essentially, Thailand would not invest heavily in new primary steel capacity, especially if it deems itself at a competitive disadvantage in energy or raw materials. Instead, it would ensure that it has access to environmentally acceptable steel imports (perhaps through trade agreements or a procurement policy) and concentrate on using steel in value-added products (like automobiles, appliances, machinery, construction, etc.). This strategy might be considered if, for example, neighboring countries (or major steel exporters) develop surplus green steel capacity and can supply Thailand cheaply, or if Thailand chooses to allocate its resources to other industries. The upside is lower capital expenditure and the ability to choose the source of the steel; the downside is that Thailand would remain vulnerable to external supply and pricing and miss out on the industrial development opportunity of green steelmaking.

Option 3: Import HBI, focus on EAF steelmaking

With this option, Thailand would adopt **Model C**. It will outsource the most energy-intensive stage of production by importing HBI from regions, where abundant renewable energy enables lower energy costs. Thailand's role would then be to expand its electric arc furnace capacity to melt that HBI (alone or mix with scrap) into steel for domestic use or further manufacturing. This option would allow Thailand to maintain a robust steel sector (and the associated jobs in steelmaking and downstream industries) while avoiding the most energy-intensive step on its boundary. Essentially, Thailand becomes part of a global green steel supply chain by doing the steel refinement and product manufacturing, whereas a partner country does the upstream iron reduction. It simplifies Thailand's transition: the country would need to focus on securing reliable HBI supply contracts and perhaps upgrading port facilities for bulk HBI handling, but it would not need to build electrolysers and DRI plants at the same scale. Over time, if domestic renewable costs fall, Thailand could still pivot to making more of its own iron, but initially this imported green iron model might accelerate green steel use.

Option 4: Build domestic DRI using natural gas (transitional industrial policy)

In this scenario, Thailand would develop domestic ironmaking capacity by importing natural gas (primarily LNG) to produce DRI, which would then feed into domestic EAFs for steel production. Unlike the hydrogen-import strategy, this pathway relies on commercially mature gas-based DRI technology and uses natural gas as the primary reducing agent. Strategically, this option may be considered if Thailand seeks to upgrade beyond scrap-based EAF production while avoiding the high cost and infrastructure requirements of hydrogen in the near term. In practice, this approach would require secure LNG supply contracts, potential expansion of gas production/import and regasification capacity, and investment in new DRI facilities. It would allow Thailand to retain more value in the ironmaking and steelmaking segments while improving emissions performance compared to traditional blast furnace routes (in other countries). However, it would also introduce exposure to LNG price volatility and could create a form of transitional carbon lock-in if hydrogen substitution does not materialize over time. While not a fully green solution, this strategy represents a realistic bridge toward deeper decarbonization if accompanied by a clear roadmap for gradual hydrogen integration.

Option 5: Full domestic green steel production

This strategy aligns with **Model A**. Thailand would develop the full green steel supply chain domestically: invest in large-scale renewable energy projects, produce green hydrogen domestically, build direct reduction plants to make DRI, and expand EAF steelmaking capacity, all within Thailand. Essentially, Thailand becomes a regional green steel producer, potentially even exporting green HBI or steel. This path would require significant coordination (energy, industry, finance) and likely government support, but it offers the benefit of creating a self-sufficient, decarbonized steel industry and new green jobs. It also hedges against carbon border taxes by producing low-CO_2 steel locally.

In deciding among these strategies, Thai policymakers will need to consider several factors. They might not need to choose only one option but pursue a hybrid approach. The key is that the rise of renewable- and hydrogen-based steelmaking opens new pathways: Thailand is not locked into the old model. It can choose a configuration that plays to its strengths, whether that is abundant solar or a strong industrial base and collaborate with other countries to fill in the gaps. By understanding these supply chain configuration options, policymakers can better strategize Thailand's role in the global green steel transition, positioning the country either as a full-chain producer or a specialized player in the segment that maximizes its comparative advantages.

4.6. Emission Profile of Different Pathways

The emission intensity of steel production also varies significantly across production pathways and is highly dependent on both process configuration and energy inputs.

i) Emission ranges across major steelmaking pathways

Across multiple studies, conventional blast furnace–basic oxygen furnace (BF-BOF) production remains the most carbon-intensive route, with emissions typically ranging from approximately 2.3 to 3.1 tCO_2 per tonne of crude steel (World Steel Association, 2025; IEA, 2022; IECC & UC Berkeley, 2025; Yannik, et al., 2023). These emissions are dominated by coal-based ironmaking and associated upstream processes.

In contrast, scrap-based electric arc furnace (EAF) production represents the lowest-emission pathway among commercially established routes. Reported emissions range from approximately 0.2 to 0.7 tCO_2/t, depending largely on electricity carbon intensity and scrap share (World Steel Association, 2025; IEA, 2022). In cases where electricity is highly decarbonized, emissions can fall even further.

Natural gas-based direct reduced iron combined with EAF (NG-DRI-EAF) offers an intermediate pathway, with emissions typically in the range of 0.8 to 1.7 tCO_2/t (about 50-70% less than BF-BOF) (World Steel Association, 2025; IEA, 2022; IECC & UC Berkeley, 2025; Johnson et al., 2023). While this route avoids coal use, emissions remain due to natural gas consumption in iron reduction and electricity use in EAF operations. Similar to scrap-EAF route, where electricity is highly decarbonized, emissions can fall even further.

Hydrogen-based DRI (H_2-DRI-EAF) has the potential to reduce emissions dramatically, with estimates ranging from near-zero up to approximately 0.8 tCO_2/t, depending on the carbon intensity of electricity used to produce hydrogen (IEA, 2022; IECC & UC Berkeley, 2025; Johnson et al., 2023). Under fully renewable electricity conditions, emissions can be reduced by up to 90-95% compared to BF-BOF production.

These ranges are broadly consistent across studies from the World Steel Association, IEA, and recent academic literature, although exact values vary due to differences in assumptions regarding scrap ratios, system boundaries, and electricity mix.

Table 4.1. Emission profile of different pathways (tCO_2e per tonne of crude steel) *

Study	**BF-BOF**	**Scrap-EAF**	**NG-DRI-EAF**	**H_2-DRI-EAF**
World Steel Association (2026)	2.34	0.69*	1.47	-
Share of scrap	10%	>70%	<30%	-
IEA (2022)	2.95	0.29	-	-
Share of scrap	0%	100%	-	-
IECC & UC Berkeley (2025) - India	2.5-3.1	-	1.2-1.5	95% reduction
Share of scrap	-	-	-	-
Johnson et al. (2025)	-	-	1.13-1.67 ***	0.064-0.437***
Share of scrap	-	-	12.5%	12.5%

Study	BF-BOF	Scrap-EAF	NG-DRI-EAF	H_2-DRI-EAF
Yannik et al. (2023) - Germany	-	-	0.83-1.18***	0.38-0.73***
Share of scrap	-	-	15%	15%

Note: *Values represent indicative ranges reported in the literature and may vary depending on locations, system boundaries, electricity carbon intensity, scrap share, and other assumptions.

**Data concerning global crude steel production using DRI is not currently collected. The denominator in this calculation is therefore calculated by the worldsteel data management team based on information contained in worldsteel's collective databases.

*** Low-high emissions scenarios

Source: (World Steel Association, 2025; IEA, 2022; IECC & UC Berkeley, 2025; Johnson et al., 2023)

ii) Emission implications of different supply chain configurations

When mapped onto the global supply chain configurations discussed in Section 4.3, emissions profiles vary not only by technology but also by where production occurs (Table 4.2).

- **Domestic scrap-EAF (Thailand baseline):** Emissions remain relatively low (about 0.2-0.7 tCO_2e/t), but depend on electricity decarbonization.
- **NG-DRI + EAF:** Emissions increase to about 1.1-1.7 tCO_2e/t, reflecting continued reliance on fossil fuels and depending on electricity decarbonization.
- **H_2-DRI + EAF:** Emissions can fall below 0.1 tCO_2e/t under low-carbon electricity conditions, representing the lowest-emission configuration.
- **Import HBI + EAF:** Emissions vary widely (about 0.1-1.7 tCO_2e/t), depending on the carbon intensity of HBI production (H_2 or/and natural gas) abroad and domestic electricity.
- **Import crude steel:** Emissions are highly uncertain (about 0.1-3.0+ tCO_2e/t), as they depend entirely on the production pathway of exporting countries.

Table 4.2. Emission profiles of different supply chain configurations *

Pathway	Ironmaking	Steelmaking	Electricity	Upstream	Transport	Total (tCO_2/t)
BF-BOF	High	High	Low	High	Low	~2.3-3.1
Scrap-EAF	-	Low	Medium	Low	Low	~0.2-0.7
NG-DRI + EAF	High	Low	High	Medium	Low	~0.8-1.7
H_2-DRI + EAF	Low	Low	Low-High (depends)	Medium	Low	~0.1-0.8
Import HBI + EAF	Abroad (depends)	Low	Low-High (depends)	Medium	Medium	~0.1-1.7
Import Crude Steel	Abroad (depends)	Abroad (depends)	Very Low	Abroad (depends)	Medium	~0.1-3.0+

Note: *Values represent indicative ranges reported in the literature and may vary depending on locations, system boundaries, electricity carbon intensity, scrap share, and other assumptions.

For Thailand, these findings suggest that decarbonization is not determined solely by domestic technology choices, but also by supply chain decisions and energy system characteristics. This reinforces the importance of carbon accounting systems and supply chain transparency, particularly under emerging trade mechanisms such as CBAM.

4.7. Conclusion

The transition to renewable- and hydrogen-based steelmaking represents a fundamental restructuring of the global steel value chain. Under the traditional coal-based model, ironmaking and steelmaking were vertically integrated and geographically co-located. In contrast, renewable- and hydrogen-based direct reduction enables the production of low-carbon solid, transportable iron, allowing ironmaking to shift to renewable-rich regions while steelmaking and downstream industries remain in manufacturing hubs. As a result, comparative advantage is increasingly determined by access to low-cost clean electricity, hydrogen economics, scrap availability, and existing industrial capabilities.

At the same time, the evidence shows that carbon emissions are highly pathway dependent. Conventional BF-BOF production remains the most carbon-intensive route, while scrap-based EAF offers a relatively low-emission baseline, and hydrogen-based pathways provide the deepest decarbonization potential, contingent on clean electricity. Intermediate configurations, such as gas-based DRI or imported HBI, occupy a wide range of emissions outcomes, reflecting differences in upstream processes and energy inputs. This reinforces that emissions are no longer determined solely within national borders but are increasingly embedded in traded intermediates and electricity systems.

For Thailand, this structural shift creates a set of strategic positioning choices rather than a single predetermined pathway. The country may deepen scrap-based EAF production, pursue domestic gas- or hydrogen-based DRI, import green or low-carbon HBI while strengthening steelmaking capacity, or rely more heavily on imported green steel. Each option reflects a different role within a modular and geographically fragmented supply chain, with distinct implications for emissions, cost competitiveness, and industrial development.

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Chapter 5

Socio-Economic Assessment

Decarbonizing steel production is not only a technological and energy challenge, but also a socio-economic transition with wide-ranging implications for economies, labor markets, environment, and social. As countries consider whether and how to pursue green steel pathways, questions of cost, competitiveness, employment, environment, and society become central to evaluating viability. This chapter provide a literature-based assessment of socio-economic implications of green steel. Rather than modeling precise impacts, this analysis synthesizes existing empirical studies and scenario-based evidence to identify directional effects, opportunities, and risks, with a particular focus on Thailand's specific industrial structure and development context.

5.1. Socio-Economic Assessment Framework

To evaluate the socio-economic implications of a green steel transition in Thailand, this study adopts a multi-dimensional analytical framework that captures economic performance, labor market dynamics, environmental outcomes, and broader social impacts. The objective is not only to assess whether decarbonization alters production costs or emissions, but to understand how this transition reshapes value chains, employment structures, health outcomes, and the society's distribution of benefits and burdens. The assessment is organized into four main dimensions:

- **Economic impacts:** Analysis of effects on production costs, productivity, competitiveness, trade exposure, and broader macroeconomic performance, including implications for industrial value chains.
- **Jobs and workforce impacts:** Analysis of changes in employment levels, job composition, skill requirements, and wage structures.
- **Environmental impacts:** Analysis of impacts on greenhouse gas emissions, local air pollutants, and overall environmental quality.
- **Social impacts:** Effects on public health and on the distribution of transition costs and benefits across regions, communities, income groups, and occupational categories.

This analysis adopts a qualitative approach, synthesizing international literature, comparable country experiences, and logical inference. While a full macroeconomic modeling exercise is beyond the scope of this study. As such, impacts are assessed in a directional manner. This allows for identifying whether effects are likely to be positive, negative, or mixed, while acknowledging uncertainties in magnitude and timing.

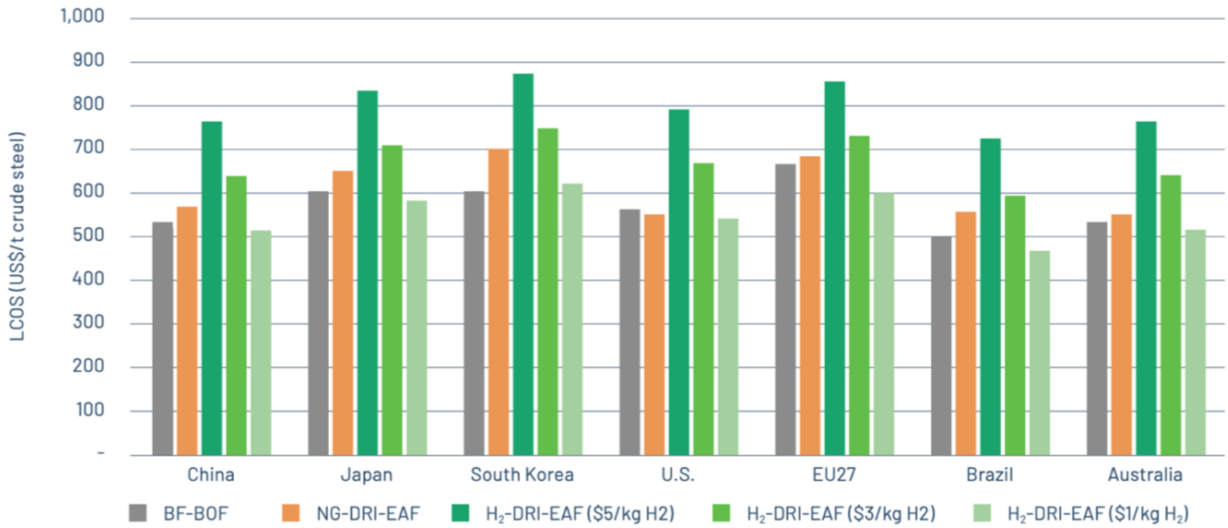
5.2. Economic Impacts

5.2.1) Cost and productivity

A substantial body of literature finds that green steel production currently carries a significant cost over conventional methods (BF-BOF), particularly for primary production via hydrogen-based direct reduced iron combined with electric arc furnaces (H_2-DRI-EAF). This premium is primarily driven by the high cost of low-carbon hydrogen, the capital-intensive nature of new production assets, and in some cases, elevated electricity costs. For instance, H_2 Green Steel, which is developing a hydrogen-based steel plant in Sweden, announced in 2023 that its low carbon steel would be priced approximately 20-30% higher than conventional steel due to higher upfront and operating costs (St. John, 2023).

Looking ahead to 2030, multiple assessments suggest that low-carbon steel will remain more expensive to produce than conventional steel, although the magnitude of this gap will vary by technology and energy assumptions. Hasanbeigi et al. (2024) estimate the incremental average production cost for H_2-DRI-EAF steel in the near term to be at approximately USD 100-200 per tonne of steel relative to conventional BF-BOF routes. But as the cost of green steel decreases (especially green H_2 cost), this price premium should diminish. Figure 5.1 illustrates the green steel premium comparison across various countries, showing the cost of steel production using both traditional and green H_2-DRI-EAF steelmaking routes at different H_2 price points. For example, with H_2 priced at \$1.0/kg, the LCOS for the green H_2-DRI-EAF route is lower than that of conventional steelmaking routes, providing a compelling economic case for its adoption without relying on subsidies or carbon pricing strategies (Hasanbeigi et al., 2024).

Figure 5.1 Levelized Cost of Steel 2030 ($/t crude steel) for BF-BOF, NG-DRI-EAF and green H_2-DRI-EAF in countries studied



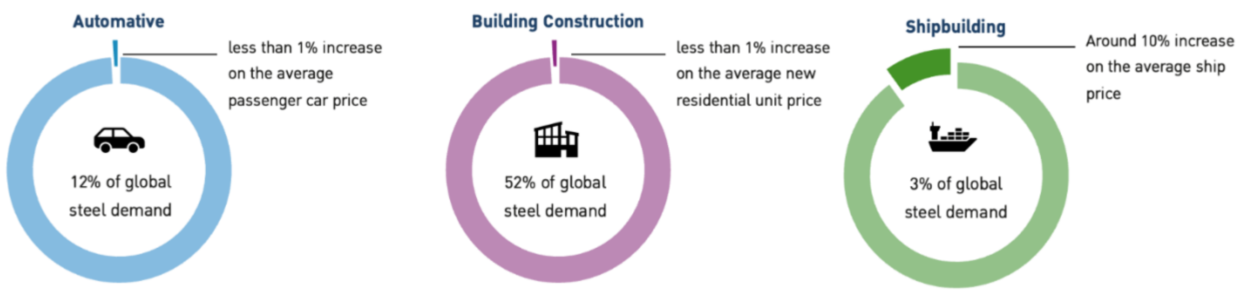
Source: (Hasanbeigi, et al., 2024)

Terry et al. (2023) estimate that converting BF-BOF production to DRI-EAF, initially using natural gas and transitioning to green hydrogen by 2030, could yield a levelized cost of hot-rolled band production of around USD 555 per tonne, rising to roughly USD 635 per tonne for a fully integrated DRI-EAF system using 100% green hydrogen (Terry et al., 2023). Another study also estimates that average BF-BOF production costs could remain below USD 400 per tonne by 2030, while the levelized cost of using other technologies range widely from around USD 430 to USD 840 per tonne (Mission Possible Partnership, 2022).

Steel market volatility further complicates comparisons between conventional and green steel costs. Historical price data indicate that conventional steel prices fluctuate widely in response to market conditions. Between 2013 and April 2024, U.S. steel prices ranged from roughly USD 400 per tonne to over USD 2,100 per tonne, with hot-rolled bands priced at around USD 920 per tonne and cold-rolled coils at approximately USD 1,140 per tonne as of April 2024 (World Steel Dynamics, 2024). The estimates suggest that, under certain conditions, green steel costs may fall within the historical range of conventional steel prices, even if they remain above long-run BF-BOF averages.

However, some studies emphasize that the economic significance of this green steel premium depends strongly on downstream cost pass-through. For end-use sectors such as automotive manufacturing and construction, the contribution of steel costs to final product prices is relatively small. The same study from Hasanbeigi et al. (2024) indicates that even when green steel is used as an input, the resulting increase in total vehicle or building costs is typically less than 1% (Figure 5.2). This suggests that, for many downstream users, adopting green steel may be economically manageable without materially affecting consumer prices, particularly where regulatory or market incentives favor low-carbon materials.

Figure 5.2 Cost pass-through to end products when the green premium is $200-$250/t increase ($5/kg H_2)



Source: (Hasanbeigi, et al., 2024)

In contrast to primary green steel, the cost of secondary steel will likely be less than steel produced via BF- BOF in the future. As of April 2024, U.S. scrap prices ranged from approximately USD 335 to USD 414 per tonne depending on scrap quality, with high-grade busheling (recycled for automotive-grade steel) priced at the upper end (World Steel Dynamics, 2024). In other words, the scrap-based production does not necessarily bear the same premium as primary green steel since recycled steelmaking is a well-established technology. Thus, future pricing likely depends on the price of scrap, which has seen less drastic fluctuation compared to primary steel over the past ten years.

While near-term cost premiums dominate current assessments, some literature also highlights potential productivity gains associated with modern low-carbon steelmaking technologies. In particular, DRI-EAF configurations are generally more automated and operationally simpler than integrated BF-BOF plants, resulting in substantially lower labor requirements per tonne of steel. Jillian et al., (2025) suggest that labor intensity in modern DRI-

EAF facilities can be much lower of that in conventional blast furnace routes, contributing to higher labor productivity and lower operating complexity. These productivity gains could improve international competitiveness if energy input costs are kept under control (Jillian, et al., 2025).

Beyond static cost comparisons, Hasanbeigi et al. (2024) also emphasize the role of learning effects, economies of scale, and declining renewable energy costs in reducing green steel production costs over time. They argue that with sufficient deployment, the cost gap between green and conventional steel could narrow substantially over the 2030s or 2040s as technology matures and clean energy prices fall (Hasanbeigi, et al., 2024).

Some studies project cost parity under specific policy conditions (e.g., high carbon prices), but these outcomes are highly scenario-dependent and not yet widely observed in practice. For example, Johnson et al. (2025) project cost parity between hydrogen-based DRI-EAF and BF-BOF production as early as the mid-2020s in Europe, driven by high carbon prices under the EU ETS and the introduction of CBAM (Johnson, et al., 2025). However, such projections rely on strong assumptions regarding carbon pricing, policy stability, infrastructure availability, and rapid scale-up of low-cost renewable energy and hydrogen. Not all studies converge on the timing of cost parity, and the applicability of one region to other regions remains uncertain.

Overall, the literature indicates that while green steel production currently carries a cost premium relative to conventional BF-BOF routes, the magnitude of this gap varies significantly depending on hydrogen costs, electricity prices, and policy conditions. Scrap-based EAF routes may avoid hydrogen-related cost premiums but remain constrained by scrap availability, quality, and electricity costs. While future cost reductions are possible through learning effects and declining renewable energy costs, the timing and extent of convergence remain uncertain and highly context specific. As such, cost competitiveness is not determined by technology alone, but by the broader energy system, resource availability, and policy environment in which production takes place.

Implications for Thailand:

These global trends in cost and productivity evidence have significant implications for Thailand's steel sector, particularly given its existing production structure and resource constraints.

Implications	Details
1. Limited near-term exposure to hydrogen cost premiums	Thailand's steel industry is already heavily concentrated in electric arc furnace (EAF) and scrap-based production rather than coal-based BF-BOF. This structural starting point reduces immediate exposure to the high-cost premiums associated with hydrogen-based primary steel routes. As a result, the transition challenge is less about replacing stranded BF assets and more about improving the carbon intensity and efficiency and overall performance of existing EAF-based production. In practical terms, this means Thailand can pursue incremental decarbonization, through cleaner iron supply or electricity sourcing, energy efficiency improvements, and higher-quality scrap utilization, without immediate reliance on capital-intensive infrastructure.
2. Scrap-based competitiveness remains a near-term advantage but with structural limits	International evidence suggests that scrap-based EAF production may not face the same "green premium" as hydrogen-based primary steel. For Thailand, this reinforces the economic logic of leveraging and upgrading its existing scrap-EAF base. However, this advantage is conditional. Scrap availability and quality are likely to become binding constraints, particularly for higher-grade steel applications such as automotive flat steel. Thailand's domestic scrap supply is influenced by historical steel consumption patterns, and quality limitations (e.g., residual impurities) may restrict the ability to produce premium steel grades using 100% scrap. As demand for higher-specification steel grows, reliance on scrap alone may limit industrial upgrading.

Implications	Details
3. Deep decarbonization would reintroduce energy and capital cost exposure	While Thailand's current EAF concentration provides short-term insulation from hydrogen cost premiums, moving beyond incremental decarbonization, especially toward higher-grade primary iron production, would require new DRI capacity or alternative low-carbon iron sources. This would reintroduce exposure to higher energy costs, more investment requirements, and infrastructure dependencies. In other words, Thailand can achieve moderate emissions reductions within its current technological structure, but full alignment with deep decarbonization pathways may necessitate new investments that face the higher cost.
4. Downstream cost pass-through is unlikely to be a major constraint	Evidence from international assessments indicates that even when green steel carries a premium, cost pass-through to final products such as vehicles or buildings is typically small. For Thailand, this implies that from a macro-level perspective, adopting lower-carbon steel is unlikely to generate significant economy-wide inflationary pressure. Steel cost increases tend to be diluted across complex value chains rather than directly transmitted to final consumers. This is particularly relevant for export-oriented sectors such as automotive manufacturing, where compliance with carbon standards in regulated markets (e.g., EU under CBAM) may be more important than marginal cost differences. However, limited pass-through does not mean limited impact at the firm level. Especially, margin-constrained manufacturers like SMEs or firms competing in highly

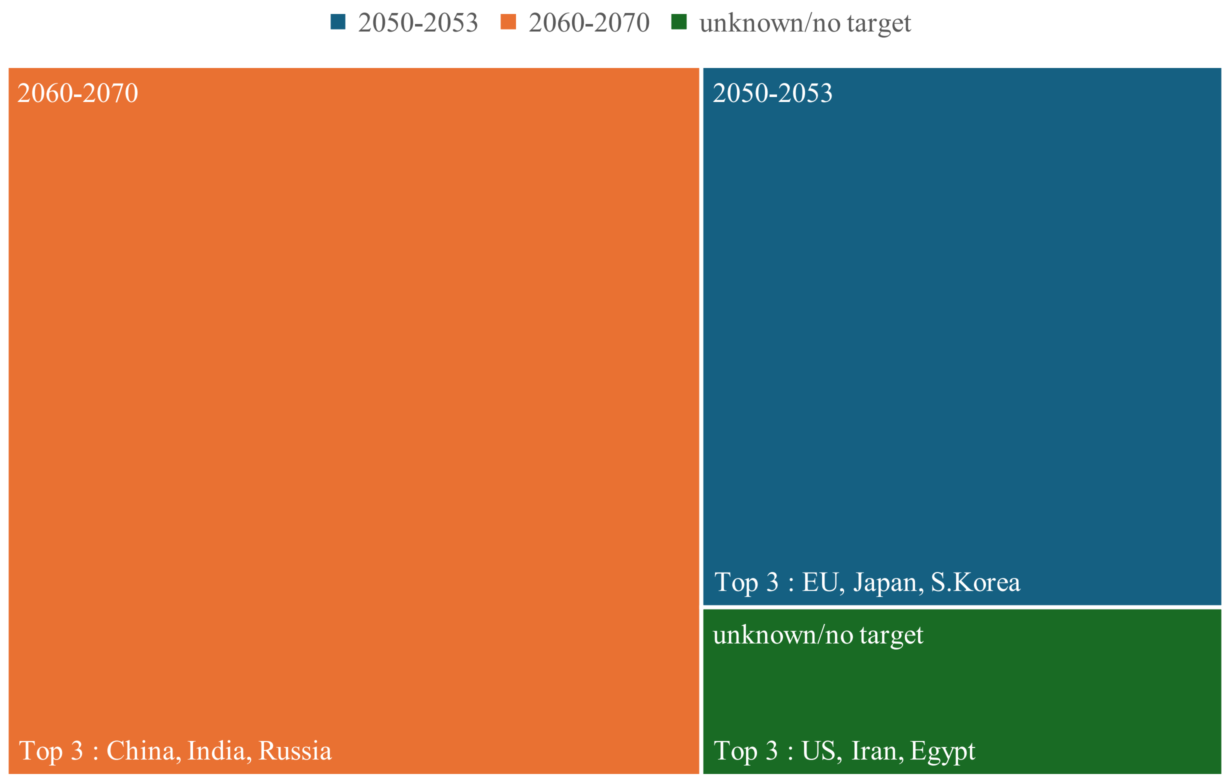
Implications	Details
	price-sensitive markets, may struggle to absorb higher input cost.
5. Productivity gains may partially offset cost pressures	Modern DRI-EAF configurations are generally more automated and labor-efficient than traditional integrated plants. If Thailand were to invest in newer low-carbon production technologies, there may be opportunities to improve labor productivity and operational efficiency.

5.2.2) Competitiveness and trade

A central concern in the green steel transition is whether higher production costs associated with decarbonization will erode international competitiveness, particularly in economies facing higher energy prices or tighter environmental standards. In the absence of compensatory policies, an incremental cost increase would typically disadvantage domestic producers in export markets and encourage imports from jurisdictions with lower production costs or weaker climate regulations. Several studies caution that, under such conditions, steel industries in carbon-constraint economies could lose market share if competitors benefit from cheaper energy or less stringent standards (Johnson, et al., 2025). These risks underpin the rationale for border and trade-related policy instruments such as the European Union's CBAM, which seeks to equalize carbon costs between domestic producers and imports.

OECD analyses, cited in ODI Europe (2025), further note that more than 90% of global steelmaking capacity is now located in countries that have adopted net-zero pledges (Figure 5.3), suggesting that carbon constraints on steel production are likely to become more widespread over time rather than remaining isolated to a few regions. In this context, competitiveness risks increasingly depend on relative policy timing and design, rather than on the presence or absence of decarbonization efforts alone.

Figure 5.3 Current total steelmaking capacity by net zero target year



Note: Some EU members have a net zero target before 2050, but these were included in the EU; Adjusted US for latest update on net zero target.

Source: (ODI Europe, 2025; OECD, 2024)

A growing number of literatures highlights the strategic advantages of early action in low-carbon steel. Rather than viewing decarbonization primarily as a cost burden, some analyses argue that countries and firms that move early can secure first-mover advantages in technology development, supply-chain positioning, and market access (Agora Industry, 2021; Algers, J. & Bataille, C., 2025). By investing ahead of competitors, early movers may establish domestic capabilities in new production processes, build relationships with downstream buyers seeking verified low-carbon materials, and shape emerging standards and certification frameworks. In this sense, proactive transition is not only about compliance with future regulation but also capturing leadership in expanding low-carbon markets and positioning domestic industry at the forefront of structural industrial transformation.

Demand-side dynamics further complicate static competitiveness assessments. Some studies highlight the emergence of explicit demand for low-carbon steel from automotive manufacturers, construction firms, and public procurement programs. Rocky Mountain Institute (RMI) argues that steel producers that fail to decarbonize risk losing customers as governments and large buyers increasingly favor cleaner materials (Masterson et al., 2025). From this perspective, maintaining conventional high-emission production may itself constitute a competitiveness risk in a carbon-constrained future, particularly for firms embedded in global value chains serving regulated or sustainability-conscious markets.

Implications for Thailand:

The international evidence suggests that competitiveness in the steel sector is increasingly shaped not only by price, but also by carbon performance and alignment with global net-zero trajectories. For Thailand, this creates both risk and opportunity.

Implications	Details
1. Carbon performance is becoming a market attribute, not a niche feature	With more than 90% of global steelmaking capacity now located in countries that have adopted net-zero pledges, carbon constraints are likely to become structural rather than exceptional. This implies that Thailand's exporters, particularly those embedded in global value chains such as automotive manufacturing, will face growing exposure to carbon-related trade measures and buyer requirements. Inaction may therefore carry a competitiveness risk. Misalignment with major trading partners could increase compliance costs, administrative burdens, or even limit market access under instruments such as CBAM and similar mechanisms.
2. Early positioning could create first-mover advantages	If Thailand moves proactively, there is potential to capture early-mover benefits. Developing credible low-emission steel production, particularly certified scrap-EAF or low-carbon iron-based routes, could strengthen Thailand's

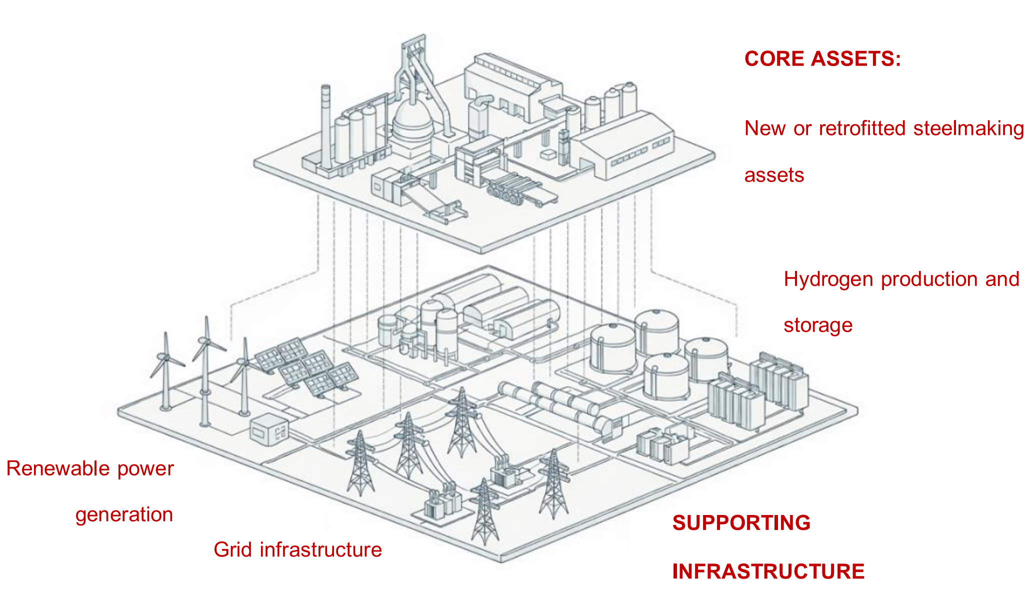
Implications	Details
	standing in regulated or sustainability-driven export markets. Rather than competing solely on cost, Thai producers could compete on verified carbon intensity, positioning themselves as preferred suppliers for green procurement programs or low-carbon automotive supply chains. In this sense, early deployment may initially be more viable in the domestic market, with export competitiveness emerging as scale improves and costs decline.
3. Trade exposure may shift	Under certain cost conditions, green steel development could reduce Thailand's import exposure by substituting some steel imports with domestic production. This would retain value within the national economy, reduce foreign currency outflows, and potentially support local GDP and employment.
4. The strategic choice is not a single pathway	Thailand does not face a simple choice between full domestic production and full import dependence. A mixed strategy is also an option. The key policy question is how Thailand positions itself within emerging low-carbon steel value chains: • As a cost-competitive secondary producer, • As a downstream industrial hub linked to global green iron trade, • Or as a more vertically integrated low-carbon steel producer. Each pathway implies different exposure to energy costs, trade risks, and industrial spillovers. The competitiveness outcome will ultimately depend less on the existence of a

Implications	Details
	green premium and more on how Thailand manages energy policy, trade alignment, and supply-chain integration in a carbon-constrained global economy.

5.3.3) Investment and spillover effect

Decarbonizing steel production entails significant capital expenditure. Transition pathways, whether scrap-based upgrading, hydrogen-based DRI, or CCUS retrofits, require investment not only in steelmaking assets but also in enabling infrastructure. Illustrated in Figure 5.5, core components include renewable power generation, grid expansion and reinforcement, hydrogen production (if the H_2-pathway is chosen) and storage facilities, industrial electrification, and in some cases CO_2 transport and storage networks (if the CCUS-pathway is chosen).

Figure 5.5 Core assets and supporting infrastructure of green steel production



Source: Authors

Beyond the steel sector itself, the literature highlights the broader investment spillovers associated with green steel development. A study notes that investments in low-carbon steelmaking can catalyze parallel investment in renewable energy infrastructure, hydrogen electrolyzers, and industrial logistics (E3G and Beyond Fossil Fuels, 2025). These complementary investments can generate wider economic activity and help accelerate energy system transformation, particularly where steel production acts as a large, stable anchor demand for clean electricity and hydrogen. In regions pursuing industrial policy strategies, such spillovers are often cited as justification for targeted public support.

In the meantime, continuing to invest in conventional steel assets may risk creating stranded assets as carbon constraints tighten and demand shifts toward low-emission materials. By contrast, investing in new technologies aligns industrial capacity with future market conditions, potentially preserving industrial output and employment over the longer term. This logic underpins recent policy responses in several advanced economies, where governments have committed significant public resources to support low-carbon upgrades in steelmaking. Examples from the United Kingdom and the United States illustrate the scale of intervention, with hundreds of millions of dollars in public funding directed toward steel producers undertaking decarbonization investments (Hannah, et al., 2025).

Implications for Thailand:

The investment dimension of green steel is particularly consequential for Thailand because it interacts directly with the country's broader energy and industrial development trajectory.

Implications	Details
1. Steel investment is inseparable from energy system planning	Low-carbon steel development would require parallel investment in renewable generation, grid reinforcement, and potentially hydrogen production and storage. For Thailand, this means that any serious move toward hydrogen-based DRI or deeper electrification cannot be treated as a stand-alone industrial upgrade; it would significantly affect electricity demand, grid stability, and long-term energy planning. Steel could serve as a large and stable anchor demand for renewable electricity. If managed strategically, this may help

Implications	Details
	accelerate renewable deployment by improving project bankability and providing long-term industrial offtake.
2. Potential system-wide spillovers, but conditional on scale	Green steel investment could catalyze complementary sectors in Thailand, including: • Renewable infrastructure development, • Electrolyzer manufacturing and hydrogen supply chains (if H_2-pathway is chosen), • Industrial logistics and port infrastructure, • Engineering and construction services. If assets operate at sufficient scale, productivity gains may emerge through modernization, automation, and integration across industrial clusters. In this scenario, steel decarbonization becomes a vehicle for broader industrial upgrading. However, spillovers are not automatic. They depend on domestic capability development, coordination between industrial and energy policy, and sustained demand signals. Without these conditions, large capital investments may deliver limited multiplier effects.
3. Capital intensity increases financial and utilization risk	Green steel pathways are capital-intensive. Large upfront investment increases exposure to: • Underutilized capacity if demand for green steel develops slower than expected, • Energy price volatility, • Policy uncertainty (e.g., carbon pricing or trade measures), • Technology lock-in if pathways evolve differently than anticipated.

Implications	Details
	For Thailand, where fiscal space and energy system constraints are more limited than in advanced economies, careful sequencing and risk-sharing mechanisms would be critical. Premature large-scale investments without stable renewable supply or credible export demand could create stranded or partially utilized assets.

5.3. Job and Workforce Impacts

5.3.1) Employment reallocation and multiplier effects

The employment implications of the green steel transition are complex and highly pathway dependent. The literature converges on a central conclusion: decarbonization tends to redistribute employment across activities and regions rather than generate uniform net job losses. However, the short-term and long-term effects differ substantially depending on technology choice, demand conditions, and the geographic location of new investment.

Direct plant-level employment effects

At the plant level, transitions from blast furnace-basic oxygen furnace (BF-BOF) routes to electric arc furnace (EAF) and DRI-EAF configurations generally reduce labor intensity per tonne of output. Modern DRI-EAF facilities involve fewer processing stages and are significantly less labor-intensive.

Empirical evidence from a case study in Southwest Pennsylvania suggests that replacing BF-BOF capacity with DRI-EAF could reduce direct plant employment by approximately 60-80%, implying that only around 20-40% of the incumbent workforce would be retained for comparable output levels (Jillian, et al., 2025). In the United Kingdom, Tata Steel's transition toward EAF-based production is projected to eliminate around 2,800 jobs (Hannah, et al., 2025).

Historical restructuring in the United States demonstrates that output stability does not guarantee employment stability. Between 1990 and 2021, U.S. steel employment declined by roughly 50% despite relatively stable production levels (Massachusetts Institute of Technology & Harvard University, 2024), reflecting automation and consolidation.

Indirect, induced, and multiplier effects

Steel production is deeply embedded in upstream and downstream value chains. As a result, employment effects extend beyond direct steelmaking jobs to include indirect jobs in supply industries and induced jobs in local economies (Figure 5.6). Several compensating channels are identified in the literature:

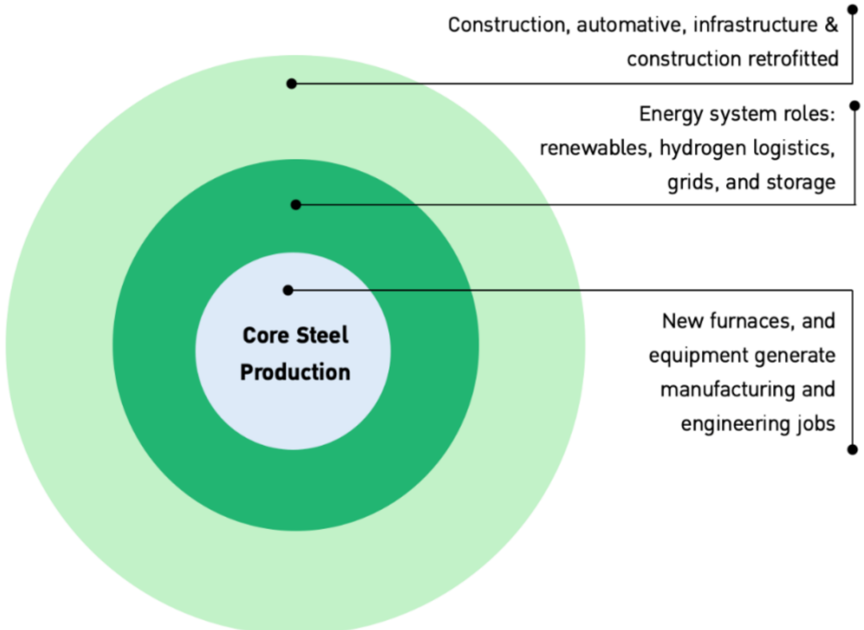
1. **Capital investment effects:** Green steel deployment requires substantial investment in furnaces, electrolyzers, renewable generation, grid infrastructure, and industrial logistics. These investments generate employment in engineering, construction, and equipment manufacturing.

2. **Downstream value chain effects:** Maintaining competitive and low-carbon domestic steel production can support employment in steel-using sectors such as automotive manufacturing, construction, machinery, and infrastructure. Analyses by Syndex (2021) and Agora Industry (2023) argue that preserving domestic steel capacity helps reduce import dependence and limits exposure to carbon-related trade barriers, thereby protecting downstream employment (Agora Industry & Wuppertal Institute, 2023; McDonald, et al., 2021).

3. **Energy-system spillovers:** Electrified and hydrogen-based pathways may stimulate job creation in renewable energy generation, hydrogen production, storage, and transport infrastructure.

   These spillovers expand the employment footprint beyond the steel sector itself.

Figure 5.6 Job multipliers of green steel development

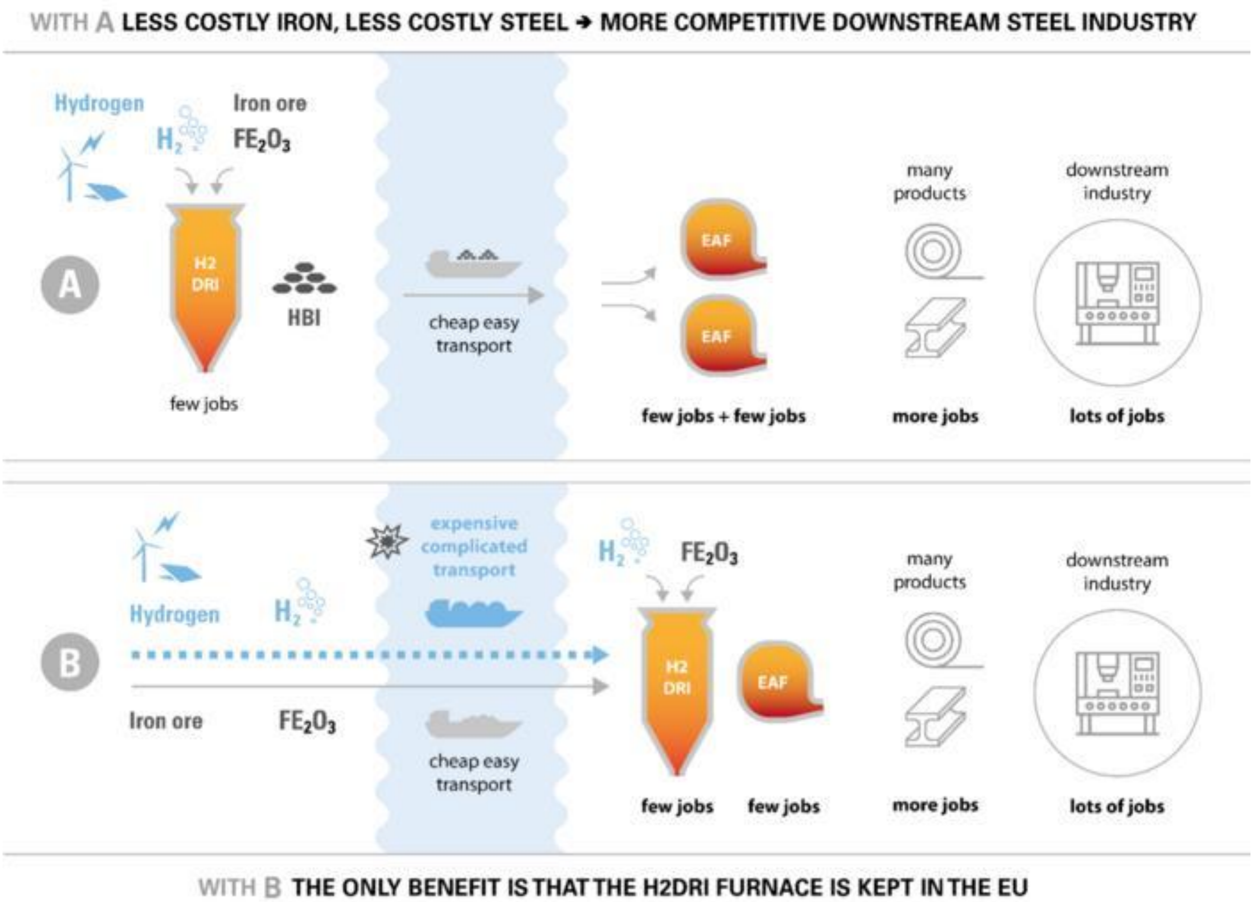


Source: (Agora Industry & Wuppertal Institute, 2023; Hannah, et al., 2025; McDonald, et al., 2021)

Case-based evidence supports the importance of multiplier effects. The Middletown steel mill case, World Resources Institute (2025) suggests that decarbonization investment would have helped preserve approximately 2,500 direct jobs while creating a large number of indirect and induced jobs in the regional economy (Hannah, et al., 2025). Conversely, allowing facilities to close would have triggered broader employment contraction across suppliers and service providers.

With supply chains evolving, as discussed in Chapter 4, Trollip's (2025) argument implies that employment risks associated with cross-border green iron trade are likely to be concentrated in upstream segments, while downstream employment in steelmaking and fabrication can potentially be preserved or even strengthened, provided domestic processing capacity remains competitive. The analysis suggests that ironmaking accounts for a relatively small share of total steel-sector employment, on the order of 10% in some industrialized contexts, while the majority of employment is concentrated in steelmaking and downstream activities (Figure 5.7). This implies that cross-border trade in green iron may shift upstream production without necessarily leading to large-scale employment hollowing-out in importing regions. However, the distribution of employment effects is context-specific and depends on national industrial structures and competitiveness conditions.

Figure 5.7 Two routes to green steel development and the employment effects



Source: (Trollip, 2025)

Taken together, the literature indicates that green steel transitions do not necessarily lead to net job losses, but rather redistribute employment across technologies, supply chains, and regions. Direct employment in traditional steelmaking is likely to decline due to automation and process simplification. However, indirect and induced employment can expand through investment in energy systems, infrastructure, and downstream industries. Whether this results in net job creation depends critically on demand growth, the location of investment, and the extent to which countries retain value within their domestic supply chains. As such, employment outcomes are not determined by decarbonization itself, but by how transition pathways are integrated into broader industrial and energy strategies.

Implications for Thailand:

For Thailand, the employment implications of green steel development depend fundamentally on its strategic positioning within supply chains.

Implications	Details
1. Limited legacy displacement risk, but lower labor intensity	Unlike mature steel-producing economies, Thailand does not currently operate large integrated BF-BOF facilities. Therefore, the risk of large-scale displacement of coal-based ironmaking jobs is structurally limited. This reduces the short-term social disruption risks observed in Europe or the United States. However, Thailand's steel sector is already predominantly scrap-based and EAF-oriented, which is inherently less labor-intensive. Transition pathways centered on electrification and efficiency improvements are therefore unlikely to generate large direct employment gains within steel plants themselves. Automation and productivity improvements, in contrast, may further reduce labor demand per tonne of output. In this context, employment growth cannot be assumed simply from technological upgrading.
2. Downstream employment is the critical anchor	Thailand's economic exposure to steel lies more heavily in downstream industries, automotive manufacturing, machinery, construction materials, appliances, and infrastructure, than in primary ironmaking. The literature's distinction between upstream ironmaking and downstream steel-using employment is therefore particularly relevant.

Implications	Details
	If Thailand were to rely on imported green iron or semi-finished inputs while maintaining competitive domestic steelmaking and rolling capacity, most downstream employment could remain intact. Conversely, failure to secure competitive access to low-carbon inputs, whether domestic or imported, could weaken Thailand's position in export-oriented manufacturing sectors that are increasingly exposed to carbon standards and supply-chain decarbonization pressures.
3. Investment location will determine multiplier outcomes	Employment spillovers depend heavily on where capital investment occurs. • If Thailand develops domestic low-carbon steel capacity (e.g., DRI-EAF, renewable integration, hydrogen infrastructure), multiplier effects may extend into construction, engineering services, renewable energy, and grid expansion. • If green iron production is imported and domestic upgrading is minimal, upstream employment benefits will accrue elsewhere, limiting domestic multiplier effects. Thus, alignment between steel decarbonization and broader industrial policy will be critical.

5.3.2) Job quality and wages

Compared to employment quantity, the literature provides less quantitative evidence on how green steel transitions affect job quality and wages. However, available studies and qualitative assessments point to heterogeneous impacts, shaped by changes in skill requirements, workplace conditions, and the distribution of opportunities within steel plants and across local labor markets.

On the positive side, green steel facilities, particularly those based on DRI-EAF configurations, are typically more automated and technologically advanced than conventional blast furnace operations. These plants often offer cleaner and safer working environments, with reduced exposure to hazardous conditions such as coke ovens, extreme heat, and particulate pollution. The shift away from coal-based processes can therefore improve occupational health and safety outcomes. At the same time, the operation and maintenance of advanced furnaces, digital control systems, and energy infrastructure tend to require higher technical skills, potentially increasing demand for skilled technicians, engineers, and maintenance staff. Where workers are able to upskill and transition into these roles, this may support improvements in job quality and, potentially, higher wages.

However, these gains are not evenly distributed. A qualitative study of Finnish steelworkers finds that workers perceive the transition in divergent ways: some view it as an opportunity to acquire new skills and improve career prospects, while others fear that they lack the educational background or training opportunities needed to adapt (Kortetmäki, et al., 2025). This divergence reflects uneven capacity to respond to changing skill requirements and suggests that improvements in job quality are not automatically shared across the workforce.

Wage risks are particularly acute for workers whose skills are closely tied to legacy production processes. Jillian et al. (2025) estimate that skill overlap between conventional and green steel jobs is high, with existing workers able to meet over 95% of job requirements in DRI-EAF facilities. This indicates that employability is not the primary constraint; rather, the key challenge lies in the limited number of available positions. For workers who must transition into the broader labor market, the same study finds that around 15% of occupations are more constrained by wage considerations than by skill compatibility. In other words, while these workers are qualified for alternative roles, the available opportunities may not match their previous earnings, increasing the risk of downward wage adjustment.

Implications for Thailand:

For Thailand, the implications of green steel transition on job quality and wages are likely to be less visible than large-scale employment loss, but potentially more socially sensitive.

Implications	Details
1. Limited exposure to coal-based occupational risks	Thailand does not operate large-scale integrated BF-BOF facilities with coke ovens and coal-intensive upstream processes. As a result, the occupational health gains associated with phasing out coal-based ironmaking, such as reduced exposure to extreme heat, particulate emissions, and hazardous by-products, may be smaller relative to countries undergoing deep coal-to-hydrogen transitions. However, modernization toward more automated and digitally controlled EAF and DRI-EAF systems could still improve workplace safety standards, reduce manual handling risks, and formalize skill requirements. Job quality improvements in Thailand would therefore likely arise more from technological upgrading and formalization than from dramatic improvements in hazardous working conditions.
2. Upskilling pressure in a mid-skill industrial base	Thailand's steel sector is predominantly scrap-based and relatively labor-light. A transition toward more advanced process control, digital monitoring, energy optimization, and potential hydrogen integration would increase demand for technicians, engineers, and energy-management specialists. This creates both opportunity and risk: • **Opportunity:** Higher technical requirements may raise average wages for skilled workers, particularly in engineering, maintenance, automation, and energy integration roles. • **Risk:** Workers in routine or manual roles may face reduced bargaining power or stagnating wages if automation increases and number of positions decline.

Implications	Details
	Given that Thailand's broader industrial workforce includes many mid-skilled workers with vocational training backgrounds, the capacity of training institutions (e.g., technical colleges and firm-based programs) to provide targeted reskilling will be decisive.
3. Wage portability risks for specific occupational groups	The literature suggests that a subset of steel occupations faces limited wage portability. In the Thai context, while legacy coal-based occupations are limited, there may still be niche roles tied to specific production processes or plant configurations. If technological upgrading reduces demand for certain functions (e.g., manual sorting, older maintenance systems, or routine operational roles), displaced workers may struggle to secure equivalent wages outside the sector.
4. Skill overlap suggests potential for transition, but outcomes remain uneven	Evidence from international studies suggests that skill overlap between conventional and green steel roles can be relatively high (around 95%), indicating that many workers may be broadly compatible with emerging production systems. In the Thai context, where steel production is already largely EAF-based, the technological shift associated with green steel is likely to be more incremental than radical. This suggests that large-scale displacement may be less pronounced than in integrated BF-BOF systems. However, this does not imply a smooth or uniform transition. While some workers may be able to move into upgraded technical roles, others, particularly those in semi-skilled or routine positions, may face limited pathways for advancement.

Implications	Details
	As a result: • Wage losses are not structurally inevitable, but remain a risk for certain groups of workers. • The transition is likely to involve uneven changes in job quality and wages, rather than uniform upgrading across the workforce. Without early investment in targeted training and reskilling programs, the transition could lead to widening wage polarization between higher-skilled technical roles and remaining semi-skilled positions. This highlights the importance of just transition policies, particularly those focused on reskilling, income protection, and job matching, to mitigate distributional risks and support affected workers.

5.4. Environmental Impacts

The transition of the steel industry is one of the key issues in reducing greenhouse gas emissions in the industrial sector, as the steel industry accounts for a high share of global emissions and relies intensively on fossil fuel-based energy (IEA, 2020; IEA, 2021). However, the environmental impacts of the steel industry are not limited only to climate change, but also include local air pollution, water resource use, waste management, and the ability of production systems to adapt to increasingly stringent environmental regulations.

In the context of transitioning toward green/low-carbon steel production, new technologies such as Electric Arc Furnace (EAF), Direct Reduced Iron (DRI) combined with low-carbon hydrogen, and Carbon Capture, Utilization and Storage (CCUS) have been proposed as key approaches to reduce greenhouse gas emission intensity. However, the environmental outcomes of such a transition depend on systemic conditions, such as the electricity generation structure, the availability of raw materials for steel production, and the efficiency of pollution control systems.

5.4.1) Climate change

The transition to EAF and DRI-EAF systems, particularly when using low-carbon hydrogen, has significant potential to reduce CO_2 emission intensity. Several studies indicate that under low-carbon energy assumptions, shifting from BF-BOF to hydrogen-based DRI-EAF can reduce emissions by 90-95% compared to a baseline of approximately 1,600 kg CO_2 per ton of crude steel (Rozanski, et al., 2022).

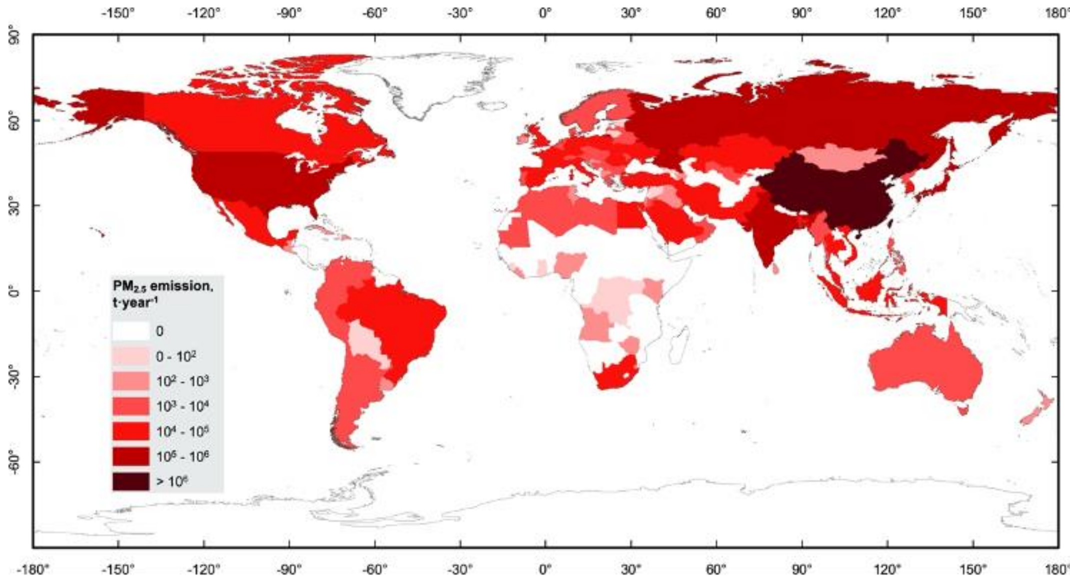
However, this potential depends significantly on the carbon intensity of the electricity system. Since EAF processes and hydrogen production require large amounts of electricity, if the power generation structure continues to rely on fossil fuels, emission reductions in the steel sector may be limited, and the emission burden may shift from the industrial sector to the power sector. Therefore, decarbonizing the steel industry is closely linked to decarbonizing the electricity sector.

5.4.2) Air pollution

While climate impacts occur at the global level, air pollution from steel production directly affects air quality in industrial areas and surrounding communities. In particular, the BF-BOF process involves coal combustion in multiple stages, leading to high emissions of particulate matter (PM), sulfur dioxide (SO_2), and nitrogen oxides (NO_X) (Zhang, et al., 2023).

Figure 5.8. shows the volume of PM2.5 emissions from the steel industry at the country level. These data reflect the air pollution burden generated by the steel production sector and demonstrate that the environmental impacts of the steel industry are not limited to CO_2 but also include local air quality impacts.

Figure 5.8 Annual PM2.5 emissions from the iron and steel industry in 2019, by country



Source: (Zhang, et al., 2023)

The concentration of emissions is also highly uneven across countries. The top 9 steel producing countries, which are China, India, USA, Russia, Japan, Korea, Turkey, Iran, and Ukraine, account for more than 75% of global steel-related emissions in 2019. This indicates that environmental pressures from steel production are geographically concentrated rather than evenly distributed.

In particular, East Asia emerges as a major global pollution hotspot, contributing approximately 64% of CO_2 emissions: 46% of PM2.5 and 59% of NO_X emissions from the steel sector (Zhang, et al., 2023).

BF-BOF production generates significantly higher environmental and health impacts than EAF. It emits around 2.6 times more CO_2 and roughly seven times more dust, with sintering and ironmaking processes being the primary sources of particulate emissions (Li, et al., 2018). Moreover, dust from steelmaking often contains hazardous heavy metals, such as chromium (Cr), nickel (Ni), zinc (Zn), and lead (Pb), which can pose greater health risks than particulates from typical combustion sources (Zhang, et al., 2023).

The transition to EAF reduces direct coal combustion, significantly lowering SO_2 and NO_X emissions. However, high scrap usage may increase the risk of heavy metal contamination in dust and waste if proper sorting and quality control systems are not in place (Zhang, et al., 2023).

Therefore, the effectiveness of dust filtration systems plays a crucial role in reducing impacts on surrounding communities (Gonzalez, et al., 2017).

<u>Implications for Thailand</u>

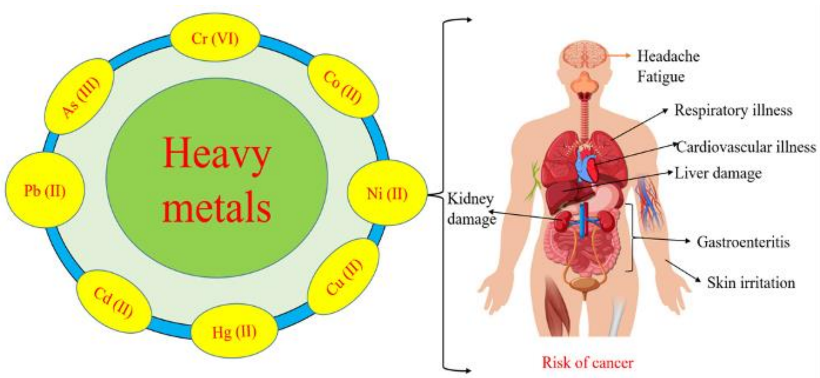
Implications	Details
1. Potential to reduce pollution through power sector decarbonization	Since EAF primarily uses electricity, if Thailand increases the share of renewable energy in the power system, the carbon intensity of Thai steel will immediately decrease without requiring additional changes in production technology.
2. Reducing fossil fuel use helps lower PM, SO_2, and NO_X	Thailand would reduce pollution sources from direct fossil combustion processes, which are major sources of emissions.
3. Risk from scrap contamination	Large-scale use of scrap in EAF production may increase the risk of dust emissions containing hazardous heavy metal components compared to traditional methods, if strict sorting and quality control systems are not in place.

5.4.3) Water use and waste

The steel industry requires water for cooling, gas cleaning, and other production processes, with water consumption ranging from approximately 3-8 cubic meters per ton of steel, depending on the level of technological development and internal water circulation systems. Inefficient management systems may result in wastewater containing heavy metals and suspended solids, which can impact soil and water bodies (Niu, et al., 2023), as well as ecosystems and human health.

In terms of water pollution, a case study in Ma’anshan, China, shown that concentrations of cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn) in soil sediments in areas affected by the steel industry were significantly higher than in control areas, with particularly high accumulation observed for Cd and Zn (Niu, et al., 2023). These findings suggest that inadequate wastewater control may contribute to long-term contamination of surrounding environments. Wastewater contaminated with heavy metals can pose serious risks to human health, including liver and kidney damage, increased cancer risk, and adverse effects on the reproductive system (Figure 5.9).

Figure 5.9 Water pollution and its harmful impacts on human health



Source: (Zhang, et al., 2023)

In the context of hydrogen-based technology transition, water demand may increase due to hydrogen production processes. Hydrogen production via electrolysis requires approximately 9-30 liters of water per kilogram of hydrogen (The International Renewable Energy Agency (IRENA), 2023). This is particularly relevant when hydrogen is produced using electricity from gas-fired power plants with cooling systems, which can significantly increase overall water consumption. When electricity generation is included, total water consumption increases further and varies significantly by energy source, with substantially higher levels observed under thermal power. In contrast, water demand remains relatively low when renewable energy is used. Additionally, the adoption of closed-loop water systems can further reduce water consumption and wastewater discharge, with some cases achieving water recirculation rates exceeding 90% (Liang, et al., 2023).

Implications for Thailand

Implications	Details
1. Waste control infrastructure and investment needs	Transitioning to green technology does not mean achieving zero waste. Additional investments are still required, such as closed-loop water systems and advanced treatment technologies.

Implications	Details
2. Increased water demand from future hydrogen production	Hydrogen production will require more water, which may affect areas facing water security risks or during dry seasons.

5.4.4) End of life and recycling potential

The availability and quality of scrap represent a critical structural factor influencing environmental outcomes. Scrap serves as the primary feedstock for Electric arc furnace (EAF) production. Adequate scrap supply is therefore a key condition for reducing reliance on iron ore and coal. However, scrap quality affects heavy metal contamination, dust generation, and the characteristics of process-related waste. Consequently, the effectiveness of scrap collection, sorting, and quality control systems plays a central role in determining both decarbonization potential and local pollution impacts.

Scrap recycling provides significant environmental advantages compared to primary steelmaking. It plays an important role in reducing environmental impacts, as steel production from scrap consumes significantly less energy and emits substantially lower greenhouse gases compared to production from iron ore. Studies indicate that recycling steel can reduce CO_2 emissions by approximately 1.5 kilograms per 1 kilogram of recycled steel, and requires much less energy than iron ore-based production (Broadbent, 2016; Harvey, 2020). It can also reduce air pollution by 86%, water use by 40%, and water pollution by 76% (Stena Recycling, 2025).

Recycling potential, however, depends on the quality and quantity of scrap available in the system. Scrap has limitations in chemical composition and contamination, which may restrict its use in certain products.

In practice, scrap can be blended with DRI/HBI or high-quality iron to improve metallic purity, reduce residual elements, and enhance final steel quality. This blending strategy enables producers to increase scrap utilization while maintaining product standards, particularly for high-grade steel applications.

While scrap can reduce pressure on natural resources, it cannot fully replace iron ore-based production. Instead, optimized combinations of scrap and primary iron inputs offer a more balanced pathway that supports both environmental performance and product quality.

Implications for Thailand

Implications	Details
1. Alignment with the circular economy model	Thailand's reliance on EAF aligns well with circular economy principles. By using scrap as the primary input, the production system reduces energy demand, lowers emissions, and minimizes the need for virgin natural resources.
2. Opportunity to develop domestic scrap infrastructure	Improving the efficiency of scrap collection and sorting systems can reduce imports and increase value within the domestic supply chain.
3. Risk from scrap contamination	There is a risk of toxic contamination from scrap if proper sorting systems are not in place.

5.5. Social Impacts

Focusing solely on greenhouse gas emission reductions may not be sufficient to ensure a truly sustainable transition of the steel industry. Decarbonization in the industrial sector is not merely a technological or environmental shift; it is also a social transition process that affects workers, regional economies, institutional structures, public acceptance, and public health.

5.5.1) Global and regional inequalities

At the international level, decarbonizing the steel industry may create or exacerbate inequalities between countries. Advanced economies possess structural advantages in terms of finance, technology, clean energy systems, and supportive policy frameworks, enabling them to adopt low-carbon steel technologies more rapidly. In contrast, developing countries often face constraints related to costs, competitiveness, and institutional capacity (IEA, 2021; OECD, 2024; OECD, 2025).

These constraints reflect not only issues of industrial competitiveness but also the capacity of governments to allocate budgets to support affected workers and regions. Where such capacity is limited, social vulnerability may increase during the transition period.

Structural imbalances also influence countries' positions within global supply chains. Early movers with stronger economic capacity are better positioned to secure critical resources, such as high-quality iron ore, low-cost renewable electricity, and hydrogen infrastructure. As demand for these resources increases, bargaining power may shift toward resource-rich and economically stronger countries, while resource constrained countries face risks related to import dependence and supply insecurity (Agora Industry, 2021; European Climate Foundation, 2024).

These dynamics may affect domestic perceptions of fairness, particularly in countries that industrialize later, where global climate policies may be viewed as imposing disproportionate burdens on their societies.

<u>Implications for Thailand</u>

Implications	**Details**
1. International competitiveness	Thailand's steel industry relies heavily on imported raw materials and technology and still depends largely on fossil fuels. If trading partners especially the European Union or other developed countries accelerate carbon measures such as carbon border adjustment mechanisms (CBAM): • **Risk:** Thai steel producers may face higher costs and lose competitiveness. • **Opportunity:** If Thailand can accelerate clean energy infrastructure and support low-carbon steel production in time, it could access markets that prioritize green supply chains and increase product value in the long term.

5.5.2) Labor and regional inequality

Decarbonization in the steel industry brings both new opportunities and adjustment pressures for the workforce. On one hand, it supports job creation in emerging green value chains, such as renewable energy, hydrogen, and electrification technologies. On the other hand, it places workers in conventional production processes at risk of displacement. Without effective reskilling programs and adequate social protection, these impacts may become concentrated in specific industrial regions, potentially widening domestic inequality (ILO, 2024; ILO, 2024).

At the same time, uncertainty over the net employment effects of technological change can heighten concerns among workers in the sector. If issues of fairness and inclusion are not properly addressed, this may erode trust in policy and lead to resistance against decarbonization efforts (European Climate Foundation, 2024)

Ensuring a sustainable transition therefore requires a strong focus on worker participation, targeted skills development, and the equitable distribution of economic opportunities.

Implications for Thailand

Implications	Details
1. Employment and labor in the steel industry	Thailand's steel production is concentrated in certain provinces and industrial areas. Technological transition may reduce labor demand in some positions, particularly low-skilled workers or those in traditional production processes. • **Risk:** Without clear reskilling and upskilling measures, inequality and social resistance may increase. • **Opportunity:** If the government links the transition with green industry development such as renewable energy, energy storage, or hydrogen it could create higher-value jobs and upgrade the labor structure in the long term.

5.5.3) Cost distribution and social acceptance

The distribution of transition costs remains unclear, particularly regarding who should bear the green steel premium whether end consumers through higher prices, taxpayers through public subsidies, or producers through reduced profit margins. Public acceptance of green steel depends critically on how such cost-sharing arrangements are perceived by different social groups, including workers, consumers, and taxpayers. This uncertainty has important implications for social acceptance and the long-term fairness of low-carbon industrial policy (Agora Industry, 2021). Where cost burdens are perceived as disproportionately affecting specific groups, public support for green steel policies may weaken, even where climate objectives are broadly supported.

Implications for Thailand

Implications	Details
1. Cost burden of green steel	If green steel production costs increase and are passed on to consumers, affecting especially low-income groups. In the short term, support measures such as clear and targeted transition support or temporary incentives can help improve public acceptance and speed up the transition. However, clear goals and proper planning are needed, as relying on government support may put pressure on public finances.
2. Social acceptance & policy stability	If the transition is perceived as a burden on industries, workers, or consumers, it may trigger resistance and weaken policy stability. While, with stakeholder participation, transparent policy direction, and clear communication of health and economic co-benefits, the transition may gain broad support and strengthen long-term confidence.

5.5.4) Health co-benefits and social well-being

Decarbonizing the steel industry can deliver important social co-benefits, particularly through improved air quality and public health. Shifting from the BF-BOF route to lower-carbon DRI-EAF processes not only reduces greenhouse gas emissions but also cuts air pollutants that are harmful to human health.

Evidence from impact assessments in the United States suggests that such a transition could reduce industrial emissions by around 4 million tonnes of CO_2 equivalent per year at the state level. The resulting improvements in air quality are associated with lower risks of respiratory illnesses, such as asthma, and with avoided health, social, and environmental costs estimated at approximately USD 380 million (Ohio River Valley Institute, 2024).

Globally, IEA (2021) estimates that emission reductions in the energy and heavy industry sectors, including steel, could reduce premature deaths by approximately 50% by 2050 compared with 2020 levels, potentially saving around 2 million lives per year. Around 85% of these benefits would occur in emerging and developing economies (IEA, 2021).

Thus, decarbonizing the steel industry is not only a climate measure but also a public health and social welfare policy that enhances quality of life, reduces public health expenditures, and strengthens long-term societal resilience.

Implications for Thailand

Implications	**Details**
1. Public health co-benefits	Thailand faces serious air pollution challenges, particularly PM2.5 in industrial and urban areas. Reducing fossil fuel use in the steel industry would improve air quality around industrial sites. Expected outcomes include: • Lower risk of respiratory diseases • Reduced public health expenditure • Higher labor productivity These health benefits may be more policy-relevant than carbon value alone and can serve as a strong justification for transition policies in the Thai context.

5.6. Conclusion

On the socio-economic implications of the green steel transition across economic, environmental, and social dimensions, the findings show that decarbonization is not merely a technological shift, but a structural transformation affecting value chains, energy systems, labor markets, and institutions.

Economically, green steel—particularly hydrogen-based production—remains more costly than conventional methods, with costs highly dependent on energy prices and policy design. However, the impact on final product prices is generally limited. For Thailand, the key constraints lie less in hydrogen costs and more in electricity carbon intensity, scrap quality, and access to low-carbon inputs. As decarbonization deepens, energy policy and grid reform will become central to maintaining competitiveness.

Competitiveness is increasingly shaped by carbon performance rather than cost alone. As global markets embed carbon criteria, Thailand's risk lies in falling out of alignment with export requirements. Strategic positioning within value chains—rather than full domestic production—will determine long-term competitiveness.

Investment needs are significant and extend beyond steel production to energy and infrastructure systems. While there are potential spillovers, poorly sequenced investments risk underutilization or stranded assets, particularly under energy constraints.

Labor impacts are expected to involve reallocation rather than large-scale job losses. While automation may reduce plant-level employment, new opportunities may arise in related sectors. The main challenge is ensuring workforce adaptation through reskilling and maintaining competitiveness in downstream industries.

Environmental benefits depend largely on electricity decarbonization. While EAF production reduces direct emissions, indirect emissions remain high under fossil-based power systems. Broader outcomes, including air quality and resource use, depend on industrial practices and system design.

Socially, the transition raises issues of cost distribution, inequality, and public acceptance. The allocation of transition costs will influence policy sustainability, while health benefits from reduced pollution provide strong justification for action.

Overall, green steel in Thailand is feasible but conditional. Moderate decarbonization within the current system is achievable, but deep decarbonization requires broader structural reform. Long-term success will depend not only on reducing emissions, but on maintaining competitiveness, supporting employment, and ensuring an inclusive transition.

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[Accessed 20 February 2026].

Chapter 6

Preliminary Viability Assessment

Transitioning Thailand's steel industry toward lower-carbon production is not merely a question of technological feasibility; it is fundamentally a question of economic realism, infrastructure readiness, and institutional alignment. While multiple supply chain configurations are theoretically possible, from scrap-based EAF to imported HBI, natural gas-based DRI, or full hydrogen routes, their viability differs substantially when assessed against Thailand's current conditions.

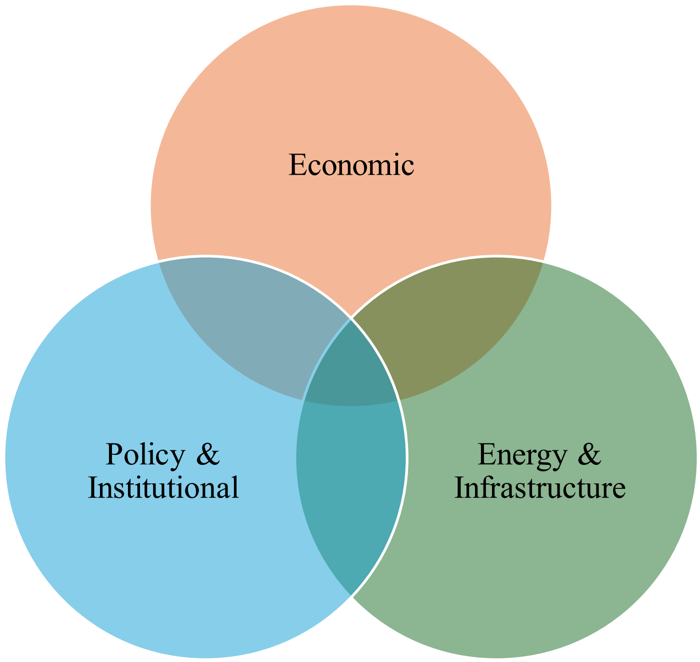
This chapter provides a preliminary comparative assessment of these pathways. It evaluates each option across three dimensions: economic, energy and infrastructure, and policy and institutional feasibility. Rather than identifying a single "ideal" pathway, the objective is to clarify which configurations are immediately viable, which are conditionally feasible, and which require structural transformation before becoming realistic options for Thailand.

6.1. Framework for Assessing Viability

Assessing the viability of green steel in Thailand requires a multi-dimensional perspective. This preliminary evaluates viability across three core dimensions (Figure 6.1).

- **Economic viability:** This considers the capital and operating costs of green steel technologies relative to other routes, including the role of carbon pricing mechanisms and the potential avoidance of CBAM-related costs. It also examines market conditions, such as import prices and competition.
- **Energy and infrastructure viability:** This considers the availability of low-carbon electricity and fuels, the reliability of supply to steel plants, and the ability of existing infrastructure to accommodate new demand and variability in energy supply.
- **Policy and institutional viability:** This considers the presence of supportive regulations, including incentives, carbon pricing mechanisms, trade policies, and power market rules, as well as the degree of coordination among government bodies. It also considers whether policy misalignment could hinder project implementation.

Figure 6.1 Framework for assessing viability



Source: Authors

Within each dimension, factors such as cost competitiveness, resource adequacy, and regulatory support are assessed qualitatively. Viability is treated as relative and dynamic, for example, options that are not viable today may become viable under future conditions (e.g., by 2030 or 2050) due to declining renewable energy costs or policy shifts. Conversely, the analysis distinguishes between pathways that are currently feasible and those that depend on further development.

It is important to clarify that this assessment is high-level and directional. Detailed modeling will not be evaluated, but rather a literature-based and scenario-based analysis. Limitations include uncertainty in future technology cost, unpredictability of policy changes, and lack of precise data on certain factors. Thus, the viability in this study is discussed in qualitative or order-of-magnitude terms. This framework helps laying structure the evaluation across the key dimensions that determine success or failure of green steel in Thailand.

6.2. Potential Green Steel Pathways

Thailand has five possible pathways to decarbonize its steel production as mentioned in Chapter 4. The most plausible routes and their characteristics shown in Table 6.1.

Table 6.1 Thailand's potential green steel pathways

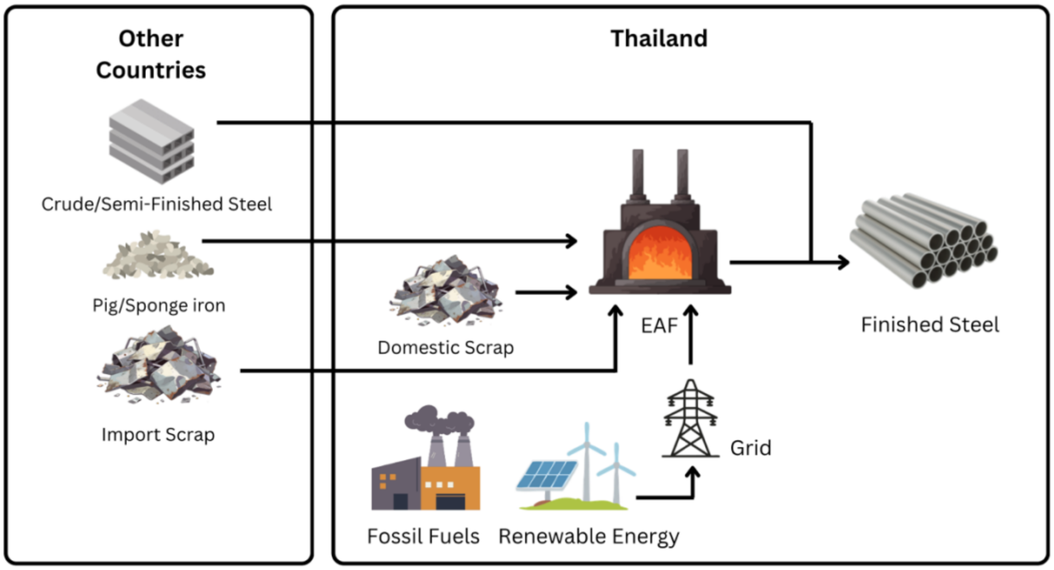
Pathway	Details
1) **Scrap-EAF based with grid power**	Domestic scrap & imported scrap → EAF → steel products
2) **Import of green DRI**/HBI **and upgrade EAF**	Rich RE/NG countries → green/low-carbon HBI → domestic EAF → steel products
3) **Domestic DRI using natural gas**	LNG/gas → domestic DRI (with natural gas and later hydrogen blend) → EAF domestic → steel products
4) **Full hydrogen green steel domestically**	Domestic H_2 → domestic DRI → domestic EAF → steel products
5) **Import of crude green steel**	Import crude/semi-finished steel

Source: Authors

6.2.1) Scrap-EAF with grid power (with increasing RE later)

This pathway maximizing Thailand's existing infrastructure by utilizing Electric Arc Furnaces to melt scrap, while drawing electricity from the national grid. It is essentially an upgraded & upscaled version of current production (Figure 6.2). The advantage is that it is technologically proven and Thailand already have expertise here. Scrap-based EAF steel has also significantly lower CO_2 emissions than the traditional BF-BOF steel because most carbon-intensive reduction is bypassed.

Figure 6.2 Scrap-EAF with grid power



Source: Authors

1. Economic Viability

i) Cost competitiveness

Globally, scrap-EAF is generally the lowest-cost steelmaking route, provided scrap is available. It avoids the capital intensity of hydrogen-based DRI and does not require major upstream investment in hydrogen production. For Thailand, which does not operate blast furnace-BOF assets, this pathway aligns with existing capabilities and minimizes stranded asset risk.

Capital expenditure requirements are relatively modest and typically involve furnace modernization, energy efficiency improvements, digital optimization, and enhancements in scrap sorting and preprocessing. Operating costs, meanwhile, are driven primarily by scrap prices and availability, electricity tariffs, and grid reliability.

However, Thailand imports some share of scrap, meaning price volatility remains a structural risk. Moreover, an equally important constraint is scrap quality. Producing higher-grade flat steel for such automotive and machinery applications requires precise control over residual elements, which accumulate in recycled scrap and are difficult to remove during EAF processing. Consequently, without access to sufficient volumes of high-quality scrap or dilution with virgin iron units (e.g., DRI or HBI), the ability to produce advanced grade flat steel may be technically constrained.

Overall, while scrap-EAF is financially accessible in the near term, its economic viability for higher-grade steel segments depends on improved scrap quality, advanced sorting capabilities, and reliable access to supplementary virgin iron inputs.

ii) Carbon competitiveness

The main constraint lies in carbon intensity. If grid electricity r continues to rely on partly fossil-based, particularly natural gas-fired, scrap-EAF production will continue to carry non-negligible indirect (Scope 2) emissions. Although these emissions are substantially lower than those of BF-BOF routes, they may still exceed thresholds required for CBAM compliance (especially in the absence of robust MRV systems, requiring reliance on default values), as well as the expectations of downstream decarbonization commitments and premium low-carbon steel markets. As a result, while economic viability remains strong in conventional markets, it may be weaker in carbon-sensitive export segments.

Overall, this pathway is economically viable in the near-term, but its long-term competitiveness under stricter carbon regimes depends on advanced scrap sorting, and grid decarbonization, and a reliable supply of high-purity virgin iron.

2. Energy and Infrastructure Viability

i) Low incremental infrastructure burden

This pathway requires no large-scale hydrogen infrastructure and no new ironmaking assets. It leverages existing EAF capacity, current grid infrastructure, and established scrap logistics. From an infrastructure standpoint, it represents the least disruptive and most immediately implementable pathway.

ii) Grid dependency

Energy viability is, however, directly tied to Thailand's electricity mix. If renewable penetration remains limited and LNG dependence persists, the steel sector's carbon intensity will remain partially locked into the power grid's emission profile. This dependency creates two structural constraints:

1. **Grid-Dependent Decarbonization**: Emissions reductions become dependent on national power grid reform rather than steel-sector initiative alone.
2. **Energy Price Exposure**: Industrial electricity prices, heavily influenced by LNG volatility, creates a structural risk to cost stability.

Unlike hydrogen-based routes, which anchors new renewable demand, this pathway may not significantly catalyze additional renewable investment. Its decarbonization potential is therefore externally determined by broader national energy policy rather than industry-led innovation.

Overall, from an energy-system perspective, this pathway offers high feasibility but remains structurally linked to the carbon intensity of the national grid.

3. Policy and Institutional Viability

i) Alignment with existing structure

Thailand's steel sector is already scrap-based and EAF-oriented, meaning institutional resistance is minimal. No major coal-based workforce displacement occurs, and no politically sensitive blast furnace closures are required. Policy efforts would therefore focus on strengthening the existing system, including expanding scrap collection and quality control, managing scrap import regulations, facilitating industrial access to renewable electricity (e.g., through corporate PPAs), and improving overall electricity market efficiency.

ii) Limitations in long-term climate alignment

However, as export markets increasingly shift toward certified near-zero steel, scrap-EAF using current grid electricity may face growing constraints. Without parallel decarbonization of the power sector, Thailand could encounter limited eligibility for green procurement, increased exposure to CBAM (particularly if Scope 2 emissions are accounted for), and reduced access to premium downstream supply chains.

Overall, policy viability is high for incremental improvement, but strategic alignment with long-term net-zero competitiveness may be weaker compared to pathways that integrate low-carbon iron inputs or dedicated renewable supply.

4. Overall Viability Assessment

Under the three-dimensional framework:

- **Economic viability:** Strong in the short term, supported by low capital requirements and technological maturity.
- **Energy-infrastructure viability:** Highly feasible, as it is relying on existing systems.
- **Policy & institutional viability:** Institutionally aligned, but contingent on broader progress in power-sector decarbonization.

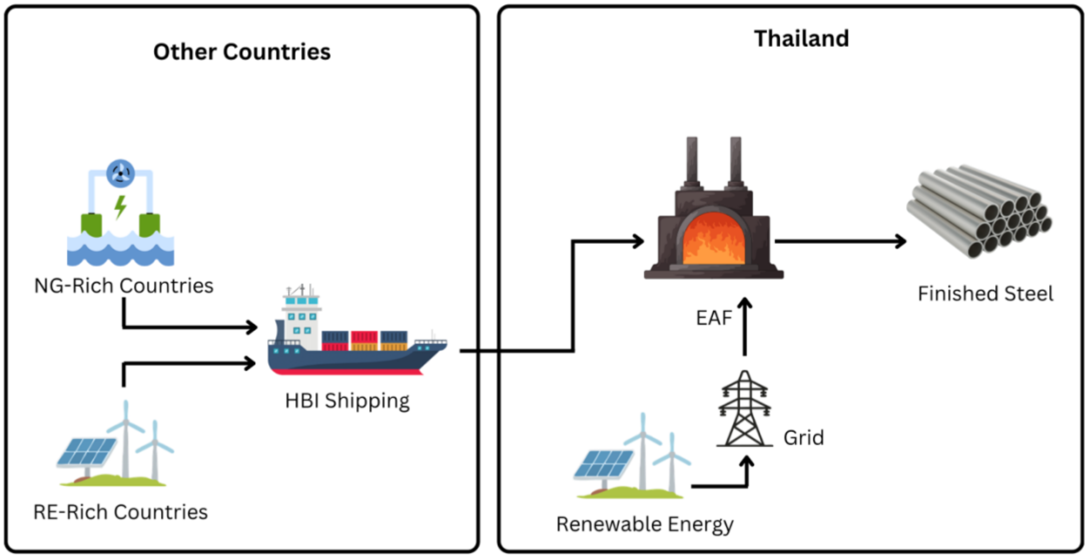
This pathway offers incremental emissions reductions rather than a fundamental transformation of the production system. Its performance depends heavily on the pace of grid decarbonization, the availability and quality of scrap, and evolving carbon requirements in export markets.

From a strategic perspective, scrap-based EAF using current grid electricity represents a low-risk transitional option, but is unlikely on its own to position Thailand as a competitive player in emerging low-carbon steel markets.

6.2.2) Imported DRI/HBI with domestic EAF

One emerging decarbonization configuration relevant for energy-constrained industrial economies is the combination of imported green or low carbon hot briquetted iron (HBI) with domestic electric arc furnace (EAF) steelmaking pathway (Figure 6.2). This model geographically separates the energy-intensive ironmaking stage from downstream steelmaking and finishing activities, allowing each segment of the value chain to locate where it is most economically and structurally advantageous.

Figure 6.2 Imported HBI with domestic EAF



Source: Authors

1. Economic Viability

i) Cost competitiveness

The central economic logic of this pathway is energy cost arbitrage. Hydrogen-based iron production is highly electricity-intensive, and international studies show that producing HBI in renewable rich areas can reduce input costs significantly relative to hydrogen-based DRI in energy-constrained economies. When incorporated into full steelmaking economics, imported green HBI has been shown in other contexts to reduce total steel production costs by approximately 15-20% compared to domestic hydrogen-based DRI routes (Trollip, 2025).

For Thailand, which relies heavily on importing steel input, faces relatively high LNG import exposure and limited low-cost renewable energy compared to some other regions, importing HBI may be structurally more cost-competitive than building domestic hydrogen-based ironmaking capacity.

However, the economic viability of this pathway depends on several key factors, including the delivered cost of HBI (inclusive of freight and insurance), the credibility of carbon certification (to avoid CBAM-related penalties), the availability of long-term supply contracts to mitigate price volatility, and the relative availability and price of scrap.

ii) Market demand and premium

If Thai downstream industries (e.g., automotive, machinery) require certified low-carbon steel for export markets such as the EU or Japan, the imported HBI combined with domestic EAF pathway could allow Thailand to maintain market access without paying or paying less carbon border penalties. In this scenario, competitiveness may derive not from premium pricing but from avoided trade frictions. The case, therefore, hinges less on domestic willingness to pay a green premium and more on maintaining export competitiveness under tightening carbon trade regimes.

Overall, economic viability appears moderately strong under carbon-constrained trade scenarios, particularly if hydrogen-based domestic ironmaking remains structurally expensive.

2. Energy and Infrastructure Viability

i) Reduced hydrogen requirement

A key advantage of this pathway is that it avoids the need for large-scale domestic hydrogen infrastructure for ironmaking. This substantially lowers the requirements for renewable capacity expansion, electrolyzer investment, hydrogen storage and transport systems, and reduces exposure to LNG price volatility (in the case of blue hydrogen). As a result, domestic energy demand is concentrated on electricity use in EAF operations, which is significantly less costly per tonne than hydrogen-based DRI production.

ii) Grid integration

EAF operations are electricity-intensive but technically compatible with Thailand's existing steel structure, which is already largely scrap-based and EAF-oriented. Scaling up production with HBI blending, however, may require targeted upgrades, including grid reinforcement, stable and predictable industrial tariffs, and expanded access to corporate PPAs, particularly for renewable energy.

Compared to fully integrated hydrogen-based DRI production, this pathway is less infrastructure-intensive and therefore more compatible with Thailand's current grid capacity and renewable energy deployment trajectory.

iii) Power market design

Domestic EAF competitiveness depends on electricity pricing structures. If industrial tariffs remain high or volatile, cost advantages from imported HBI could be partially eroded. Therefore, power market reforms (e.g., expanded third-party access or corporate PPA frameworks) may strengthen viability.

Overall, this pathway appears more energy-feasible in the near term than full domestic hydrogen-based ironmaking.

3. Policy and Institutional Viability

i) Trade and carbon alignment

For this pathway to be viable, Thailand must ensure that imported HBI is recognized as low carbon under international accounting frameworks. This requires clear certification standards, alignment with EU CBAM methodologies, and robust monitoring, reporting, and verification (MRV) systems. Without credible carbon verification, imported HBI would not deliver a meaningful competitiveness advantage.

iii) Industrial strategy alignment

From an institutional perspective, this pathway fits well with Thailand's existing industrial structure. The country does not operate blast furnace-BOF assets, the domestic industry is already EAF-based, and key downstream sectors, such as automotive and manufacturing, are export-oriented. This reduces political resistance compared to economies with large coal-based ironmaking sectors. Moreover, maintaining domestic steelmaking capacity can support local industry and help mitigate trade exposure relative to importing finished steel products.

Overall, policy and institutional viability is conditional but achievable, particularly if trade alignment and electricity market reforms are effectively addressed.

4. Overall Viability Assessment

Under the three-dimensional framework, the Imported HBI & Domestic EAF pathway appears:

- **Economically viability:** Strong, particularly under carbon-constrained trade conditions and in the presence of high domestic hydrogen costs.
- **Energy-infrastructure viability:** Feasible in the near term, given the reduced need for hydrogen-related infrastructure.
- **Policy & institutional viability:** Conditional, but broadly aligned with Thailand's existing industrial structure.

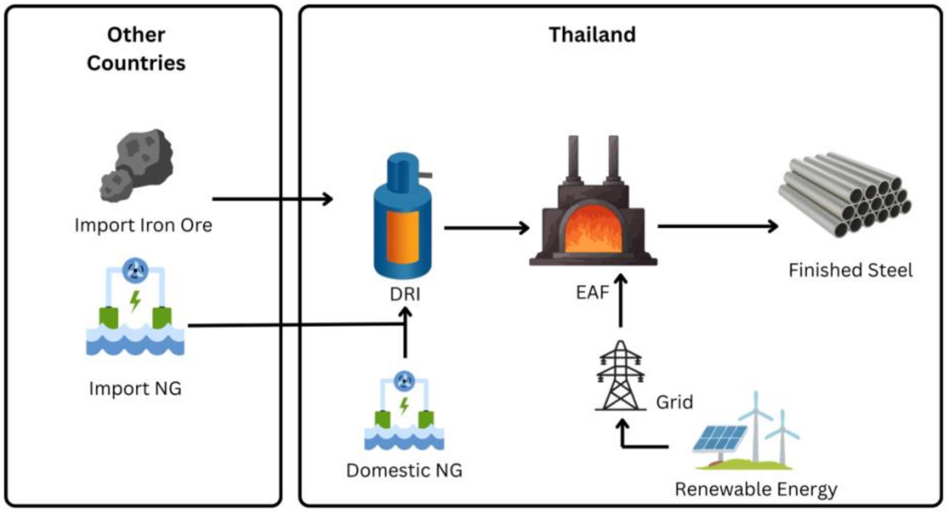
Compared to a vertically integrated hydrogen-based DRI route, this pathway lowers capital intensity, reduces infrastructure risks, and enables faster decarbonization. However, it also increases exposure to global trade dynamics and shifts part of the value added upstream to exporting regions. As noted by Trollip (2025), ironmaking accounts for a relatively small share of total employment in the steel value chain, suggesting that downstream activities remain more labor-intensive.

Therefore, attractiveness of this pathway depends on Thailand's strategic priorities: to maximize domestic value capture across the entire steel supply chain, or to prioritize cost-competitive decarbonization while retaining the country's downstream industrial strength.

6.2.3) Domestic DRI using natural gas

This pathway develops domestic direct reduced iron (DRI) production using natural gas as the initial reductant (NG-DRI), supplying DRI to domestic EAF steelmaking (Figure 6.4). Over time, the reductant mix may shift toward hydrogen blending, and potentially toward fully hydrogen-based DRI, contingent on the availability of low-carbon hydrogen and electricity. Conceptually, this serves as a "bridge" strategy: it enables early emissions reduction relative to coal-based routes and builds technological optionality required for deeper decarbonization later.

Figure 6.4 Domestic DRI using natural gas



Source: Authors

1. Economic Viability

i) Near-term cost competitiveness

NG-DRI is generally more mature and near-term cost-competitive than hydrogen-DRI because it avoids the high cost of green hydrogen and the need for very large renewable power inputs. It can reduce dependence on high-quality scrap for certain grades (especially when scrap quality is a constraint) and can improve product quality consistency by supplying virgin iron units to EAFs.

However, viability of this pathway in Thailand is critically dependent on gas pricing and supply stability. Given the country's high exposure to imported LNG and global gas price volatility, NG-DRI operating costs may be structurally uncertain. If gas prices remain elevated or volatile, the "bridge" can become a cost burden rather than a transition enabler.

ii) Carbon-related competitiveness

Relative to BF-BOF, NG-DRI-EAF can significantly lower emissions, but it is not "near-zero." As carbon pricing tightens, NG-DRI route may face rising compliance costs (but lower than BF-BOF route), and its competitiveness will depend on its recognition as a legitimate transition strategy with a credible pathway to hydrogen.

The key risk is carbon lock-in: if the pathway is framed as "hydrogen-ready" but hydrogen remains costly or unavailable, the system could stall at a medium-carbon equilibrium and may lose competitiveness in premium low-carbon markets.

iii) Demand and product positioning

This pathway can be economically attractive if Thailand's downstream industries, particularly in automotive and appliances, require low-residual iron units to maintain consistent quality standards. Moreover, by providing a credible decarbonization narrative, this route secure Thailand's position in premium export markets where green certification is increasingly becoming a prerequisite for market access.

Overall, economic viability is conditional: it depends on competitive natural gas pricing and a transparent transition toward low-carbon hydrogen.

2. Energy and Infrastructure Viability

i) Gas system feasibility

Compared to hydrogen-DRI, NG-DRI route is more compatible with Thailand's existing industrial energy systems. Leveraging established gas infrastructure and operational experience with gas-fired industrial processes could lower the barrier to early deployment. However, this pathway deepens Thailand's exposure to gas supply security risk, LNG price shocks, and potentially long-term gas availability constraints.

ii) Hydrogen readiness is not automatic

While NG-DRI plants are often "hydrogen-ready"; the practical transition to hydrogen is a complex process. It involves a scalable hydrogen supply chain, significant modifications to reformers, burners and process control system, and potentially new safety and materials standards. Crucially, if green hydrogen is used, the system requires a massive input of low-carbon electricity to sustain production.

Consequently, the viability of the "later hydrogen blending" phase is fundamentally tied to Thailand's ability to scale renewables generation, grid capacity, and hydrogen logistics. Without those factors, hydrogen blending risks remaining a marginal technical feature rather than a meaningful decarbonization driver.

Overall, the energy and infrastructure viability of this pathway is therefore moderate in the near term (for NG-DRI), but its long-term success is uncertain regarding the feasibility of meaningful hydrogen blending.

3. Policy and Institutional Viability

i) Alignment with transition narratives

This pathway can be positioned within a "transition fuel" framework, particularly if Thailand adopts a phased approach to decarbonization with clearly defined emissions reduction trajectories. However, its credibility depends on avoiding perceptions of merely extending fossil-based investment. This requires clear standards for "hydrogen-ready" claims, time-bound milestones for increasing hydrogen use, robust MRV requirements for emissions intensity, and alignment with international certification schemes.

ii) Trade and carbon policy exposure

As export markets increasingly demand near-zero materials, NG-DRI may face limitations in qualifying for green procurement or may remain subject to carbon-related penalties. Institutional viability would improve if Thailand develops product-level carbon footprint standards, establishes verification systems aligned with buyer requirements, and defines how "transition steel" is treated within trade frameworks.

iii) High coordination requirements

This pathway depends on strong coordination across multiple domains, including energy planning (renewables and hydrogen), industrial policy, gas supply strategy, and electricity market reform. Where institutions are fragmented or policy signals are inconsistent, there is a risk that progress stalls at partial decarbonization rather than advancing toward deeper transformation.

Overall, policy viability is highly dependent on credible long-term commitment and governance coordination.

4. Overall Viability Assessment

Under the three-dimensional framework, the NG-DRI (with potential hydrogen blending) pathway can be characterized as a conditional bridging strategy:

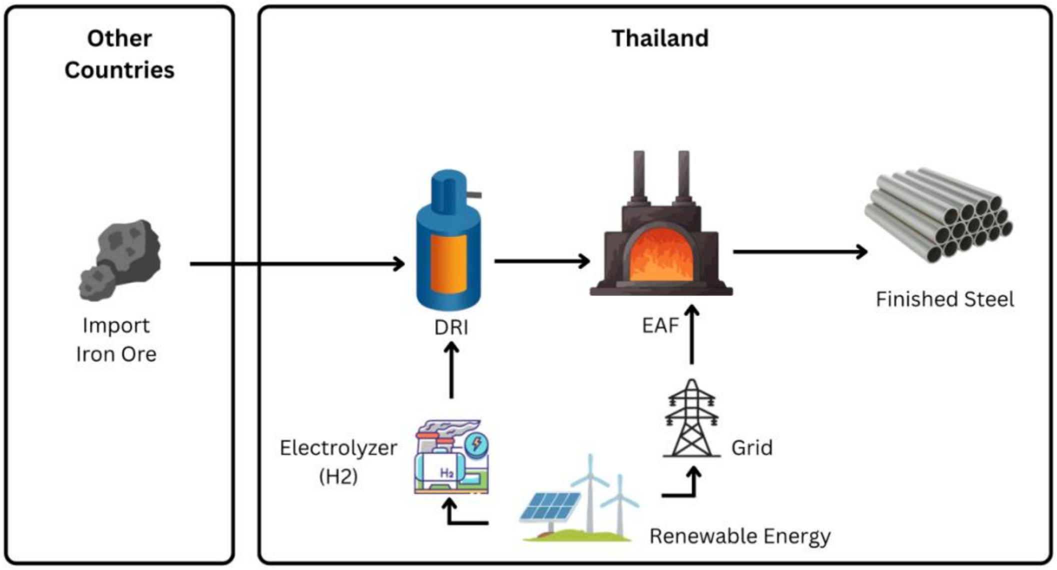
- **Economic viability:** Potentially strong relative to hydrogen-based DRI in the near term, but exposed to gas price volatility and longer-term carbon constraints.
- **Energy & infrastructure viability:** Feasible for initial deployment, though long-term viability depends on scaling renewable energy and hydrogen systems; "hydrogen-ready" designs may not translate into actual transition without further investment.
- **Policy & institutional viability:** Dependent on strong coordination and clear transition milestones; without these, the pathway risks fossil lock-in and diminished credibility in carbon-sensitive markets.

Strategically, this pathway is viable if Thailand aims to pursue a middle-ground approach, easing constraints related to scrap availability, enabling higher-quality steel production, and preserving flexibility for deeper decarbonization. However, this depends on parallel progress in power market reform and the expansion of renewable energy and hydrogen systems, ensuring that the "bridge" functions as a transition rather than becoming a structural endpoint.

6.2.4) Domestic H_2-DRI and EAF

This pathway involves producing direct reduced iron (DRI) domestically using green hydrogen derived from low-carbon electricity, followed by steelmaking in electric arc furnaces (EAF) (Figure 6.5). Both ironmaking and steelmaking occur within Thailand. This represents the most vertically integrated and infrastructure-intensive decarbonization option.

Figure 6.5 Domestic H_2-DRI and EAF



Source: Authors

1. Economic Viability

i) Capital intensity

The domestic H_2-DRI pathway is highly capital-intensive, requiring substantial upfront investment across multiple components, including DRI modules, large-scale electrolyzers for hydrogen production, dedicated renewable electricity capacity, hydrogen storage and transport infrastructure, and EAF upgrades with system integration. Compared to alternative pathways, the initial capital requirements are significantly higher, increasing financing risks, particularly given the current cost gap between green hydrogen and other alternatives.

ii) Operating costs

Hydrogen costs are the key determinant of economic viability. Hydrogen-based DRI is only competitive under conditions of very low-cost renewable electricity. At present, Thailand faces structural constraints, including high reliance on LNG in the power sector, moderate renewable penetration, and limited access to low-cost solar and wind resources relative to renewable-rich regions. Unless renewable electricity costs decline substantially and can be directly accessed by industrial users (e.g., through corporate PPAs), domestic hydrogen production is likely to remain relatively expensive.

iii) Carbon exposure and trade positioning

The main economic advantage of this pathway lies in its deep decarbonization potential. Fully domestic H_2-DRI enables near-zero Scope 1 emissions (and scope 2 if the hydrogen is green), reduces exposure to carbon border measures, and enhances eligibility for premium low-carbon markets. However, the extent to which such premiums will materialize at scale remains uncertain. While sectors such as automotive may increasingly demand certified low-carbon steel, willingness to pay significant price premiums is still evolving, particularly when hydrogen is produced domestically at higher cost.

Overall, under current cost structures, economic viability appears limited in the near term but potentially improves under future conditions with lower renewable and hydrogen costs, strong carbon pricing, or targeted policy support.

2. Energy and Infrastructure Viability

i) Electricity demand scale

Hydrogen-based DRI significantly increases electricity demand compared to scrap-EAF routes. Producing green hydrogen at industrial scale requires large volumes of dedicated renewable capacity, a stable and continuous power supply, and substantial grid reinforcement. For Thailand, this raises two key structural questions: whether renewable capacity can be deployed at sufficient scale and speed, and whether the grid can accommodate large industrial loads without compromising reliability. Given current trends in renewable deployment and existing grid constraints, scaling hydrogen production for ironmaking would pose a considerable system-level challenge.

ii) System transformation potential

At the same time, this pathway offers the strongest potential to drive system-wide transformation. Hydrogen-based steel production can act as anchor demand for renewable energy, accelerating capacity expansion, enabling economies of scale in hydrogen production, and supporting broader industrial decarbonization. As such, while energy and infrastructure feasibility is limited in the near term, the pathway holds significant long-term transformative potential.

Overall, while energy and infrastructure feasibility remains challenging in the near term, this pathway offers strong long-term potential as a driver of system-wide transformation, contingent on accelerated renewable deployment, grid upgrades, and hydrogen scaling.

3. Policy and Institutional Viability

i) Policy alignment

A fully domestic H_2-DRI pathway requires a coherent and coordinated policy framework, including a clear hydrogen strategy and roadmap, stable renewable energy policies, effective carbon pricing to level the playing field with conventional routes, reforms to industrial electricity pricing, and targeted investment incentives or public co-financing mechanisms. Without such alignment, private investors are unlikely to absorb the high capital risks involved.

ii) Institutional coordination

This pathway cuts across multiple policy domains, requiring close coordination among agencies responsible for energy (renewables, hydrogen, grid reform), industry (steel policy and industrial upgrading), trade (carbon border alignment), and finance (investment incentives and risk-sharing mechanisms). In the absence of strong inter-agency coordination, institutional fragmentation could significantly delay implementation.

iii) Industrial ambition

Strategically, this pathway aligns with ambitions for technological leadership and industrial upgrading. It maximizes domestic value added and reduces reliance on imported intermediates. However, it also exposes Thailand to higher technology risks and potential first-mover cost disadvantages.

Overall, policy and institutional viability is highly conditional and depends on sustained long-term strategic commitment.

4. Overall Viability Assessment

Under the three-dimensional framework:

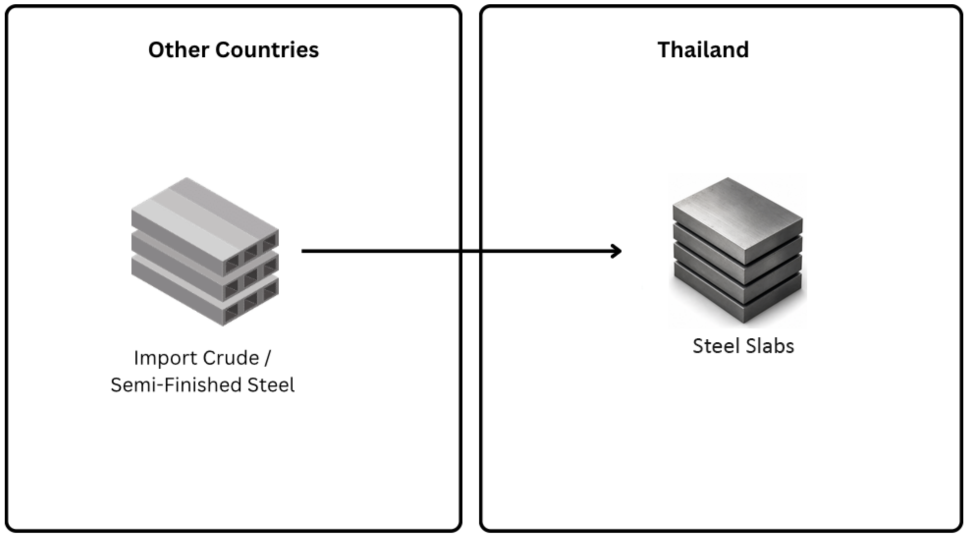
- **Economic viability:** Weak in the near term due to high hydrogen costs and capital intensity, but potentially improves under future scenarios with lower renewable energy costs and stronger carbon pricing.
- **Energy & infrastructure viability:** Challenging under current grid capacity and renewable deployment conditions, requiring large-scale system transformation.
- **Policy & institutional viability:** Highly dependent on strong and coordinated industrial and energy policies; unlikely to develop organically without significant state support.

Compared to other pathways, the domestic H_2-DRI configuration offers the highest potential for domestic value capture, the deepest decarbonization, and the most significant industrial transformation. However, it also entails the greatest capital risk, imposes the highest strain on the energy system, and involves the longest implementation timeline. In Thailand's current structural context, this pathway is better understood as a long-term strategic option rather than an immediately viable commercial pathway.

6.2.5) Import of crude steel

Under this pathway, Thailand reduces or avoids domestic primary steelmaking & ironmaking and instead imports crude or semi-finished steel (slabs or billets) from foreign producers, while domestic firms focus on rolling, coating, forming, and manufacturing (Figure 6.6). Decarbonization outcomes depend largely on the emissions intensity of the exporting country rather than domestic production technology. This represents a supply-chain relocation rather than technological transition.

Figure 6.6 Import of crude steel



Source: Authors

1. Economic Viability

i) Short-term cost competitiveness

Importing crude steel can be economically attractive in the near term, as it avoids the need for large capital investments in ironmaking and new decarbonization technologies. Firms do not need to develop DRI capacity, hydrogen infrastructure, or major energy system upgrades, instead relying on international suppliers that may benefit from lower energy costs, economies of scale, and established integrated production. This can result in lower input costs compared to domestic production under high energy price conditions.

ii) Exposure to price volatility and dependency

However, this approach is highly dependent on global market dynamics. It introduces structural exposure to international steel price cycles, exchange rate fluctuations, trade restrictions, geopolitical risks, and freight costs. Unlike domestic production, competitiveness cannot be improved through productivity or technological upgrades, as costs are largely determined externally.

iii) Carbon competitiveness

As global trade increasingly incorporates carbon disclosure and border adjustment mechanisms, imported steel may face rising compliance costs. If exporting countries have higher emissions intensity, downstream Thai manufacturers could be exposed to carbon tariffs, supply chain exclusion, or procurement restrictions. As a result, while this pathway may remain cost-competitive in conventional markets, its competitiveness may weaken in regulated or sustainability-driven value chains, such as automotive exports.

Overall, economic viability is strong in the short term but remains uncertain over the longer term, particularly as carbon-related trade measures become more stringent.

2. Energy and Infrastructure Viability

i) Minimal domestic infrastructure requirements

This pathway places the lowest burden on domestic infrastructure. Thailand would not need to invest in hydrogen systems, DRI facilities, or large-scale renewable energy dedicated to steelmaking. Energy demand is concentrated in downstream activities such as rolling and finishing, which are significantly less energy-intensive than primary steel production.

ii) Limited domestic decarbonization leverage

However, emissions reductions are entirely dependent on foreign producers. Thailand has limited ability to reduce the embedded carbon intensity of steel unless it selectively imports low-carbon materials, which may be constrained by cost or availability. This creates a structural limitation, as industrial decarbonization becomes decoupled from the domestic energy transition.

Overall, from a system perspective, the pathway is easy to implement but offers limited domestic decarbonization capability.

3. Policy and Institutional Viability

i) Low implementation complexity

From an institutional perspective, this pathway is relatively straightforward to implement. It does not require extensive coordination across energy planning, hydrogen strategy, or industrial transformation initiatives, allowing firms to respond independently to market conditions.

ii) Strategic industrial risks

However, it introduces several strategic challenges, including reduced domestic industrial capability, limited opportunities for technological learning, loss of upstream value added, and greater vulnerability to supply disruptions. In carbon-regulated trade environments, policymakers may also have less control over emissions exposure, as compliance depends on production standards in exporting countries rather than domestic regulation.

Overall, while institutional feasibility is high from an administrative standpoint, it is weaker from a strategic perspective, particularly if national policy prioritizes industrial upgrading and supply chain resilience.

4. Overall Viability Assessment

Across the three dimensions:

- **Economic viability:** Attractive in the short term due to avoided capital investment, but exposed to global market fluctuations and tightening carbon policies.
- **Energy & infrastructure viability:** Very high feasibility, as the pathway requires minimal domestic infrastructure.
- **Policy & institutional viability:** Relatively simple to implement, but at the cost of reduced industrial autonomy and technological capability.

From a strategic perspective, importing crude steel represents a pathway that leans toward deindustrialization. While it lowers investment risk, it also shifts both emissions responsibility and value creation abroad. Although it may serve as a short-term adjustment mechanism, it does not position Thailand to capture opportunities in emerging low-carbon industrial markets.

This pathway therefore offers near-term cost advantages but provides limited long-term competitiveness and control over decarbonization, particularly for export-oriented manufacturing sectors that increasingly depend on access to verifiable low-carbon materials.

6.3. Implications for Thailand

The comparative assessment indicates that Thailand's steel viability is no longer determined solely by production cost competitiveness. Instead, it increasingly depends on energy system integration, trade positioning, and institutional readiness. The transition toward low-carbon steel reshapes the constraints and opportunities facing Thailand's industry.

Table 6.1. summarizes the relative viability of each pathway across three dimensions: economic competitiveness, energy and infrastructure feasibility, and policy and institutional alignment. The classifications (Strong, Feasible, Conditional, Weak, or Challenging) reflect comparative positioning rather than absolute judgments. A pathway rated "Strong" or "Feasible" does not imply it is optimal in all respects, but that it faces fewer binding constraints under current Thai conditions. Conversely, a "Weak" or "Challenging" rating indicates significant structural barriers that would require major policy intervention or system transformation.

Table 6.2 Comparative Viability Matrix

Pathway	Economic	Energy & Infrastructure	Policy & institutional
(1) Import HBI	Strong	Feasible	Conditional
(2) Scrap-EAF	Strong	Feasible	Conditional
(3) NG-DRI	Conditional	Feasible	Challenging
(4) Domestic H_2	Weak	Challenging	Conditional
(5) Import Steel	Strong	Feasible	Weak

Source: Authors

The matrix in Table 6.1 highlights several key implications for Thailand's steel transition strategy.

6.3.1) Immediate viability: scrap-EAF and imported HBI

In the near term, scrap-based Electric Arc Furnace (EAF) production and the import of green HBI emerge as the most feasible pathways. Scrap-EAF remains economically attractive due to its relatively low capital requirements and reliance on existing infrastructure. Thailand already operates EAF capacity, and the grid can accommodate incremental increases in electricity demand. Institutionally, this pathway is well aligned with current structures, although limitations in scrap quality, particularly for flat steel used in automotive applications, constrain its ability to fully upgrade the industry.

Imported HBI provides a complementary and strategically important option. It enables Thailand to leverage cost advantages from renewable-rich regions for ironmaking while utilizing domestic steelmaking capacity. Energy and infrastructure requirements are manageable, as this pathway avoids the need for domestic hydrogen production. However, its viability depends on trade conditions, credible carbon accounting frameworks, and access to long-term supply contracts. Establishing robust MRV systems and aligning with international certification standards are therefore critical.

Together, these two pathways offer the strongest near-term viability and should form the foundation of Thailand's short-term strategy.

6.3.2) Transitional considerations: natural gas-based DRI

Natural gas-based DRI (NG-DRI) represents a conditional medium-term pathway. While Thailand has existing gas infrastructure and LNG import capacity, economic viability is highly sensitive to volatile gas prices. In addition, this pathway introduces policy and institutional complexity, particularly due to the risk of fossil lock-in.

If pursued, NG-DRI should be clearly framed as a transitional strategy rather than a long-term solution. This requires explicit hydrogen-readiness standards, defined milestones for hydrogen blending, and regulatory safeguards to prevent stranded fossil assets. Without such governance, NG-DRI could increase exposure to energy price volatility while delaying deeper decarbonization.

6.3.3) Long-term ambition: domestic hydrogen-based DRI

A fully domestic hydrogen-based DRI pathway represents the most ambitious option but is currently the least feasible. High capital requirements, the need for large-scale renewable deployment, and the development of hydrogen infrastructure present significant barriers.

For this pathway to become viable, Thailand would need substantial expansion of renewable capacity, reforms to ensure competitive electricity pricing, strong alignment between industrial and energy policy, and targeted public support or risk-sharing mechanisms. Under current structural conditions, hydrogen-based steel production is best understood as a long-term strategic option, contingent on broader energy system transformation.

6.3.4) Importing finished steel: a short-term relief with long-term risk

Importing crude or semi-finished steel may appear economically attractive in the short term due to lower upfront costs and minimal infrastructure requirements. However, from a strategic perspective, this pathway risks weakening Thailand's industrial base and increasing dependence on external supply.

Over time, it may erode domestic capabilities in ironmaking and steelmaking, limit opportunities for technological learning, and increase exposure to foreign carbon standards and trade regimes. While imports can play a supplementary role, they do not constitute a sustainable long-term industrial strategy.

The core implication is that Thailand's competitiveness in green steel will depend less on replicating vertically integrated hydrogen production and more on positioning itself strategically within a modular global supply chain.

Scrap-EAF optimization and imported HBI integration align most closely with Thailand's current industrial structure, energy constraints, and trade exposure. These pathways allow Thailand to maintain and potentially upgrade its steel sector while minimizing energy risk and infrastructure strain. In contrast, fully domestic hydrogen steelmaking represents a high-ambition scenario requiring structural energy transformation, while reliance on steel imports risks erosion of domestic industrial capability.

6.4. Key Enablers for Green Steel Transition

While the feasibility of different decarbonization pathways varies, several cross-cutting enablers are essential regardless of the configuration chosen. The analysis highlights three foundational conditions for long-term competitiveness: grid decarbonization and industrial access to clean electricity, upgrading the scrap ecosystem, and establishing credible carbon certification systems.

6.4.1) Grid decarbonization and industrial accessibility

The carbon intensity of Thailand's power system is a structural determinant of steel competitiveness across nearly all pathways. Even scrap-based EAF production, often considered low-emissions, can lose its advantage in export markets if it relies on a fossil-intensive grid. Under emerging trade mechanisms such as CBAM, Scope 2 emissions are increasingly scrutinized and directly influence market access, particularly in premium segments.

Grid decarbonization therefore serves two key functions: it reduces embedded emissions across production routes and helps preserve access to export markets. At the same time, industrial access to renewable electricity is critical. Without mechanisms that enable large industrial users to procure clean power at competitive prices, through instruments such as corporate PPAs, grid reforms, or renewable allocation schemes, Thai steel producers may face structural disadvantages regardless of the technological pathway adopted.

6.4.2) Scrap quality ecosystem development

Scrap availability alone is not sufficient to support industrial upgrading. Entry into higher-value segments, particularly automotive and appliance-grade flat steel, requires tighter control over residual elements. Without advanced sorting, preprocessing, and quality control, scrap-based EAF production faces technical limitations.

Strengthening the domestic scrap ecosystem involves investment in modern sorting and treatment facilities, the establishment of clear quality standards and traceability systems, and the integration of informal scrap flows into formal supply chains. Without these improvements, Thailand will remain dependent on scrap and imported virgin iron inputs such as semi-finished steel, HBI, or DRI, to meet quality requirements. As such, scrap ecosystem development is both a decarbonization priority and an industrial upgrading strategy.

6.4.3) Credible carbon certification and MRV systems

The emergence of a "green premium" in steel markets depends not only on emissions reduction but also on credible verification. International buyers, particularly in the EU, require transparent monitoring, reporting, and verification (MRV) systems aligned with CBAM and other carbon accounting frameworks. Without credible certification, Thai steel may not qualify for premium markets, emissions claims may lack international recognition, and compliance costs or trade frictions may increase.

Establishing robust MRV systems and ensuring alignment with major importing jurisdictions is therefore essential. Certification infrastructure should be treated as a core element of industrial policy rather than a secondary consideration.

These enablers cut across all pathways. Even the most immediately viable options, such as scrap-EAF or imported HBI, will face structural constraints if the power system remains carbon-intensive, scrap quality systems are underdeveloped, or certification lacks credibility.

6.5. Conclusion

No single green steel pathway currently satisfies all objectives of cost competitiveness, deep decarbonization, and energy security in Thailand. Instead, viability depends on a phased and adaptive approach aligned with evolving system conditions.

In the near term, scrap-based EAF and imported HBI represent the most practical options, leveraging existing industrial capabilities while minimizing exposure to infrastructure constraints. Natural gas-based DRI may serve as a transitional pathway but carries risks related to fuel price volatility and carbon lock-in.

In the long term, hydrogen-based steelmaking offers the most complete decarbonization solution but remains contingent on significant improvements in renewable energy availability, cost, and supporting infrastructure.

Across all pathways, three enabling factors are critical: access to low-carbon electricity, development of a high-quality scrap ecosystem, and credible carbon accounting systems. Without progress in these areas, even technically viable pathways may not be economically or institutionally feasible.

Ultimately, green steel development in Thailand should be approached as a sequencing problem rather than a binary choice—prioritizing feasible options today while building the conditions for more ambitious transitions in the future

Chapter 7

Conclusions and Policy Recommendations

This study examines the prospects for green steel development in Thailand through a structured, multi-dimensional lens. Drawing from the global transformation of the steel sector, Thailand's domestic structural constraints, the readiness and limitations of the power system, evolving global supply chain configurations, socio-economic implications, and a comparative pathway assessment, several core conclusions emerge.

The transition to low-carbon steel is not merely a technological substitution. It represents a structural reconfiguration of energy systems, industrial organization, trade relationships, and comparative advantage. For Thailand, the key issue is not whether green steel will emerge globally, but how Thailand positions itself within that restructuring.

7.1. Overall Conclusion

Steel lies at the center of the global decarbonization challenge, accounting for a significant share of industrial energy use and CO_2 emissions, with growing alignment between regulatory frameworks, market expectations, and corporate supply chains toward lower carbon intensity. For an export-oriented economy such as Thailand, this shift fundamentally changes the competitive landscape. The issue is no longer whether green steel is technically feasible, but whether Thailand can remain competitive without aligning with emerging low-carbon markets.

Thailand's steel sector already faces structural constraints independent of climate policy. Production is concentrated in long products, while higher-value flat steel relies heavily on imports. Volatility in scrap prices, relatively high electricity costs, and increasing trade pressures have constrained competitiveness, with carbon-related measures such as CBAM adding further financial and regulatory risks. In this context, decarbonization is not a standalone environmental issue but intersects with broader challenges of industrial upgrading, import dependence, and value capture. Failure to adapt risks reinforcing existing structural weaknesses.

At the same time, the energy system sets the boundaries of feasible pathways. While Thailand's power system is reliable, it remains carbon-intensive and increasingly exposed to LNG price volatility. Electrification alone does not ensure low-carbon production if the grid remains fossil-heavy. For electricity-intensive pathways such as expanded EAF use or hydrogen-based DRI, the key constraint is access to competitively priced, low-carbon electricity. Without accelerated renewable deployment, grid modernization, and effective market mechanisms, industrial decarbonization risks becoming a cost burden rather than a source of competitive advantage.

The impacts of transitioning to green steel are therefore conditional. Hydrogen-based primary steel remains more costly in the near term, but cost pass-through to end products is typically modest. Given Thailand's existing reliance on scrap-based EAF, exposure to hydrogen cost premiums is limited. More binding constraints lie in scrap quality, electricity carbon intensity, and access to reliable low-carbon iron inputs. Competitiveness is increasingly shaped by carbon performance rather than price alone. Early alignment can strengthen export resilience, while delays may lead to higher compliance costs and trade frictions.

Employment effects are likely to involve reallocation rather than large-scale displacement. The absence of coal-based BF-BOF operations in Thailand reduces the risk of major job losses. Instead, the key challenge lies in maintaining competitiveness in downstream industries such as automotive and machinery, which depend on access to low-carbon steel. While automation may reduce labor intensity, high skill overlap between conventional and low-carbon processes suggests that just transition policies could support workforce upgrading and mitigate wage risks.

From an environmental perspective, scrap-based EAF production already offers advantages in reducing direct emissions and local pollutants. However, indirect emissions remain significant under a fossil-based grid, making electricity decarbonization critical to achieving meaningful climate benefits. Improvements in air quality also generate public health co-benefits, although these depend on complementary measures such as scrap quality control, waste management, and water treatment systems.

Given these structural conditions, Thailand's optimal pathway is neither immediate full integration into hydrogen-based steelmaking nor passive reliance on imports. A phased and modular strategy is more consistent with current economic, energy, and institutional realities. In the near term, optimizing and decarbonizing the existing scrap-EAF base offers the most practical approach. Enhancing scrap systems, improving energy efficiency, expanding renewable electricity access, and establishing credible carbon certification can reduce emissions while maintaining competitiveness.

At the same time, selective integration into the emerging global green iron trade, particularly through imported low-carbon HBI, can strengthen domestic steelmaking without requiring large-scale hydrogen infrastructure. This reflects a broader shift in the global steel value chain, where ironmaking and steelmaking can increasingly be geographically separated. Natural gas-based DRI may serve as a transitional option if carefully governed, while domestic hydrogen-based steel production should be viewed as a long-term ambition, contingent on large-scale energy system transformation.

Ultimately, Thailand does not need to pursue maximal technological ambition to remain competitive, but coherent sequencing. Green steel becomes viable when embedded within coordinated energy reform, industrial policy, and trade alignment. Success should not be measured solely by emissions reduction, but by the extent to which the transition strengthens export resilience, reduces structural import dependence, supports workforce upgrading, improves environmental outcomes, and maintains social legitimacy. The strategic challenge is therefore not whether to move, but how to move in a way that aligns industrial capability with the realities of a carbon-constrained global economy.

7.2. Policy Recommendations

Thailand's steel transition will not be driven by a single flagship project or isolated subsidy. It requires coherent sequencing, institutional alignment, and realistic prioritization grounded in the country's structural starting point: a scrap-based EAF industry, limited domestic iron ore resources, a reliable but carbon-intensive power system, and strong integration into export-oriented manufacturing. The recommendations below are organized across short-term stabilization, medium-term positioning, and long-term structural transformation.

7.2.1) Short-term measures

In the short term, Thailand should focus on measures that reduce structural constraints while preserving competitiveness. The objective is not immediate deep decarbonization, but the establishment of credible enabling conditions.

1. Enable industrial access to renewable electricity

Lead agencies: Ministry of Energy (MOE), Energy Regulatory Commission (ERC), Electricity Generating Authority of Thailand (EGAT)

- Implement a **full Third-Party Access (TPA) framework** by 2027, allowing large industrial users (including steel producers) to procure renewable electricity via direct PPAs.
- Establish a transparent **wheeling charge mechanism** to enable grid access.
- Expand corporate renewable procurement schemes beyond pilot sectors.

Electricity access, rather than generation capacity, constitutes the primary constraint on the viability of green steel development.

2. Establish a national MRV and green steel certification system

Lead agencies: Thailand Greenhouse Gas Management Organization (TGO), Ministry of Industry (MIND), Ministry of Commerce (MOC)

- Develop a **plant-level MRV system aligned with international standards (e.g., EU CBAM requirements)**.
- Create a **national low-carbon steel certification scheme** with international recognition.
- Support firms in emissions accounting and verification processes.

Without credible certification, Thai steel risks losing access to premium export markets and facing inflated carbon costs.

3. Upgrade the scrap ecosystem

Lead agencies: Ministry of Industry (MIND), local governments, private sector

- Introduce **scrap quality standards and classification systems**.
- Promote **domestic scrap collection and sorting infrastructure**.
- Reduce contamination and improve traceability.

Scrap quality, rather than quantity alone, is the key constraint on producing higher-value steel.

7.2.2) Medium-term measures

Once foundational systems are established, Thailand must more closely align energy reform with industrial strategy.

1. Broaden electricity market reform aligned with industrial decarbonization

Short-term access mechanisms must evolve into broader structural reform to ensure long-term competitiveness and investment stability. Medium-term priorities include:

Lead agencies: Ministry of Energy (MOE), Energy Policy and Planning Office (EPPO), Energy Regulatory Commission (ERC)

- Gradual modernization of the Enhanced Single Buyer (ESB) framework to enable greater renewable procurement flexibility for large industrial users, while maintaining system reliability.
- Accelerated deployment of renewable capacity linked to industrial demand clusters.
- Improved tariff design to enhance price predictability and reduce exposure to fuel price volatility.
- Integration of grid expansion, energy storage, and industrial demand forecasting into long-term planning.
- Establishment of formal coordination mechanisms between energy planning authorities and industrial policy agencies to align decarbonization timelines.

Over time, industrial competitiveness will increasingly depend on stable, low-carbon electricity markets rather than limited or ad hoc procurement solutions.

2. **Evaluate transitional domestic DRI options**

Natural gas-based DRI may serve as a transitional pathway, but only under strict governance. Required actions include:

Lead agencies: Ministry of Energy (MOE), Ministry of Industry (MIND)

- Define clear **eligibility criteria and sunset conditions** for NG-DRI investments.
- Link support to **future decarbonization pathways (e.g., hydrogen readiness)**.
- Clear conditions to prevent fossil lock-in.

Transitional technologies should expand flexibility, not create new structural dependencies.

3. **Develop workforce transition and industrial capability programs**

Lead agencies: Ministry of Labour, Ministry of Higher Education, Science, Research and Innovation, Industry Associations

- Launch reskilling and upskilling programs for green steel technologies.
- Strengthen engineering and technical capabilities in:
    - EAF optimization
    - Energy management
    - Emissions monitoring.

Employment impacts will be driven by skill shifts, not job losses.

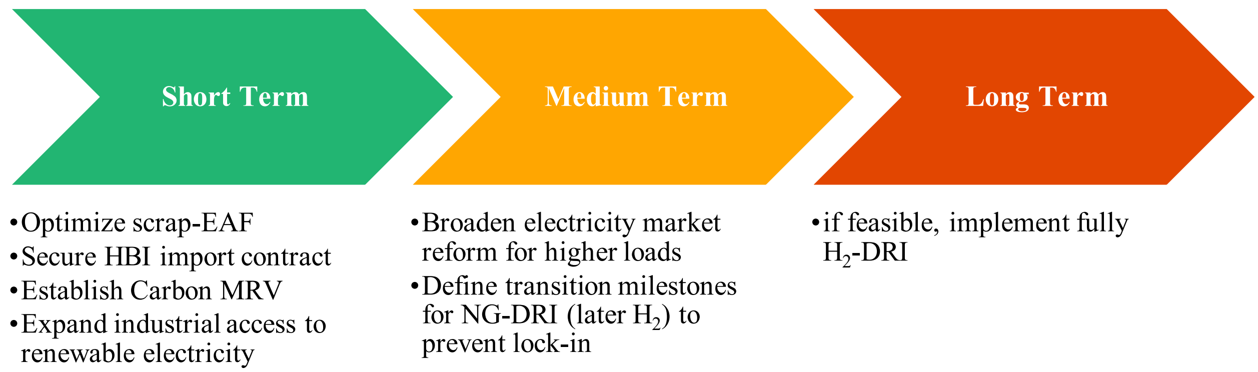
7.2.3) Long-term measures

Deep decarbonization through domestic hydrogen-based ironmaking should be treated as a conditional long-term objective rather than an immediate commitment. Large-scale hydrogen-based steelmaking should proceed only if enabling conditions are met, including:

- Renewable electricity becomes abundant and cost-competitive at scale.
- Electricity market reform allows long-term industrial offtake certainty.
- Grid infrastructure can accommodate high-load industrial clusters.
- Hydrogen production, storage, and transport systems are economically viable.
- Export markets provide durable carbon price signals or green premiums.

In the interim, Thailand should invest in research, pilot projects, and institutional capacity building to maintain technological readiness without premature capital exposure.

Figure 7.1 Thailand green steel development pathways



Source: Authors

Appendix

List of acronyms

Acronym	Definition
BAU	Business As Usual
BF	Blast furnace
BOF	Basic oxygen furnace
BF-BOF	Blast furnace-basic oxygen furnace route
CBAM	Carbon Border Adjustment Mechanism
CO_2	Carbon dioxide
DRI	Direct-reduced iron
EAF	Electric arc furnace
ESB	Enhanced Single Buyer model
ESG	Environmental, Social, and Governance
EU	European Union
EU ETS	European Union Emissions Trading System
FiT	Feed-in Tariff
DRI-EAF	Direct reduced iron-electric arc furnace route
GJ	Gigajoule
H_2	Hydrogen
H_2-DRI-EAF	Hydrogen-based direct reduced iron-electric arc furnace route
HBI	Hot briquetted iron
MMSCFD	Million Standard Cubic Feet per Day
Mt	Million tonnes
MW & MWh	Megawatt & Megawatt-hour
PDP	Power Development Plan
PPA	Power Purchase Agreement
R&D	Research and development
Scrap-EAF	Scrap-based electric arc furnace
t CO_2e	Metric tonne of carbon dioxide equivalent