Bridging The Green Premium: Policy Strategies for Competitiveness in Indonesia's Low-Carbon Steel

The Habibie Center

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Contents

List of Tables

List of Figures

Foreword

We express our deepest gratitude to Almighty God for His blessings and grace, which have enabled the completion and publication of this research report titled **"Bridging the Green Premium: Policy Strategies for Competitiveness in Indonesia's Low-Carbon Steel."** This research addresses one of the most pressing and consequential challenges at the heart of Indonesia's industrial decarbonisation agenda, how to make green steel not only environmentally responsible, but economically viable and competitive.

The green premium is commonly known as a fundamental barrier to the widespread adoption of cleaner production technologies, including in the context of the iron and steel industry. For a developing economy like Indonesia, where the steel industry plays a vital role in supporting infrastructure development, manufacturing, and employment, this cost gap poses a particularly complex policy dilemma: how can the country honour its climate commitments without compromising the competitiveness and growth trajectory of a strategically important sector?

This publication confronts that dilemma head-on. Drawing on rigorous analysis, the research maps the landscape of policy instruments and stakeholders' experience that can collectively narrow and ultimately bridge the green premium. The goal is not to romanticise the green transition, but to offer actionable, context-sensitive strategies that make it genuinely attainable for Indonesia's steel producers and policymakers alike. We believe that with the right enabling environment, Indonesia's steel industry can emerge as a regional leader in low-carbon production, unlocking new export opportunities and positioning the country favourably in an increasingly carbon-conscious global market.

We extend heartfelt gratitude to the research team for their intellectual rigour, commitment, and sustained effort in producing this work. We are equally grateful to the government officials, industry practitioners, academic experts, and civil society representatives whose perspectives and expertise have enriched the depth and relevance of this publication. Their willingness to engage openly and critically has been invaluable.

We offer this publication not as a final word, but as an invitation to deeper conversation among stakeholders about how Indonesia can chart a credible and competitive path toward a low-carbon steel future. The transition will require courage, creativity, and coordination across sectors and institutions. We hope this research serves as a catalyst for precisely that kind of bold, collaborative action in accelerating the competitiveness of iron and steel in Indonesia while advancing its decarbonization.

Dr. Ilham Akbar Habibie

Chairperson of the Board of Trustees, The Habibie Center

Executive Summary

The Indonesian iron and steel industry occupies a strategic position within the national economic structure as an upstream sector supporting infrastructure development, manufacturing activities, and export performance. Despite its substantial economic contribution, the iron and steel industry is also among the most carbon-intensive sectors. This high emissions intensity positions the sector as a critical node in national decarbonization efforts. In line with Indonesia's commitment to achieving net-zero emissions by 2060 or earlier, the transition towards low-carbon steel production is not optional but imperative.

At the global level, pressures to decarbonise the iron and steel sector are intensifying alongside the proliferation of climate-related trade policies. The European Union, through the Carbon Border Adjustment Mechanism (CBAM), has introduced emissions-based tariffs on imported products. Meanwhile, the United States and the United Kingdom have begun integrating environmental considerations into trade instruments, including cost-based approaches to carbon-intensive imports and import restrictions linked to deforestation risks. In this evolving landscape, global trade dynamics are no longer determined solely by traditional comparative advantage, but increasingly by the carbon intensity of production processes.

Despite the growing urgency of decarbonising the iron and steel industry, a fundamental tension persists between environmental objectives and economic competitiveness. Low-carbon (green) steel production currently faces significant cost barriers. However, in the Indonesian context, current policy approaches to industrial decarbonization remain predominantly technology-driven. While these measures are essential, the existing policy framework has yet to be complemented by broader economic instruments, including fiscal incentives, trade policies, and market-shaping mechanisms capable of addressing market failures associated with carbon externalities.

Using quantitative and qualitative approaches, this study seeks the economic and environmental impacts on green iron and steel, and also captures industry realities and stakeholder perspectives regarding the decarbonization of the iron and steel industry. Furthermore, the study places particular emphasis on the design of protection mechanisms and competitiveness-enhancing strategies for domestic green steel by comparing business-as-usual trajectories with intervention scenarios involving fiscal incentives and trade protection measures.

Using four decarbonisation scenarios: the EAF scenario; the Natural Gas DRI-EAF scenario; the Hydrogen DRI-EAF scenario; and the Hydrogen + Renewable EAF scenario, this study shows that the cost of low-carbon technology pathways remain high, although these technology options offer much lower environmental cost. However, the BAU scenario, with a Levelized Cost of Steel (LCOS) of 589.21 USD/ton, appears economically stable in the short term but it generates highly carbon-intensive, producing over 48 million tCO_2 with a carbon intensity of 1.46 tCO2/ton, which underscores a fundamental trade-off between cost efficiency and environmental sustainability.

Scenario	Total Emission (tCO_2)	Carbon Competitiveness	LCOS (USD/ton)
Business as Usual	48,021,312.40	Very Low (1.46 tCO_2)	589.21
Scenario 1: EAF	12,558,131.60	High (0.38 tCO_2)	582.98
Scenario 2: DRI-EAF with Natural Gas	21,536,480.00	Medium (0.66 tCO_2)	721.33
Scenario 3: DRI-EAF with Hydrogen	2,495,080.00		901.95
Scenario 4: DRI-EAF with Hydrogen and Renewable	-	Perfect (0.00 tCO_2)	912.95

On the other hand, Indonesia potentially faces a "Catch-22": continuing with carbon-intensive production supports short-term growth but risks long-term export exclusion if decarbonization efforts are not undertaken. For instance, International climate-linked trade policies, such as the EU's CBAM, could impose tariffs of €40–€90 per ton on carbon-intensive exports, effectively making green steel a strategic necessity for exporters. To avoid this situation, the sector's transformation toward low-carbon production is expected to unfold in three phases:

- **2025–2030 (Transition):** Conventional coal-based steel remains dominant due to cost advantages (USD 589/ton), with green steel penetration below 5%, largely driven by external regulatory pressure (e.g., CBAM).
- **2030–2045 (Scaling):** Rapid demand growth (toward ~100 Mt) coincides with green steel expansion to 40–55% market share. Managing the **"green premium"** (20–30% higher costs) becomes central, requiring policy support and technological progress.
- **2045–2060 (Net-Zero):** Green steel becomes the industry norm (>95% share), as renewable energy and carbon pricing eliminate cost disadvantages.

However, key drivers and constraints will shape this transition. Stakeholder interviews and empirical analysis identified five structural constraints currently impeding the green steel transition:

- **Policy Design:** Ineffective fiscal incentives structured as general corporate income tax reductions, rather than direct per-unit cost support for low-carbon production.
- **Weak Demand:** Absence of mandatory green procurement standards, leaving no reliable domestic demand signal for green steel producers.
- **Distorted Competition:** Imported steel faces no carbon-related penalties, creating an uneven playing field against domestic producers investing in decarbonization.
- **Carbon Pricing Gap:** Current carbon pricing (USD 2/tCO_2) is negligible and insufficient to incentivize any shift in production decisions.
- **Institutional Gaps:** Incomplete emissions data systems and MRV (Measurement, Reporting & Verification) frameworks limit policy credibility and hinder CBAM compliance

To overcome these barriers, this study proposes an integrated policy architecture to bridge the green premium and protect Indonesia's industrial competitiveness:

Pillar 1	**Coordinated Regulatory Signals** Establish long-term sectoral emissions targets, investment roadmaps, and enforceable benchmarks to provide credible planning horizons for industry.
Pillar 2	**Standards & Market Credibility** Introduce mandatory green steel classification linked to procurement eligibility and financial incentives, aligned with international frameworks including CBAM.
Pillar 3	**Targeted Financial Support** Deploy direct cost-reduction instruments—including renewable energy subsidies, scrap supply support, and green hydrogen offtake guarantees—to reduce the per-unit green premium.
Pillar 4	**Trade Exposure Management** Develop carbon border measures and revise domestic industrial policies (e.g., TKDN) to include emissions performance criteria, preventing carbon leakage from lower-standard imports.
Pillar 5	**Demand-Side Activation** Mandate green steel use in public infrastructure and procurement, creating a reliable domestic demand base that de-risks investment in low-carbon production.

In conclusion, the green premium is not a permanent barrier, it is a transitional condition shaped by policy design. With sufficient carbon pricing, targeted financial instruments, and a credible institutional framework, Indonesia can transform the green premium from a competitive liability into a strategic advantage. The transition to green steel is, at its core, an economic and institutional challenge rather than a technological one. Early, coordinated, and coherent policy action is the critical determinant of whether Indonesia leads or lags in the emerging global market for low-carbon industrial products.

CHAPTER 1 INTRODUCTION

1.1. Problem context

The Indonesian iron and steel industry occupies a strategic position within the national economic structure as an upstream sector supporting infrastructure development, manufacturing activities, and export performance. In recent years, the sector has demonstrated relatively stable growth, with domestic consumption reaching 18.19 million tonnes in 2023 (IISIA, 2024). However, national production capacity, which stood at only 14.4 million tonnes, indicates a structural gap between domestic demand and supply. This gap has led to a significant reliance on imports, estimated at approximately 16 million tonnes in 2024 (IESR, 2024). At the same time, the industry remains a key contributor to Indonesia's trade balance, with export values around USD 25.8 billion by 2024 and USD 27.97 billion by 2025 (Antara, 2026).

Despite its substantial economic contribution, the iron and steel industry is also among the most carbon-intensive sectors. In the Indonesian context, it accounts for approximately 4.9% of total industrial greenhouse gas emissions, amounting to around 20 to 30 million tonnes of CO_2 annually (IESR, 2024). This high emissions intensity positions the sector as a critical node in national decarbonization efforts. In line with Indonesia's commitment to achieving net-zero emissions by 2060 or earlier, the transition towards low-carbon steel production is not optional but imperative.

At the global level, pressures to decarbonise the iron and steel sector are intensifying alongside the proliferation of climate-related trade policies. The European Union, through the Carbon Border Adjustment Mechanism (CBAM), has introduced emissions-based tariffs on imported products. Meanwhile, the United States has also begun integrating environmental considerations into import instruments, imposing import tariffs based on the carbon footprint of products (ICEL, 2025). In this evolving landscape, global trade dynamics are no longer determined solely by traditional comparative advantage, but increasingly by the carbon intensity of production processes.

Despite the growing urgency of decarbonising the iron and steel industry, a fundamental tension persists between environmental objectives and economic competitiveness. Low-carbon (green) steel production currently faces significant cost barriers, with production costs for low-carbon steel approximately 20–30% higher than those of conventional coal-based methods (Gunung Prisma, 2022). This cost differential creates a competitiveness risk for domestic producers undertaking decarbonization, particularly when competing against lower-cost, carbon-intensive imports.

In the Indonesian context, current policy approaches to industrial decarbonization remain predominantly technology-driven, focusing on measures such as energy efficiency improvements, raw material substitution, industrial electrification, and the development of carbon capture, utilisation, and storage (CCUS) technologies (Indonesia Economic Forum, 2025). While these measures are essential, the existing policy framework has yet to be complemented by broader economic instruments, including fiscal incentives, trade policies, and market-shaping mechanisms capable of addressing market failures associated with carbon externalities.

Furthermore, there is an absence of a comprehensive transition framework to support conventional steel producers in shifting towards low-carbon production systems. This lack of support risks slowing the adoption of green technologies and increasing the vulnerability of domestic industry to global competitive pressures. Under such conditions, emerging green steel producers face structural disincentives, whereby efforts to decarbonise may paradoxically undermine their market competitiveness.

1.2. Research gap

Existing literature on the iron and steel industry has largely concentrated on greenhouse gas emissions and solid waste generation, with a strong emphasis on technological pathways for decarbonization. At the global level, scholarly and policy-oriented studies have extensively examined low-carbon production routes, including hydrogen-based direct reduced iron (H_2-DRI), carbon capture, utilisation and storage (CCUS), electrification through renewable energy-based electric arc furnaces (EAF), and circular economy strategies centred on scrap recycling and material efficiency (Material Economics, 2019). Complementing these technological perspectives, a growing body of economic analysis has employed cost-benefit analysis (CBA) frameworks to assess the cost differential between green and conventional steel production (IEA, 2022).

Beyond technological and economic dimensions, the literature has increasingly incorporated the role of international trade policy in shaping decarbonization pathways. Instruments such as the European Union's Carbon Border Adjustment Mechanism (CBAM) (European Commission, 2021), carbon pricing initiatives in the United States (Shapiro, A. F., & Metcalf, G. E. (2023), and sustainability-linked trade measures in the United Kingdom illustrate how climate policies are being embedded within global trade regimes.

However, within the Indonesian context, several critical research gaps remain. First, while global literature increasingly emphasises the importance of trade-related policy instruments, Indonesia has yet to develop a comprehensive protection framework for green steel industries. Current policy tools remain limited, for instance to voluntary green product labelling schemes in iron and steel, which lack enforceability and market-shaping capacity. As a result, domestic producers face dual exposure: vulnerability to the influx of low-cost, carbon-intensive steel imports—particularly from major producing countries—and the risk of market exclusion due to external regulatory regimes such as the CBAM.

Second, unlike international studies that have begun to explore consumer and investor preferences for low-carbon products (BCG, 2023), empirical research on demand-side dynamics for green steel in Indonesia remains scarce. This creates an incomplete understanding of market formation processes and limits the design of effective demand-pull policies.

Taken together, these gaps indicate that research on steel decarbonization in Indonesia has yet to fully integrate market dynamics, trade policy instruments, production cost structures, and their combined implications for industrial competitiveness and trade performance. Addressing this gap requires a more holistic analytical framework that bridges technological, economic, and policy dimensions.

This study seeks to fill this gap by adopting a mixed-methods approach that integrates quantitative analysis—such as cost-benefit analysis, price gap assessment, and policy scenario modelling—with qualitative inquiry, including focus group discussions and in-depth stakeholder interviews. Through this approach, the study not only evaluates the economic and environmental impacts of various policy options, but also captures industry realities and stakeholder perspectives.

Furthermore, the study places particular emphasis on the design of protection mechanisms and competitiveness-enhancing strategies for domestic green steel—an area that remains underexplored in the Indonesian context. By modelling alternative policy scenarios, the research compares business-as-usual trajectories with intervention scenarios involving fiscal incentives and trade protection measures, thereby providing an evidence-based basis for policy prioritisation.

By situating Indonesia within the evolving landscape of global climate-linked trade instruments—such as CBAM and sustainability-based import restrictions—this study identifies both strategic challenges and emerging opportunities. Ultimately, it advances a more integrated perspective that balances decarbonization objectives with industrial competitiveness. The findings are expected to contribute both theoretically and practically, offering an evidence-based foundation for policymakers to design regulatory frameworks that protect and strengthen the competitiveness of Indonesia's green steel industry in an increasingly sustainability-driven global trade system.

Based on the gaps in the literature that have been identified, this study aims to answer the following questions:

RQ1. *To what extent does decarbonization in the iron and steel sector affect the competitiveness of Indonesia's iron and steel industry?*

RQ2. *What are the economic and environmental costs and benefits associated with green iron and steel production in Indonesia?*

RQ3. *Which policy instruments are most effective in enhancing the competitiveness of green iron and steel products in the domestic market?*

CHAPTER 2 CONCEPTUAL FRAMEWORK

2.1. Decarbonization and Industrial Transformation

Decarbonization in the iron and steel industry refers to the systematic reduction of greenhouse gas (GHG) emissions—particularly carbon dioxide (CO_2)—across the production value chain. This transition is critical given that the sector accounts for approximately 7–9% of global fossil fuel-related CO_2 emissions (IEA., 2020). On average, producing one tonne of steel emits around 1.85 tonnes of CO_2, underscoring the carbon-intensive nature of conventional production processes (Muslemani et al, 2021).

The literature identifies multiple technological pathways for reducing emissions in the iron and steel sector, including hydrogen-based direct reduced iron (H_2-DRI), carbon capture, utilisation and storage (CCUS), and electrification through renewable energy-based electric arc furnaces (EAF) (Pauliuk et al., 2021). These technologies represent varying degrees of emissions reduction and technological maturity. Two dominant production routes illustrate the trade-offs between emissions and cost:

- The Blast Furnace–Basic Oxygen Furnace (BF-BOF) route, which remains the industry standard but is highly carbon-intensive (~1.85 tonnes CO_2 per tonne of steel).
- The Direct Reduction Iron–Electric Arc Furnace (DRI-EAF) route, which offers lower emissions (~0.97 tonnes CO_2 per tonne) and is considered a transitional pathway towards green steel production.

In addition, circular economy approaches—particularly scrap-based steel production—play an important role in reducing emissions intensity. Scrap recycling accounts for approximately 24% of global steel production and can significantly reduce carbon emissions, although its scalability is constrained by supply limitations, particularly in import-dependent markets such as Indonesia (Pintowantoro et al., 2025).

From an economic standpoint, these technological transitions are associated with higher capital and operational costs. Green steel production is currently estimated to be 20–30% more expensive than conventional methods, largely due to the cost of green hydrogen, renewable energy infrastructure, and emerging technologies (IEA, 2020). This cost differential forms a central component of the conceptual framework, as it directly affects price competitiveness and market outcomes.

2.2. Competitiveness and Trade in a Carbon-Constrained Economy

The relationship between decarbonization and industrial competitiveness can be analysed through the lens of comparative advantage under carbon constraints. Traditional trade theory suggests that countries specialise based on factor endowments; however, the emergence of climate policies introduces carbon intensity as a new determinant of competitiveness (Grossman & Krueger, 1991).

In this context, firms that adopt low-carbon technologies may face short-term competitiveness losses due to higher production costs. However, in markets with carbon regulations—such as those implementing carbon border adjustment mechanisms (CBAM)—low-carbon producers may gain a relative advantage (European Commission, 2021).

This duality reflects a broader theoretical tension between:

- Static competitiveness (cost-based, short-term), and
- Dynamic competitiveness (innovation-driven, long-term).

The LCOS analysis, IRR/EIRR tables, MAC curve, and carbon credit sensitivity are all exclusively **static** measurements. They capture cost at a point in time under fixed technology assumptions.

The most tractable proxy for dynamic competitiveness in this context is the technology learning curve — the empirical regularity that unit costs fall by a fixed percentage (the learning rate) for every doubling of cumulative installed capacity. Wright's law estimates put electrolysers in the 16–21% range (IRENA, 2020), with broader reviews of learning-curve technologies (solar PV, wind, battery storage, and electrolysers) finding declines as high as 16–34% per doubling of deployment (Way et al., 2022). If the LCOS model had been run at projected 2030 and 2040 cost parameters (incorporating learning curve cost reductions) rather than only at 2026 costs, it would operationalise dynamic competitiveness: the question becomes not just "which technology is cheapest today" but "which technology gains the most competitive ground over time." The Green-H_2 scenario is particularly sensitive to this — its LCOS of $806/t today falls to approximately $620/t at $2/kg hydrogen, a 23% reduction that EAF cannot match because it is already mature. That convergence *is* dynamic competitiveness, but the report never frames it as such.

Thus, decarbonization can be both a constraint and an opportunity, depending on the policy environment and market structure.

2.3. The Role of Policy Instruments: Green Industrial Policy Perspective

The transition towards green steel cannot be fully explained by market dynamics alone. The literature on green industrial policy emphasises the role of the state in shaping markets, supporting technological transitions, and correcting systemic market failures (Rodrik, 2015).

Policy instruments can be categorised into three main groups:

- Fiscal Instruments
  Including subsidies, tax incentives, and carbon pricing mechanisms aimed at reducing production costs and internalising carbon externalities.
- Trade Instruments
  Such as tariffs on carbon-intensive imports, carbon border adjustments, and local content requirements, which protect domestic industries and level the playing field.
- Demand-Side Instruments
  Including green public procurement (GPP) and mandatory standards, which create stable demand for low-carbon products.

These instruments act as moderating variables within the conceptual framework, influencing the relationship between cost structures and competitiveness outcomes.

CHAPTER 3 METHOD

This study employs both qualitative and quantitative approaches. The quantitative approach is used to analyze cost competitiveness between green and conventional steel, and to analyse market dynamics under the assumption that the Indonesian iron and steel industry decarbonizes. To provide data and identify key barriers to the competitiveness of decarbonising iron and steel by (i) cost competitiveness analysis between green and conventional steel and (ii) market analysis under the assumption that the Indonesian iron and steel industry decarbonizes.

Meanwhile, the qualitative approach is used to analyze market barriers for green steel, as well as the strategy and policy innovation to protect green steel. Through in-depth interview and policy document analysis, this approach enables researchers to understand the context, barriers, and enabling factors of policy implementation that cannot be adequately captured through quantitative data alone (Dawadi et al., 2021).

3.1. Qualitative Approach

According to Hennink et al. (2020), a qualitative approach allows researchers to examine the experiences of individuals or groups in detail using a range of specific research methods such as in-depth IDI, focus group discussions, content analysis, and life histories or biographies. This approach is used because it enables a more contextual understanding of market barriers, particularly in the iron and steel industry, especially from the perspective of parties involved in the steel industry. Thus, the experiences, perceptions, and actions expressed by various stakeholders can provide insights and recommendations for policy innovation to protect green steel.

Data Collection Techniques

This study conducted in-depth IDI to further explore the experiences, perceptions, and views of parties involved within the iron and steel industry. The selection of interviewees was carried out purposively to obtain detailed information related to specific topics, considering that the selected participants have direct experience and relevance to the research topic (Etikan, 2016).

Table 1. List of In-Depth Interview Informants[1]

Institution	Affiliation of Informant (Division/Directorate/Field)	Informant Code
Ministry of Industry	Green Industry Centre	N1
An Indonesian Environmental NGO focuses on Industrial Decarbonization	Researcher	N2
Institute for Essential Services Reform	Researcher	N3
Indonesian Iron & Steel Industry Association	Co-Executive Director	N4
Indonesian Chamber of Commerce and Industry (KADIN)	Vice Chairman for Iron and Steel Downstreaming Development of the Indonesian Chamber of Commerce and Industry	N5
Ministry of Trade	Center for International Trade Policy	N6
Ministry of Finance	Directorate General of Economic and Fiscal Strategy	N7

1. For information, the researchers sent interview request letters to the BP BUMN, Social and Environmental Responsibility Division, but did not receive a response until this research was published.

In conducting the IDI, the researcher used a semi-structured interview guide (King & Horrocks, 2010). Although the IDI were conducted in a semi-structured format, the discussions were carried out adaptively, allowing the researcher to conduct probing based on the responses of the informants. This was done to obtain more in-depth information in specific areas of discussion, clarify ambiguities, and explore particular topics that were not included in the interview guide questions. The questions in the discussion guide were developed from the conceptual framework. In addition to IDI, the study also used secondary data sources such as policy documents, journals, articles, and mass media reports.

Data Analysis Techniques

After the interview data were collected, the researcher conducted a thematic analysis to identify patterns or themes within the discussion transcript data (Maguire & Delahunt, 2017). This process involved several steps, including familiarizing oneself with the data, generating initial codes, identifying potential themes, reviewing and defining those themes, and then writing up the findings (Maguire & Delahunt, 2017). The codes were aligned with the analytical framework used in this study.

In the thematic analysis—particularly in the coding of in-depth IDI—this study employed both deductive and inductive approaches. The deductive approach was used to guide the analysis of findings based on the research questions and the predetermined GPP framework, while the inductive approach helped explore new findings emerging from the informants.

3.2. Quantitative approach

An integrated economic and emissions model is developed to assess the two primary production pathways:

1. Baseline (Conventional): The dominant BF-BOF (Blast Furnace-Basic Oxygen Furnace) route.
2. **Green (Decarbonized):** The most viable green-field alternative, with 4 scenarios:
   - **a.** EAF
   - **b.** DRI-EAF with Natural Gas
   - **c.** DRI-EAF with Green Hydrogen
   - **d.** DRI EAF with Green Hydrogen based Renewable

The quantitative approach translates the qualitative findings into numerical, scenario-based comparisons. It applies established techno-economic and welfare-economic methods to a 20-year evaluation horizon (2026–2045), covering a sector capacity of 44,450 kTPA aggregated from the 14 Indonesian plants in the source dataset. The model adopts a deterministic, scenario-driven structure in which each of the five technology pathways is applied to the entire sector and evaluated against the same reference price, utilization rate, discount rates, and external valuation parameters. Sensitivity analysis tests the robustness of the rankings against the most uncertain inputs.

Data collection

a. Data Stratification

Quantitative inputs were drawn from four distinct categories of sources, each chosen for its authoritativeness in the relevant domain:

Table 2. Quantitative Input and Variables

Input category	Variables	Primary source
Plant inventory	Capacity, technology, status, energy consumption, raw materials	SteelData Indonesia (GEM 2025 Tracker)
Technology coefficients	CO_2, SO_2, NO_x, $PM_{2.5}$ emission factors; CAPEX; OPEX (all-in); job intensity	WSA 2024; IEA Iron & Steel Roadmap 2024; Columbia CKI 2024; MIT EPPA 2023
Externality valuation	Social cost of carbon; air-pollution health damage values; GDP multiplier; wage rate	US EPA SC-GHG 2023; OECD/WHO; World Bank Indonesia I-O table; BPS Indonesia
Macro and market	Steel price; discount rates; tax rate; exchange rate; carbon credit price	World Steel Association 2025; Bank Indonesia; PwC Indonesia; IDX Carbon; Article 6 trades

All monetary values are expressed in 2026 US dollars unless stated otherwise. Where values were originally denominated in Indonesian rupiah, the Bank Indonesia mid-rate of IDR 15,800 per USD was applied. Carbon-credit prices were collected as a range — IDR 32,612 (~USD 1.98) on IDX Carbon in March 2025; USD 25–50 typical range for Article 6 international transactions; USD 40–80 for high-quality verified credits — and a base value of USD 25/tCO_2 was selected as representative of the price Indonesia is plausibly able to capture on its decarbonization-driven credits over the analysis horizon.

b. Data Collection Methodologies

To ensure the model is grounded in reality, a multi-tiered data collection approach should be utilized:

A. Secondary Desktop Research & Benchmarking (Primary Method)

Since building a steel plant model relies heavily on established thermodynamic and economic benchmarks, secondary data will form the baseline.

- Industry Standards & Guidelines: Extracting mass-balance and energy-intensity baselines from authoritative bodies such as the International Energy Agency (IEA), World Steel Association (WSA), and the EU Best Available Techniques (BAT) Reference Documents.
- Market Intelligence Platforms: Gathering historical and projected commodity pricing (Iron Ore 62% Fe, DR-grade pellets, Premium Hard Coking Coal, Scrap) from platforms like S&P Global Platts, Argus Media, or BloombergNEF.
- Academic & Think-Tank Literature: Utilizing recent peer-reviewed techno-economic assessments (TEAs) focusing specifically on green hydrogen LCOS and DRI-EAF transition pathways.

B. Regulatory & Policy Document Review

To accurately model the localized context (e.g., if modeling for Indonesia or a specific region):

- Energy Tariffs: Collecting industrial electricity tariffs from local utilities (e.g., PLN in Indonesia) and assessing national renewable energy pricing.
- Carbon Regulations: Reviewing national NDC (Nationally Determined Contributions) documents and carbon pricing roadmaps to input accurate carbon penalty variables into the financial model.

C. Proxy Data & Vendor Specifications (Primary Data)

For the emerging H2-DRI-EAF pathway, historical data is scarce.

- Equipment Vendor Estimates: Sourcing CAPEX intensity approximations from public feasibility studies or press releases of major technology providers (e.g., Midrex, Tenova, SMS group) and electrolyzer manufacturers.

- Case Study Extrapolation: Analyzing data from earli-mover green steel projects (e.g., HYDRIT or H_2 Green Steel in Sweden) to establish realistic cost-reduction curves and operational assumptions.

c. Data Validation & Harmonization Technique

Raw data collected from various sources will often have different boundaries or units. The following techniques will be applied before feeding the data into the model:

- Unit Standardization: Converting all energy inputs to a uniform metric (e.g., GJ or MWh per ton of crude steel) and financial inputs to a single currency and base year (e.g., Real 2024 USD).
- Boundary Synchronization: Ensuring that the CAPEX for both BF-BOF and H_2-DRI-EAF covers the exact same "gate-to-gate" boundaries (e.g., both including raw material handling and casting, but separating the hydrogen production facility if treated as a Levelized Cost of Hydrogen input).

Cost competitiveness analysis

The analysis will utilize the industry-standard Levelized Cost of Steel (LCOS) framework (Betaille, 2020. This robust financial model enables a dynamic comparison of production costs over the asset's lifetime, which is far superior to a simple static price comparison.

Key Variables: The LCOS model will be sensitized to the specific "green premium" drivers, including :

1. Energy Cost: The high electricity demand (3-4 times that of BF-BOF) for EAF operation and green hydrogen production via electrolysis (IEA, 2026) . This will be modelled against Indonesia's projected renewable energy costs.
2. Feedstock Cost: The price and supply-chain availability of scarce DR-grade iron ore, which currently constitutes less than 5% of the global iron ore supply (IEA, 2026).
3. Capital Cost: The high-CAPEX and perceived high technological risk of "first-of-a-kind" green steel plants (Global Energy Efficiency, 2025).
4. Policy Levers: The model will be used to simulate the impact of policy interventions, such as a hypothetical carbon price or green hydrogen subsidies, to identify the "break-even point" at which green steel becomes cost-competitive with conventional steel (Betaille, 2020).

The cost competitiveness analysis is built around four interlocking metrics: **Levelized Cost of Steel (LCOS), Net Present Value (NPV)** (computed both at the financial discount rate of 10% and the economic discount rate of 5%), **Internal Rate of Return (IRR)** and **Economic Internal Rate of Return (EIRR),** and **Benefit-Cost Ratio (BCR).** Each is computed for the same five-scenario set, on the same 20-year horizon, applied to the same aggregated capacity.

LCOS — Levelized Cost of Steel

LCOS measures the lifetime average cost of producing one tonne of steel and is the standard cost benchmark used in industrial techno-economic studies. It is computed as the present value of all costs incurred over the project life divided by the present value of physical output:

$$LCOS = NPV(CAPEX + OPEX) \div NPV(Production)$$

Both numerator and denominator are discounted at the financial rate of 10%. CAPEX is split equally over a two-year construction period (years 1–2). OPEX is reported as the all-in operating cost (energy, raw materials, labour, consumables) per tonne, and is incurred from year 3 once production begins. The model also computes an LCOS net of carbon credit revenue, which subtracts the present value of credit revenue from the cost numerator and indicates the effective cost of steel after the policy incentive is captured.

Financial NPV and IRR

Financial NPV measures the present value of net cash flows accruing to the firm. The financial cash flow comprises:

- **Revenue** from steel sales at the prevailing market price ($650/t hot-rolled benchmark);
- **Carbon credit revenue** earned by scenarios S2–S5 in proportion to emissions avoided versus the BAU baseline, multiplied by the

carbon credit price (with a real escalation of 5%/yr) and discounted by a verification haircut of 10%;

- **Operating expenditure (OPEX)** covering all in-plant production costs;
- **Capital expenditure (CAPEX)** for new (greenfield) capacity, plus retrofit CAPEX for existing capacity at 40% of greenfield cost where the scenario differs from BAU;
- **Tax and royalty payments** at 18% of revenue (combined corporate income tax and minerals royalty).

Financial IRR is the discount rate at which financial NPV equals zero. It is benchmarked against the 10% private hurdle rate, which reflects the typical weighted-average cost of capital for Indonesian steel investments. A scenario with IRR > 10% is privately viable on a stand-alone basis.

Economic NPV and EIRR

Economic NPV widens the boundary of analysis to incorporate externalities — the costs and benefits not captured by the firm's accounts but borne by society. It adds the monetary value of jobs (wage income to households), the GDP multiplier benefit from sectoral linkages, and the value of avoided environmental damages, while subtracting the social cost of carbon and air-pollution health damages. It is discounted at the economic (social) rate of 5%, consistent with OECD/Bappenas guidance on infrastructure CBA. Pure financial transfers — taxes and carbon credits — are excluded from the economic flow because they redistribute resources rather than create them.

EIRR is the corresponding internal rate of return on the economic cash flow, benchmarked against the 5% social discount rate. EIRR is the public-sector decision metric: a scenario with EIRR > 5% delivers positive social value and merits public support, even if its IRR falls short of the private hurdle.

Benefit-Cost Ratio (BCR)

BCR is the ratio of the present value of all positive flows (revenue, social benefits) to the present value of all negative flows (OPEX, CAPEX, environmental damages, taxes), discounted at the economic rate. BCR > 1.0 indicates a socially worthwhile investment. The metric complements EIRR by expressing efficiency rather than rate of return — useful for ranking projects of different scale.

Trade & Market analysis

The trade and market analysis component contextualises the cost-competitiveness results within Indonesia's external environment. Three lenses are applied:

- **Domestic market positioning**
  The aggregated 44,450 kTPA capacity is benchmarked against Indonesia's projected domestic demand growth, identifying surplus capacity and export-orientation requirements over the analysis horizon.
- **Import competition and price discipline**
  The reference steel price ($650/t) is calibrated against the East Asian hot-rolled coil benchmark, which sets the de facto ceiling on Indonesian producer prices given import availability from China, Vietnam, and Korea.
- **Carbon-border adjustment exposure**
  The EU Carbon Border Adjustment Mechanism (CBAM), fully operational from 2026, imposes a charge on the embedded carbon content of imported steel. Scenarios are evaluated for their CBAM exposure: BAU (high embedded carbon) faces the largest implicit tariff, while DRI-EAF routes (especially Blue-H_2 and Green-H_2) face a much smaller adjustment. This gives clean technologies an export-market advantage that is not reflected in the domestic financial NPV but materially shapes the longer-term competitive landscape.

Carbon credit revenue is treated as a market-based incentive rather than a subsidy. It reflects Indonesia's commitments under Presidential Regulation No. 110/2025 and the planned 2027 expansion of the Indonesian carbon trading system to industrial sectors including steel. Sensitivity to the credit price ($0–$120/tCO_2) tests the policy lever directly.

CHAPTER 4
COST COMPETITIVENESS & MARKET ANALYSIS

4.1. Cost analysis

The cost analysis evaluates each scenario on five complementary dimensions: Levelized Cost of Steel (LCOS), financial-economic indicators (NPV, EIRR, BCR), cost competitiveness against the prevailing market price, technology readiness and enabling conditions, green public procurement as a demand-side mechanism, and marginal abatement cost. Together, these lenses produce an integrated view of both the cost structure and the institutional conditions that determine which pathways are realistically implementable in the Indonesian context.

Levelized cost analysis of steel and iron (LCOS)

LCOS captures the total lifetime production cost, normalised per tonne of steel (Ellersdorfer et al, 2024). The results show a clear hierarchy from BAU (lowest cost) to Green-Hydrogen DRI-EAF (highest cost), reflecting the cost-of-decarbonization premium that Indonesia faces under current technology economics.

Table 3. LCOS of each scenario

Scenario	LCOS (gross)	LCOS (net of credits)	Premium vs BAU (gross)	Premium net of credits	Margin vs $650/t price
S1 — BAU (BF-BOF Coal)	$500	$500	$0	$0	$150
S2 — EAF (Scrap)	$564	$509	$64	$9	$141
S3 — DRI-EAF (Natural Gas)	$635	$604	$135	$104	$46
S4 — DRI-EAF (GreenH_2)	$675	$613	$175	$113	$37
S5 — DRI-EAF (Green H_2 and Renewable Electricity)	$806	$730	$306	$230	($80)

Three observations stand out. First, the gross premium for cleaner technologies ranges from $64/t (EAF) to $306/t (Green-$H_2$) — a six-fold spread that reflects the very different maturity and feedstock economics of the underlying technologies. Second, carbon credits at the $25/t$CO_2$ base price erode the premium meaningfully — EAF's premium falls to just $9/t after credits, effectively reaching parity with BAU. Third, only Green-H_2 DRI-EAF produces an LCOS above the prevailing $650/t market price, indicating it cannot recover its costs at present without higher carbon credit values, hydrogen cost reductions, or a green-steel price premium.

The results also confirm a finding well-established in the international literature: scrap-based EAF is the cheapest decarbonization route, conditional on adequate scrap availability. Indonesia's current domestic scrap pool is limited, which is the primary constraint on a wholesale shift to S2.

(NPV at 10% and IRR) reflect the perspective of a steel-producing firm; the social metrics (NPV at 5%, EIRR, and BCR) reflect the perspective of an Indonesian social planner who internalises the full cost of carbon and air pollution but also values jobs and GDP linkages. Here these parameters explain:

- **NPV (Net Present Value)**

  NPV measures the total value a project creates or destroys over its lifetime, expressed in today's money. Because a dollar received in the future is worth less than a dollar today, all future cash flows are "discounted" back to the present using a chosen rate. A positive NPV means the project generates more value than it costs; a negative NPV means it destroys value. Two NPV figures appear in the table because two different perspectives are applied: a financial NPV at 10% represents the private investor's view, while an economic NPV at 5% represents the government and society's view. The lower social discount rate reflects the fact that public policy must account for long-term benefits — such as avoided health costs and reduced climate damage — that private markets systematically undervalue.

- **IRR (Internal Rate of Return)**

  The financial IRR is the annual return rate a project earns for its investors. It is the specific discount rate at which the project's NPV equals exactly zero — in other words, the breakeven return. A higher IRR is better. The 10% hurdle rate in the table is the minimum return private investors require before committing capital to an industrial project in Indonesia. Any scenario whose IRR falls below 10% cannot attract private financing without external support such as subsidies, concessional loans, or carbon pricing mechanisms.

- **IRR vs 10% hurdle**

  This row shows the gab between each scenario's IRR and the 10% hurdle rate, measured in percentage point (PP). A positive figure means the project comfortably exceeds investor expectations; a negative figure means it falls short. For example, a reading of −6.2pp means the project earns only 3.8% when investors require at least 10%, leaving a 6.2 percentage point shortfall that policy instruments would need to close.

- **EIRR (Economic Internal Rate of Return)**

  The EIRR applies the same breakeven logic as the financial IRR but uses a much broader definition of value. Instead of counting only cash revenues and costs, the EIRR incorporates social and environmental benefits (avoided premature deaths from reduced air pollution), the economic damage of carbon emissions avoided, energy import savings, and employment effects. It answers the question: at what discount rate does the full social value of the project equal its full social cost? A high EIRR means the project creates substantial value for society even if it is unattractive to private investors. All scenarios in the table show EIRRs far above the 5% social benchmark, confirming that every decarbonization pathway is economically sound from a public interest standpoint.

- **EIRR vs 5% social discount (pp)**

  This row performs the same spread calculation as the financial hurdle comparison, but against the 5% social discount rate. It quantifies how far each scenario exceeds the minimum social return threshold. Large positive spreads — ranging from +27.4pp to +44.0pp in the table — indicate that all scenarios generate robust social value well above the minimum required, and that the economic case for policy intervention is strong regardless of which technology pathway is chosen.

- **BCR — Benefit-Cost Ratio (social, at 5%)**

  The BCR is the single most important summary indicator for a policy audience. It is calculated by dividing the present value of all social benefits by the present value of all costs, both discounted at 5%. A BCR of 1.0 means benefits exactly equal costs. A BCR above 1.0 means every dollar of expenditure returns more than one dollar of social value, making the investment worthwhile from a public resource allocation perspective. A BCR below 1.0 would indicate the project consumes more social resources than it creates. All scenarios in the table exceed 1.0, confirming that public support for steel decarbonization is justified. The BCR is particularly useful for comparing alternative interventions: S2 EAF at 1.81x delivers $1.81 of social return per dollar spent, making it the most cost-effective use of public funds among the five scenarios examined.

Table 4. Financial Analysis of Each Scenario

Metric	S1 BAU	S2 EAF	S3 DRI-EAF Natural Gas	S4 DRI EAF Green-H_2	S5 DRI-EAF Green-H_2 and Renewable
NPV (financial @ 10%) — $M	7,978	5,819	(17,080)	(19,228)	(47,493)
IRR (Financial)	14.1%	12.2%	3.8%	4.0%	< 0%
IRR vs 10% hurdle (pp)	+4.1	+2.2	(6.2)	(6.0)	n/a
NPV (economic @ 5%) — $M	116,632	222,731	150,518	208,082	196,952
EIRR (Economic)	39.3%	49.0%	32.5%	37.2%	32.4%
EIRR vs 5% social discount (pp)	+34.3	+44.0	+27.5	+32.2	+27.4
BCR (social, at 5%)	1.30x	1.81x	1.40x	1.59x	1.42x

The most striking pattern is the wedge between the financial and economic perspectives. From the firm's standpoint, BAU is by far the most attractive: it is the only scenario with a meaningfully positive financial NPV ($8.0 billion) and an IRR comfortably above the 10% hurdle (14.1%). EAF is the only clean alternative that also clears the financial hurdle, at 12.2% IRR. The three DRI-EAF variants all fail the private test at base assumptions.

The economic perspective inverts this ranking. Under the social discount rate of 5%, EAF dominates with the highest economic NPV ($222.7 billion), the highest EIRR (49.0%), and the highest BCR (1.81x). Every scenario clears the 5% social discount rate, meaning every option generates positive social value at present-day externality prices. But the gap between scenarios is decisive: cleaner technologies generate substantially more social value per dollar of CAPEX once externalities are priced.

The financial-economic wedge is the quantitative justification for policy intervention. Blue-H_2 and Green-H_2 DRI-EAF have the largest gaps and therefore the strongest economic case for direct subsidy or carbon credit support; Natural-Gas DRI-EAF sits in the middle as a transitional option; and EAF is the closest to private viability and would benefit most from scrap-supply policies rather than direct financial incentives.

Cost competitiveness analysis

Cost competitiveness is the synthesis question: at the prevailing market price of $650/t, which scenarios make competitive sense, and which are dependent on policy support? The answer integrates the LCOS and financial findings.

Scenario	Margin at $650/t	Carbon-price needed for IRR > 10%	Competitiveness verdict
S1 — BAU	+$150/t (gross)	Already met (14% IRR)	Privately competitive — but exposed to CBAM and SCC ramp-up
S2 — EAF	+$141/t (with credits)	~$15/t$CO_2$	Most competitive clean route — scrap supply is the binding constraint
S3 — NG-DRI-EAF	+$46/t (with credits)	~$80/t$CO_2$	Cost-competitive but below private hurdle — needs carbon-price boost
S4 — Green-H_2	+$37/t (with credits)	~$60/t$CO_2$	Highest emissions cut among gas-based routes — needs carbon support and CCS infrastructure
S5 — Green-H_2 and Renewable Electricity	(–$80/t)	~$120/t$CO_2$	Not yet competitive — viable only with hydrogen cost ↓ or strong carbon pricing

Table 5 — Cost competitiveness verdict by scenario

Three competitiveness archetypes emerge. Privately competitive today (S1, S2): BAU and EAF are both above the 10% hurdle and earn positive margins at current steel prices. EAF is the only clean technology in this category. Carbon-price dependent (S3, S4): Natural-Gas DRI-EAF and Blue-H_2 DRI-EAF are within striking distance of private viability — they cross the 10% IRR threshold at carbon prices of $60–$80/tCO_2, well within the range of the EU ETS price. Long-run only (S5): Green-H_2 DRI-EAF requires either substantially cheaper hydrogen or carbon prices above $120/t$CO_2$ to clear the private hurdle.

From a market-dynamics perspective, the implications are clear. The Indonesian steel sector's near-term decarbonization will most likely be led by EAF expansion (where scrap is available) and Natural-Gas DRI-EAF (where new builds and brownfield retrofits are planned). Hydrogen-based routes are unlikely to deploy at scale before 2030 unless carbon prices are substantially higher, a green-steel premium is secured through offtake contracts, or hydrogen costs fall step-change.

Technology Readiness and Enabling Conditions

Cost metrics alone do not determine which technologies get built. A route must also be technically mature enough to deploy at industrial scale, and the Indonesian enabling environment — feedstock availability, infrastructure, skills, and regulation — must be in place to support it. This section evaluates each scenario on four enabling dimensions: Technology Readiness Level (TRL), feedstock and infrastructure constraints, local industrial-policy alignment, and key implementation risks.

Scenario	TRL	Feedstock / energy constraint	Infrastructure needed	Policy alignment	Key implementation risk
S1 BAU	9	Coking coal import dependency; volatile freight costs	Existing; no new build required	Contradicts NDC; exposes to CBAM	CBAM cost escalation after 2026; stranded asset risk by 2035–2040
S2 EAF	9	Scrap availability: only ~4.5 Mt/yr domestic scrap vs 35 Mt/yr capacity	Grid upgrade for 80% higher electricity load; scrap logistics	Aligned with efficiency & circular economy goals	Scrap gap (~30 Mt/yr) requires import or domestic collection build-up
S3 NG-DRI	8-9	Natural gas; existing Pertamina/ Pertagas pipelines cover key clusters	DRI shaft furnace; pellet plant; gas pipeline spur	Consistent with gas transition policy; supports new plants at Morowali	Gas price volatility; risk of gas lock-in if H_2 pathway delayed
S4 Green -H_2	6-7	Requires domestic gas + CCS; 19 CCS projects planned by MEMR by 2030	CCS pipeline/ storage; H_2 distribution; green DRI shaft furnace	Aligned with PR 14/2024 CCS framework; Indonesia–Singapore MoU	CCS geological storage verification; Blue-H_2 cost reduction timeline
S5 Green-H_2 and Renewable Electricity	5-6	Renewable electricity: PLN RUPTL 2025–2034 adds 71 GW renewables	Large-scale electrolyser park; H_2 transport/ storage; DRI furnace	Aligned with Net Zero 2060; MoI green industry targets	H_2 cost far above break-even ($4–6/ kg vs $1.4–1.7/ kg needed); electrolyser scale-up

Table 6. — Technology readiness and enabling conditions by scenario. TRL 9 = fully commercial; TRL 5–6 = early demonstration.

BAU (S1) — Commercially proven but institutionally stranded

BF-BOF technology is TRL 9 and requires no new infrastructure build — it is precisely what the majority of Indonesia's 44,450 kTPA announced capacity is designed for. However, its enabling conditions are eroding. Coking coal import costs are exposed to freight-price volatility and Indonesian coal export policy shifts. More decisively, the EU CBAM — which applies carbon charges on the embedded emissions of imported steel from 2026 — creates an escalating implicit tariff on BAU-produced steel sold into European markets. Indonesia's Ministry of Industry acknowledges this exposure (Mongabay, February 2026), noting that without mandatory emissions-intensity limits and third-party verification, Indonesian producers risk losing access to premium export markets. A 2024 Ministry of Industry regulation already sets product-level emissions limits for flat steel under the Standar Industri Hijau (SIH) framework, marking the beginning of regulatory pressure on BAU.

EAF (S2) — Commercially proven but feedstock-constrained

Electric Arc Furnace technology is also TRL 9, used globally and in Indonesia today (PT Gunung Raja Paksi, PT Ispat Indo, among others). Its primary enabling constraint is scrap availability. In 2023, Indonesia's scrap demand rose 10.7% y-o-y to 18.5 million tonnes, with this demand well served by domestic supply, while imports actually declined 8.5% y-o-y to 1.1 million tonnes (SEIASI, 2023), while the full-sector EAF scenario requires approximately 35 Mt per year — a factor-7 gap. Closing this gap would require a combination of: (i) organised domestic collection and processing infrastructure; (ii) scrap import arrangements (feasible given regional availability from Japan, South Korea); and (iii) a decades-long build-up of the domestic scrap pool as Indonesia's steel-in-use base accumulates. In the near term, partial EAF deployment — targeting 8–12 Mt of the announced capacity at plants already using EAF or planned for it — is realistic by 2030. The GEI Net-Zero Roadmap for Indonesia's Steel Industry (2024) identifies EAF expansion as the single highest-priority near-term decarbonization action.

DRI-EAF with Natural Gas (S3) — Mature technology with Indonesian gas-sector alignment

Natural-gas DRI-EAF (Midrex, Energiron processes) is TRL 8–9 with approximately 150 Mt/yr of global operating capacity and is the standard technology in Middle Eastern steel hubs. In Indonesia, existing Pertamina and Pertagas infrastructure covers the Cilegon, Ciwandan, and Morowali clusters where announced DRI expansions are concentrated. The PT Dexin Cilegon 14,000 kTPA project and several of the announced Morowali plants are already designed around natural-gas DRI-EAF configurations. The primary enabling constraints are: (i) a dedicated pellet plant for high-grade DRI feed (iron ore pellets, not lump ore); and (ii) a gas tariff structure that makes DRI economics viable — current industrial gas prices in Java are approximately USD 6–7/MMBTU, at the upper end of DRI feed cost tolerance. The government's planned gas downstream regulation (in revision as of 2026) could support lower industrial gas pricing for strategic decarbonization investments.

Natural-gas DRI-EAF is also the technology best positioned to provide a transition bridge to hydrogen: the same shaft-furnace DRI plant can co-fire hydrogen once it becomes available, at increasing blending rates (20%, 50%, 100%), allowing a hydrogen-ready build today to fully transition tomorrow. This 'H_2-ready DRI' design approach is explicitly recommended by the IEA Iron and Steel Roadmap 2024 and the Global Efficiency Intelligence Indonesia Net-Zero Roadmap 2024.

DRI-EAF with Green Hydrogen (S4) — Enabling conditions under construction

Blue hydrogen — produced from natural gas with Carbon Capture and Storage — is at TRL 6–7 in the DRI-steel context. The key enabling condition is CCS infrastructure, which Indonesia is actively developing: MEMR has identified 19 potential CCS projects expected to commence operations by 2030, anchored by the Tangguh CCUS project (BP, West Papua) and the Gundih project (Pertamina, Central Java). Presidential Regulation No. 14 of 2024 provides the legal framework for CCS implementation, and the Indonesia–Singapore MoU of June

2025 opens the prospect of cross-border carbon capture trading. The Blue-H_2 scenario is the most strategically aligned with Indonesia's emerging CCS infrastructure trajectory, and is the pathway with the best combination of deep emissions reduction (78% vs BAU) and reasonable CAPEX step-up versus Natural-Gas DRI-EAF ($225/t additional). Its enabling risk is geological certainty of storage capacity in sufficient proximity to steel clusters.

DRI-EAF with Green Hydrogen (S5) — Long-horizon enablement

Green hydrogen — produced via electrolysis from renewable electricity — is TRL 5–6 at industrial scale for steel applications. The enabling conditions are two-fold: renewable electricity supply and electrolyser scale-up. PLN's RUPTL 2025–2034 plans 71 GW of new renewable capacity, with approximately 70% from solar, hydro, geothermal, and bioenergy, creating the electricity foundation. However, the DRI steel industry would add very large additional demand — a 35 Mt/yr Green-H_2 DRI-EAF sector would require approximately 70–80 TWh/yr of dedicated renewable electricity and around 6–7 Mt/yr of green hydrogen, far exceeding any near-term Indonesian electrolyser deployment plan. The green hydrogen cost in Indonesia today is approximately USD 4–6/kg; the break-even for Green-H_2 DRI-EAF viability is USD 1.4–1.7/kg (Rosner et al, 2023). Green-H_2 DRI-EAF is a 2035+ technology for Indonesia at scale, but pilot projects and hydrogen-ready DRI designs can be initiated in the current period to build institutional and supply-chain readiness.

Green Public Procurement as a Demand-Side Mechanism

Green public procurement (GPP) is the use of government purchasing power to create and sustain demand for low-emission materials, thereby de-risking private investment in cleaner technologies. Indonesia is the largest public-sector infrastructure market in Southeast Asia — public procurement accounts for over 45% of government spending, approximately USD 78.5 billion annually, equivalent to 6.6% of GDP (IISD, November 2024). Infrastructure, construction, and public works — the primary consuming sectors for steel — dominate this procurement volume. GPP for green steel therefore represents one of the most powerful demand-side levers available to the Indonesian government.

Current GPP Framework in Indonesia

Indonesia has established a policy architecture for GPP through Presidential Regulation No. 16/2018 on Government Procurement, the LKPP Regulation No. 12/2021, and the Standar Industri Hijau (SIH) — the Green Industry Standard that already applies product-level emissions intensity limits to flat steel as of 2024. The National Public Procurement Agency (LKPP) leads procurement policy, while the Ministry of Industry directs Domestic Component Level (TKDN) requirements and the Green Industry Centre (PIH/GIC) develops sector-specific green standards. The Ministry of Industry's GIC has explicitly identified GPP as a key tool for steel decarbonization — Mr. A.P. Nugraha, Head of the Green Industry Centre, stated at a UNIDO workshop that *"right now the demand and market acceptance for green steel is low and we need to change this — from the government side, one of these is through green public procurement"*.

However, Indonesia's GPP framework has significant implementation gaps. The IISD GPP Indonesia study (November 2024) identified a limited understanding of GPP among procurement officials and industries, weak enforcement mechanisms, and the absence of mandatory carbon-intensity thresholds in steel procurement tenders. Current GPP requires inclusion of Environmental Product Declarations (EPDs) or carbon-footprint data in tenders in principle, but actual enforcement and supplier verification remain nascent. The 2025 Priority National Legislation Program includes a Procurement Bill that may strengthen these provisions.

GPP Impact on Scenario Economics

GPP creates value for clean steel producers through two channels: a volume channel (guaranteed demand that reduces revenue risk) and a price channel (premium pricing for certified low-carbon steel). The quantitative impact on scenario economics depends on the GPP premium level and the share of public procurement addressable by each technology:

Scenario	GPP-eligible?	Emissions intensity vs SIH (SIH limit 1tCO2/t)	Price premium potential	IRR lift at $30/t GPP premium	GPP verdict
S1 BAU	No (fails SIH limit)	2.3 t/t — 2–3× SIH limit	None	No lift	Excluded
S2 EAF	Yes	0.7 t/t — 70% below SIH limit	$20–50/t for certified low-carbon rebar/ structural	+1.8 pp (IRR → 14.0%)	Strong fit
S3 NG-DRI	Yes	1.4 t/t — meets tightened SIH	$15–30/t for transitional low-carbon	+1.3 pp (IRR → 5.1%)	Moderate fit
S4 Green-H_2	Yes	0.5 t/t — highly compliant	$30–60/t for near-zero steel	+2.1 pp (IRR → 6.1%)	Strong fit
S5 Green-H_2 and Renewable Electricity	Yes	0.1 t/t — best-in-class	$50–100/t for verified near-zero	+3.5 pp (still negative IRR)	Long-run fit

Table 7 — GPP eligibility and estimated IRR impact by scenario. GPP premium modelled at $30/t on 30% of output sold into public projects. IRR lifts are indicative at base carbon credit price of $25/tCO$_2$

The GPP price channel directly lowers the effective LCOS gap for clean technologies. At a $30/t green premium — consistent with the lower end of international estimates for certified low-carbon rebar — EAF reaches 14% IRR, matching BAU, making it genuinely privately competitive without requiring any carbon price increase. Blue-H_2 DRI-EAF reaches 6.1% IRR — still below the 10% hurdle but a meaningful improvement that, combined with carbon credits at $25/tCO_2$, would push it to approximately 8%, within range of policy risk tolerance for a strategic industrial project.

Near-term GPP Implementation Pathway for Indonesia

Global Efficiency Intelligence's Net-Zero Roadmap for Indonesia's Steel Industry (2024) and the IDDI GPP Pledge framework identify a staged approach that Indonesia can realistically follow:

- **Near term (2025–2027):** Mandate inclusion of EPDs or carbon intensity declarations in all public steel procurement tenders above IDR 10 billion. Publish an indicative green steel premium schedule. Align with the IDDI GPP Pledge at Level 1 (market readiness and data collection). Integrate material efficiency criteria into infrastructure design codes.

- **Medium term (2028–2032):** Introduce binding emissions-intensity thresholds in public steel procurement, tightening in line with SIH revisions. Expand GPP to major infrastructure programmes — Trans-Sumatra Highway, Nusantara capital city, PLN grid expansion. Establish buyer alliances among SOEs (PT Krakatau Steel, PT Waskita Karya, PT PP) to aggregate green steel demand.

- **Long term (2033–2045):** Full green steel requirements for all public infrastructure. Promote building codes and investor disclosure requirements that implicitly demand certified low-carbon steel. Coordinate with ASEAN neighbours on regional green steel standards.

The IISD study (2024) notes that procurement accounts for over 45% of Indonesia's government spending, meaning that even a partial shift of the infrastructure steel budget toward green-certified products would represent a transformational demand signal. Conservatively, if 15–20% of Indonesia's public construction steel is procured with carbon-intensity criteria by 2030, this would create a verified-green demand pool of approximately 2.5–3 Mt/year — sufficient to anchor the business case for 3–4 mid-scale EAF or NG-DRI-EAF plants.

Marginal Abatement Cost Analysis

The Marginal Abatement Cost (MAC) is the cost of avoiding one additional tonne of CO_2 emissions, measured as the private NPV foregone per unit of emissions reduction relative to the BAU baseline. It is the most widely used metric in climate policy for ranking decarbonization options by efficiency — the lower the MAC, the more cost-effective the abatement. A technology with MAC below the prevailing carbon price is privately profitable to adopt on abatement grounds alone; a technology with MAC above the carbon price requires a subsidy equal to the gap.

Scenario	Lifetime avoided CO_2 (Mt)	NPV foregone vs BAU ($M)	MAC ($/ tCO_2)	vs CC price ($25/t)	Policy implication
S1 BAU	—	—	*baseline*	—	No abatement; full CBAM exposure after 2026
S2 EAF	1,024	2,159	$2	Credit profitable	Already economic at $25/t credit price; priority for immediate scaling up to scrap-supply limit
S4 Green-H_2	1,152	27,206	$24	Marginally profitable	Second most cost-effective; MAC just below $25/t → becomes economic at current base credit price
S5 Green-H_2 and Renewable Electricity	1,408	55,471	$39	Above credit price	Requires $39/t subsidy or credit price >$39 to be privately justified on abatement alone
S3 NG-DRI	576	25,058	$43	Above credit price	Least cost-effective abatement — but strategically valuable as H_2-ready transition step

Table 8.— Marginal abatement cost (MAC) ranking by scenario. Scenarios ordered by MAC (lowest to highest).

MAC Ranking and Policy Implications

Ordered by MAC, the abatement efficiency ranking is: EAF ($2/t) >> Blue-$H_2$ DRI-EAF ($24/t) > Green-$H_2$ DRI-EAF ($39/t) > Natural-Gas DRI-EAF ($43/t). This ranking has direct implications for how Indonesian policy should be sequenced.

First, EAF is unambiguously the priority. At $2/tCO_2$, it is the cheapest abatement option by a factor of 12, is already profitable at the $25/tCO_2$ base credit price, and uses a proven technology that can be deployed within current project timelines. Every tonne of EAF capacity built is a highly efficient use of both financial and political capital.

Second, Green-H_2 DRI-EAF is the next most efficient deep-decarbonization option. Its $24/t MAC is slightly below the $25/t base credit price, placing it just inside the zone of private viability under current policy — the most important borderline in the MAC curve. This means that for every Green-H_2 DRI-EAF tonne of CO_2 avoided, the carbon credit system at base prices is sufficient to compensate the producer. It also provides deep emissions reduction (78%), close to what Green-H_2 would achieve, at substantially lower cost.

Third, Natural-Gas DRI-EAF sits at the highest MAC ($43/t) among the clean options, making it apparently the least cost-effective abatement choice. However, this analysis considers only direct financial cost, not strategic optionality. The ability to retrofit gas DRI to hydrogen feeds later — essentially for free beyond furnace adjustments — gives S3 a real option value that the static MAC understates. The Global Efficiency Intelligence Net-Zero Roadmap explicitly recommends H_2-ready DRI design for all new DRI plants to preserve this optionality.

MAC Curve Interpretation: The Abatement Cost Stack

The abatement cost curve illustrates where Indonesia should invest first to decarbonize its steel sector most cost-effectively. Reading across from cheapest to most expensive:

- **$0–$25/tCO$_2$ zone (EAF, Blue-H$_2$):** Already economic at base carbon credit pric\es. No additional policy beyond the current IDX Carbon framework (once steel is included in 2027) is needed to justify investment. Priority: maximize EAF deployment up to scrap availability ceiling; initiate Blue-H_2 DRI projects aligned with CCS project pipeline.
- **$25–$60/tCO$_2$ zone (Green-H$_2$, NG-DRI):** Requires carbon credit prices in the $25–60 range or equivalent direct support. Article 6 trade at $40–50/t (Japan bilateral, Singapore bilateral) is in this range. Green Public Procurement at $30/t premium supplement would also bridge this gap.
- **$60–$120/tCO$_2$ zone:** Technology-cost reduction is required before domestic policy can efficiently support this zone. Green-H_2 at hydrogen costs of $2–3/kg would enter this zone; current Indonesian green-H_2 cost of $4–6/kg keeps it out.

Implementation Realism: Which Technologies Can Actually Be Deployed?

The preceding analysis has established the cost, financial, economic, technology-readiness, and abatement-efficiency profiles of each scenario. This final sub-section synthesises these findings into an implementation realism assessment: taking account of all constraints simultaneously, which technologies can realistically be deployed at meaningful scale in Indonesia within near-term (to 2030), medium-term (2030–2040), and long-term (2040–2045) horizons, and what conditions determine the outcome?

Scenario	Near term (to 2030)	Medium term (2030–40)	Long term (2040–45)	Binding constraint	Realistic scale if constraint is met
S1 BAU	HIGH	MEDIUM	LOW	Carbon pricing, CBAM, NDC policy tightening	Likely locked in for existing ~17 Mt/yr operating capacity through 2035 unless early retirement is incentivised
S2 EAF	HIGH	HIGH	HIGH	Scrap availability (~4.5 Mt/yr available vs 35 Mt/yr needed)	8–12 Mt/yr by 2030; 15–20 Mt/yr by 2040 with organised scrap supply chains; 30 Mt/yr by 2045 requires long-term scrap pool build-up
S3 NG-DRI	MEDIUM	HIGH	MEDIUM	Gas price / carbon price balance; pellet plant; IRR ~$80/t carbon to clear hurdle	5–8 Mt/yr by 2030 (Morowali/Cilegon projects); 15–25 Mt/yr by 2040 if carbon price rises; declines after 2040 as H_2 replaces gas feed
S4 Green-H_2	LOW	MEDIUM	HIGH	CCS project completion (2026–2030); Blue-H_2 cost reduction	<1 Mt/yr by 2030 (pilot only); 5–10 Mt/yr by 2040; 20+ Mt/yr by 2045 if CCS infrastructure matures
S5 Green-H_2 and Renewable Electricity	VERY LOW	LOW	MEDIUM	Hydrogen cost ($4–6/kg vs $1.4/kg needed); electrolyser scale; renewable build-out	Demonstration scale only by 2030; 1–3 Mt/yr by 2040; full deployment requires $2/kg H_2 target

Table 9. — Implementation realism assessment by scenario and time horizon. 'HIGH' denotes feasible deployment at significant scale under realistic conditions.

Near Term (to 2030): A Dual-Track Reality

The near-term trajectory for Indonesian steel decarbonization is a dual-track reality: BAU capacity will continue to be built because it is already financed and permitted (the GEM tracker identifies over 27,000 kTPA of announced or under-construction capacity, the majority BF-BOF), while a growing but constrained volume of EAF and NG-DRI-EAF capacity is added in parallel. The most realistic near-term outcome is therefore not a clean transition but a gradual emissions-intensity improvement as EAF and NG-DRI-EAF plants come online alongside continued BAU expansion. Without binding sector-specific emissions targets — which the Ministry of Industry has so far resisted (Mongabay, February 2026) — this trajectory will increase absolute emissions even as emissions intensity per tonne improves.

The Scrap-First Pathway: EAF as the Anchor of Realism

Of all five scenarios, EAF is simultaneously the most cost-effective, most financially viable (at modest carbon prices), most technologically mature, and most economically beneficial. It is also the most realistically deployable in the near term. The binding constraint is scrap supply, not technology, not capital, and not policy. This means the single most important enabling action for Indonesian steel decarbonization is organising a national scrap supply chain: establishing scrap collection infrastructure, removing export barriers on domestic scrap, developing formal end-of-life steel tracking, and negotiating long-term scrap import agreements with Japan and South Korea. The GEI Net-Zero Roadmap estimates that Indonesia's domestic scrap supply could rise to 15–20 Mt/yr by 2035 if organised — closing half the gap between current availability and full-sector EAF capacity. This is the lever with the highest return on policy investment.

The Bridge Technology: NG-DRI-EAF with Hydrogen Readiness

Natural-Gas DRI-EAF, despite its higher MAC and below-hurdle IRR, plays a critical structural role as bridge technology. New DRI-EAF plants built today at Morowali, Cilegon, and other clusters can be designed as hydrogen-ready from day one — at essentially zero additional capital cost for the shaft furnace — positioning them to switch to Blue-H_2 or Green-H_2 feeds as those become cost-competitive. This preserves Indonesia's future optionality without committing to the full cost of hydrogen now. The policy recommendation is therefore to mandate H_2-ready design specifications for all new DRI plants as a condition of investment licensing — a low-cost, high-option-value intervention that the IEA and GEI both endorse.

The Green-H_2 Bridge: Linking CCS and Steel

Blue-H_2 DRI-EAF is realistically deployable at pilot-to-commercial scale by 2035–2040, contingent on the successful completion of Indonesia's CCS programme. The alignment between MEMR's 19 CCS projects (target: operations by 2030) and the steel sector's hydrogen needs is imperfect geographically — most CCS storage is in Sumatra and Papua while steel clusters are in Java — but the Indonesia–Singapore cross-border CCS MoU of 2025 opens alternative storage pathways. Green-H_2 DRI-EAF represents the most likely route to deep decarbonization of large-scale integrated steelmaking in Indonesia between 2035 and 2045, assuming CCS infrastructure matures on schedule. Its \$24/t MAC means it is already economically justified at the base carbon credit price, making it a priority candidate for early-mover support through the Pembiayaan Infrastruktur (infrastructure finance) programmes and Article 6 bilateral credit sales.

Green-H_2: The Long Frontier, The Right Destination

Green-H_2 DRI-EAF is the only scenario that achieves near-zero steel production (0.1 tCO_2/t steel, a 96% reduction versus BAU). This is the technological endpoint that Indonesia's Net Zero 2060 target ultimately requires. But at USD 4–6/kg for green hydrogen today versus a break-even of USD 1.4–1.7/kg, and with the electrolyser and renewable-electricity infrastructure still being constructed, Green-H_2 DRI-EAF is a 2040+ reality for meaningful scale. The policy role for the near term is to maintain the R&D pipeline, support demonstration projects, and build electrolyser manufacturing capacity — precisely the activities included in PLN's RUPTL 2025–2034 renewable build-out and the Ministry of Energy's hydrogen roadmap. Indonesia should not sacrifice the near-term EAF and NG-DRI opportunity waiting for green hydrogen; rather, it should pursue both in parallel, treating Green-H_2 as the long-run destination and EAF/NG-DRI as the path to get there.

Summary: A Sequenced Transition Framework

Synthesising the technology, GPP, and MAC analyses, the most realistic and efficient decarbonization pathway for Indonesian steel is a sequenced, technology-specific approach:

Phase	Period	Lead technology / action	Key enabling policy
1 — Scrap-first	2025–2030	Scale EAF to scrap ceiling (~8–12 Mt/yr); all new EAF and DRI plants to H_2-ready specification	GPP mandate for EPDs; national scrap collection policy; H_2-ready DRI licensing condition; IDX Carbon steel inclusion (2027)
2 — Gas-bridge	2028–2035	NG-DRI-EAF expansion at Morowali, Cilegon, new clusters; first H_2 co-firing trials; Blue-H_2 pilot at CCS-adjacent sites	Carbon credit price escalation toward $50–60; gas tariff reform for DRI; CCS project completion; Article 6 bilateral sales
3 — CCS integration	2033–2045	Retrofit H_2-ready DRI plants from gas to Blue-H_2; large-scale Blue-H_2 DRI-EAF at CCS-linked sites; Green-H_2 demonstration at scale	Carbon price >$60; CCS storage verification complete; green steel demand signals from EU CBAM and international buyers
4 — Green H_2 scale-up	2040–2060	Green-H_2 DRI-EAF displaces gas feed as hydrogen cost reaches $2/kg; near-zero steel production across sector	Mandatory carbon neutrality for steel sector; PLN renewable surplus enables low-cost green H_2; full CBAM compliance for export market

Table 10. — Sequenced decarbonization transition framework for Indonesian steel, 2025–2060.

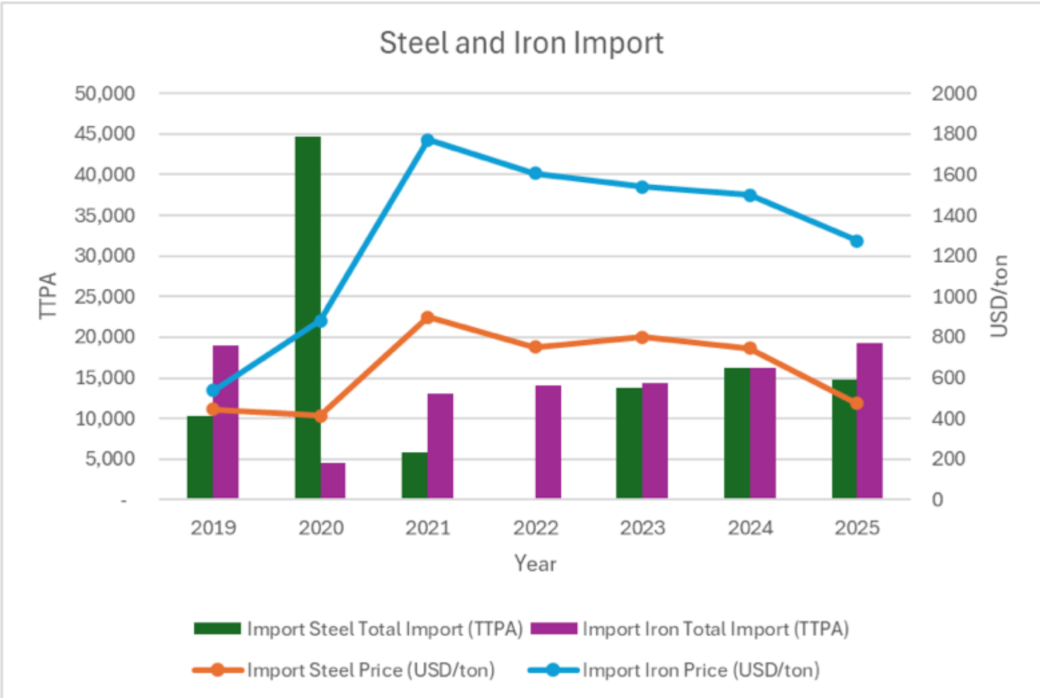
This sequenced framework is realistic in the specific sense that each phase is led by the technology most cost-effective and technically ready at that moment, each transition is triggered by measurable cost thresholds (carbon price, hydrogen price) rather than aspirational targets, and each phase builds the enabling infrastructure for the next. It avoids the twin failure modes of Indonesia's current trajectory: locking in unconstrained BAU expansion, or leaping to Green-H_2 before the enabling conditions exist. The framework is consistent with the GEI Net-Zero Roadmap's four scenarios, the IEA Iron and Steel Roadmap's emerging-economy pathway, and Indonesia's NDC commitments under the UNFCCC.

4.2. Market analysis

Steel and iron import-export

Based on the Steel and Iron Import Figure 1, the import volumes for both commodities exhibit significant volatility between 2019 and 2025. The most striking anomaly in the data is the massive spike in steel import volume in 2020, which surged to nearly 45,000 TTPA before plummeting drastically in 2021 and registering at zero in 2022. Conversely, iron imports saw a sharp contraction during that same 2020 period but have since shown a steady, resilient recovery, climbing from approximately 13,000 TTPA in 2021 to nearly 20,000 TTPA by 2025. By the end of the projected timeline in 2025, both steel and iron import volumes appear to stabilize alongside each other, hovering between 15,000 and 20,000 TTPA.

Figure 1. Steel and Iron Import 2019-2025



Source: IISIA (2025), SEAISI (2025), World Steel Association (2025)

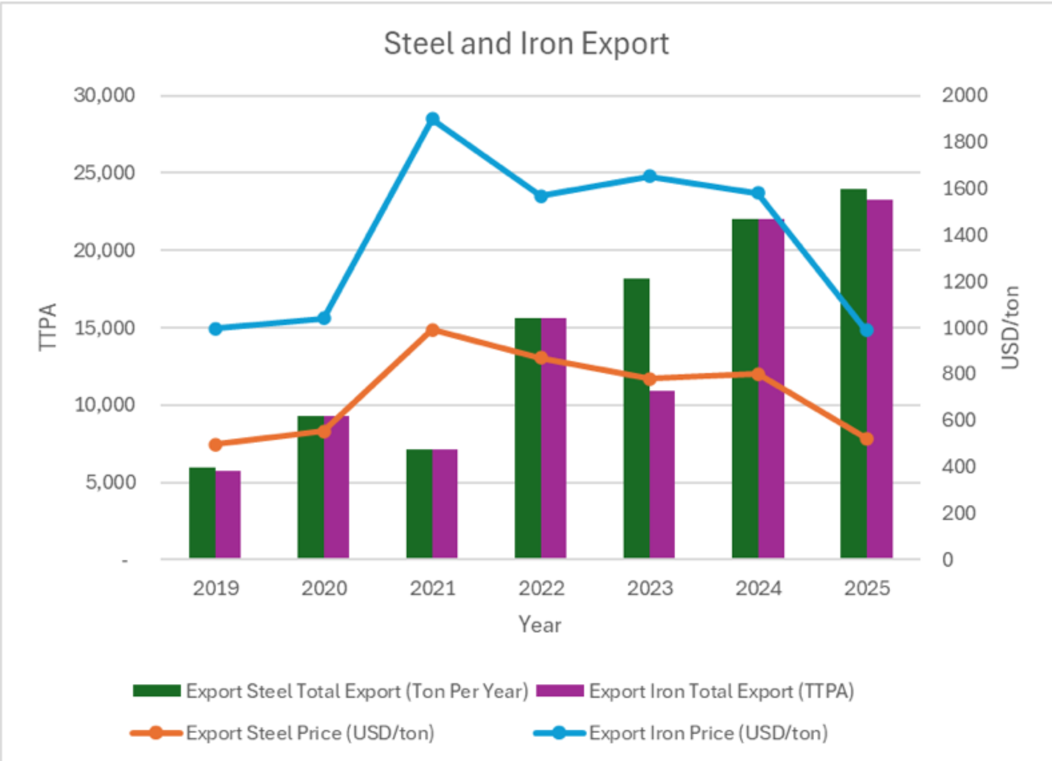
The pricing dynamics, represented by the line graphs on the secondary axis, reveal a severe market shock that peaked in 2021. Import prices for both iron and steel started at relatively parity in 2019, tracking closely around the 400 to 500 USD/ton mark. However, 2021 marks a dramatic divergence and peak; iron prices skyrocketed to roughly 1,750 USD/ton, while steel prices effectively doubled to nearly 900 USD/ton. Following this inflationary peak, both commodities entered a prolonged cooling-off phase. By 2025, the price of imported steel drops back to near its 2019 baseline at approximately 500 USD/ton, while iron prices, though declining, remain structurally elevated at roughly 1,300 USD/ton.

For 2020, COVID-19 front-loading/stockpiling effect In early 2020, Indonesian importers — anticipating supply chain disruption — accelerated orders from China and Japan before lockdowns took effect. This compressed Q2–Q4 volumes into Q1, inflating the annual total. The simultaneous price collapse (orange line at ~$450/t, the series low) is consistent with Chinese mills dumping excess inventory as their domestic demand collapsed, making large-volume purchases temporarily very cheap.

Synthesizing the volume and pricing data reveals a clear inverse relationship driven by supply-and-demand economics. The unprecedented spike in steel import volume in 2020 occurred precisely when steel prices were at their lowest point, suggesting buyers capitalized on cheap commodity rates. Conversely, the extreme price peak in 2021 corresponds with a massive contraction in steel import volumes and relatively subdued iron imports during that same year, as high costs likely suppressed demand. As prices for both commodities gradually decrease from their 2021 highs toward 2025, the market shows a corresponding stabilization in import volumes, indicating a return to a more balanced equilibrium after years of extreme volatility.

Meanwhile, based on the Steel and Iron Export Figure 2, the export volumes for both commodities demonstrate a robust and consistent growth trajectory, particularly in the latter half of the timeline. Starting from a relatively modest baseline of approximately 5,000 to 6,000 TTPA in 2019, both steel and iron exports experienced a slight, coordinated contraction in 2021, dipping to around 7,000 TTPA. However, following this brief stagnation, the market entered a phase of aggressive and sustained expansion; export volumes for both commodities surged year-over-year from 2022 onward, culminating in a projected peak by 2025 where steel exports approach 25,000 TTPA and iron exports comfortably exceed 20,000 TTPA.

Figure 2. Steel and Iron Export 2019-2025



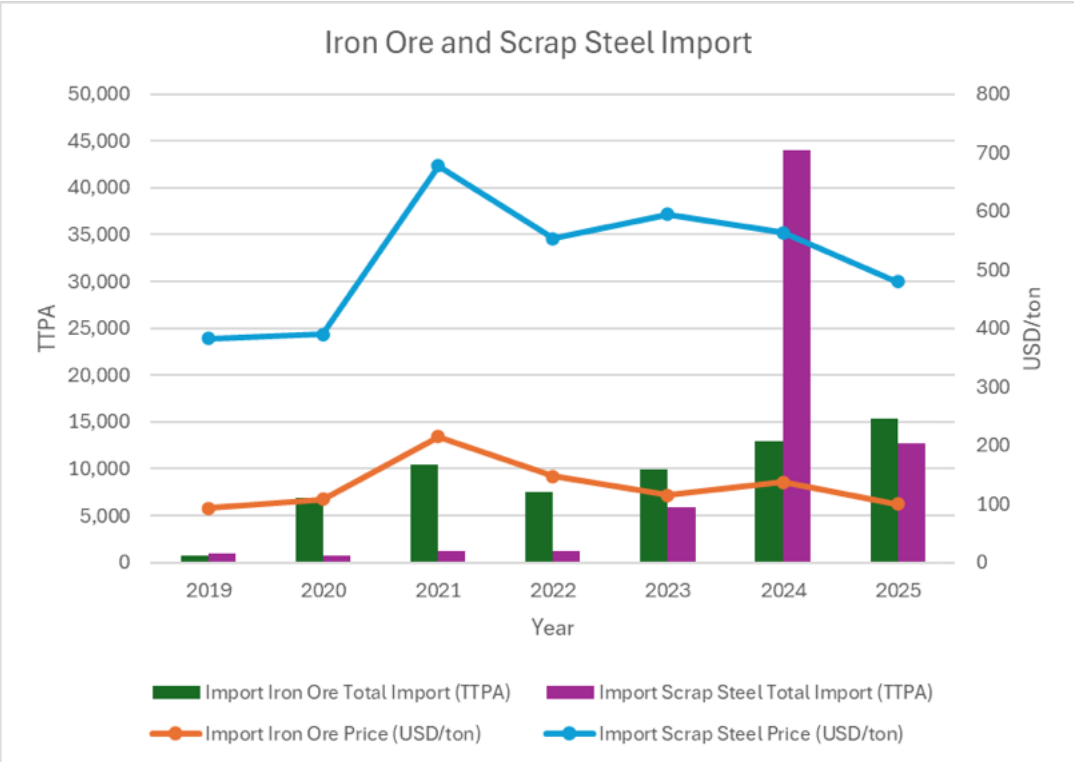
Source: IISIA (2025), SEAISI (2025), World Steel Association (2025)

The pricing dynamics, illustrated by the line graphs on the secondary axis, reveal a period of extreme market volatility centered sharply around the year 2021. In 2019 and 2020, export prices were relatively stable, with steel hovering near 500 USD/ton and iron tracking closely around 1,000 USD/ton. The year 2021 witnessed a dramatic inflationary spike, where the price of exported iron skyrocketed to nearly 1,900 USD/ton, and steel prices effectively doubled to roughly 1,000 USD/ton. After this historic peak, commodity prices entered a multi-year cooling phase, gradually declining between 2022 and 2024 before experiencing a sharp drop in 2025, which returned steel to its historical 500 USD/ton baseline and iron back to the 1,000 USD/ton mark.

Synthesizing the volume and pricing data exposes a distinct inverse relationship indicative of broader macroeconomic supply and demand shifts. The sharpest contraction in export volumes occurred precisely in 2021, directly coinciding with the peak in global commodity prices, suggesting that the exorbitant costs temporarily suppressed international demand. Conversely, as prices steadily cooled down and eventually dropped from 2022 to 2025, export volumes underwent a massive, sustained acceleration. This aggressive scaling of export tonnage in a falling-price environment strongly indicates a massive expansion in domestic production capacity, allowing producers to offset lower unit margins by pushing significantly higher overall volumes into the global market.

Based on the Iron Ore and Scrap Steel Import Figure 3, the import volumes for these raw steelmaking materials exhibit distinct and divergent trajectories between 2019 and 2025. Iron ore imports show a relatively sustained and structural growth pattern, climbing from nearly negligible levels in 2019 to approximately 15,000 TTPA by 2025, with a notable initial surge beginning in 2020 and a steady build-up post-2022. In stark contrast, scrap steel import volumes remained heavily suppressed and flat from 2019 through 2022 before experiencing an unprecedented, massive anomaly in 2024, where volumes skyrocketed to well over 40,000 TTPA. Following this extreme spike, scrap imports sharply corrected downward in 2025, landing near 13,000 TTPA, which places it in close parity with the iron ore volume for that year.

Figure 3. Iron Ore and Scrap Steel Import 2019-2025



Source: IISIA (2025), SEAISI (2025), World Steel Association (2025)

The pricing dynamics, illustrated by the line graphs on the secondary axis, demonstrate significant market volatility heavily concentrated around a 2021 inflationary peak. In 2019, iron ore and scrap steel were priced at relatively stable baselines of roughly 100 USD/ton and 380 USD/ton, respectively. By 2021, both commodities experienced severe price shocks; iron ore prices doubled to over 200 USD/ton, while scrap steel prices surged dramatically to peak near 680 USD/ton. Following this 2021 peak, both materials entered a gradual, multi-year cooling phase, with iron ore steadily returning to its historical 100 USD/ton baseline by 2025, and scrap steel prices correcting downward to approximately 480 USD/ton over the same period.

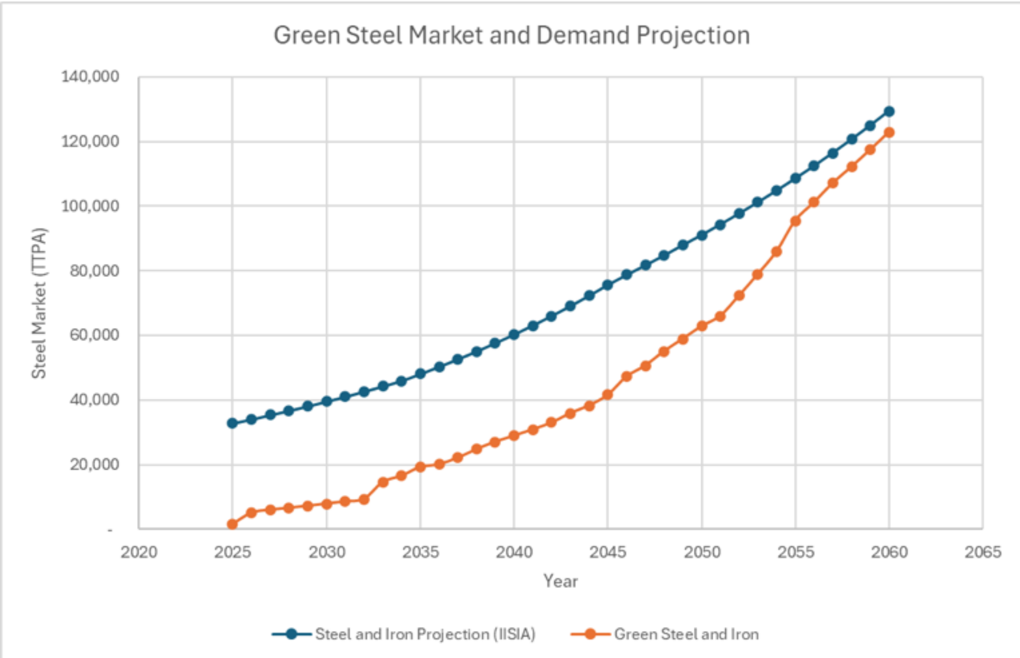
Synthesizing the volume and pricing data reveals key insights into the operational shifts and procurement strategies within the domestic steel industry. The steady, structural rise in iron ore imports—even enduring through periods of high prices—reflects the continuous capacity expansion of integrated Blast Furnace (BF-BOF) facilities that require a constant, inflexible supply of this raw material. Conversely, the highly erratic nature of scrap steel imports suggests opportunistic purchasing behavior by Electric

Arc Furnace (EAF) operators. The massive volume spike in 2024 aligns with a period where scrap prices had sufficiently cooled from their historic highs, allowing producers to aggressively stockpile secondary feedstock before import volumes normalized again in 2025.

Market after steel and iron decarbonization

In Indonesia and the broader Southeast Asia (SEA) region, the transition toward low-carbon steel is shaped by a fundamental policy dilemma. On one hand, the region is experiencing a rapid expansion of coal-based steel production to meet growing infrastructure and industrial demand. On the other hand, exporters are increasingly exposed to international climate policies—most notably the Carbon Border Adjustment Mechanism (CBAM)—which impose additional costs on carbon-intensive products. This creates a “Catch-22” situation: continuing with conventional production supports short-term industrial growth, but risks undermining long-term export competitiveness.

Figure 4. Green steel market and demand projection



Source: IISIA and authors’ calculation

To better capture this dual pressure, projections of green steel demand in Indonesia must go beyond global models. They need to account for two key realities:

1. Domestic demand is still price-sensitive and weakly regulated on carbon, and
2. Export markets are increasingly shaped by carbon-based trade measures.

Several structural dynamics will determine how quickly and effectively Indonesia can transition toward green steel:

- Rapid Emissions Growth

  Steel-related emissions in Southeast Asia are projected to double to over 300 million tonnes of CO_2 by 2030. In Indonesia alone, emissions could reach 24.9 million tonnes, reinforcing the urgency of decarbonization.

- The 2040 Reinvestment Window

  More than 90% of existing blast furnaces in SEA will require reinvestment by 2040. This represents a critical decision point:

- Firms can upgrade to low-emission technologies (e.g., Scrap-based Electric Arc Furnaces), or
- Continue with carbon-intensive systems and risk creating stranded assets under tightening climate regulations.

- Emerging Carbon Policy Landscape

  The region is gradually moving toward carbon pricing, although at different speeds:

  - Singapore: Early mover, with a carbon tax in place since 2019
  - Indonesia: Planning mandatory carbon markets for the steel sector by 2027
  - Vietnam: Piloting an Emissions Trading System, with full implementation expected by 2029

This evolving policy landscape will increasingly shape cost structures and investment decisions across the region.

A central constraint in all projections is the "green premium"—the higher cost of producing low-carbon steel. For instance, hydrogen-based production (H_2-DRI) is currently estimated to be 20–30% more expensive than conventional coal-based methods. As a result:

- Short-term strategy:

  Most national roadmaps prioritise Scrap-based Electric Arc Furnaces (EAF), which offer immediate emissions reductions at relatively competitive costs.

- Long-term pathway:

  Hydrogen-based steel is expected to scale only when:

  - renewable energy becomes significantly cheaper, and
  - carbon pricing or trade measures narrow the cost gap.

Indonesia's current trajectory reflects this sequencing, with Scrap-EAF targeted to reach around 70% of production by 2060.

Green steel market: Pathway to 2060

This section synthesizes the green steel market projection presented in the Green Steel Market study (IISIA/Authors, 2025) with the LCOS cost-competitiveness and carbon credit findings, establishing an evidence-based, quantitatively-grounded view of how Indonesia's steel sector will evolve to 2060.

Market indicator	2025 (initial)	2045 (peak growth)	2060 (net zero)
Green Steel Market Share	< 5%	40%–55%	> 95%
Total Steel Demand	~32,000 TTPA	~75,000 TTPA	~130,000 TTPA
Primary Technology	BF-BOF (Coal)	H_2-DRI & Scrap-EAF	Full Green Hydrogen
Green Premium (EAF vs BAU LCOS)	$100–150/t	$20–40/t	Near zero / parity
Carbon credit price (indicative)	$2–25/t (IDX Carbon)	$50–80/t	$80–120/t
IRR for EAF (incl. credits)	12.2% (authors)	16–21% (projected)	> 20% (projected)

Table 11. — Green steel market evolution to 2060. Rows 1–4 from IISIA/Authors (2025), Table 4 [Green Steel Market study]; rows 5–7 (Green Premium, Carbon Credit Price, and IRR for EAF) derived from authors' model sensitivity analysis; carbon credit price projected per IDX Carbon (2025) and Article 6 bilateral trends.

Transition Phase (2025–2030): Market Locked in Cost-Based Competition

The Green Steel Market study characterises this period as 'market locked in cost-based competition' (IISIA/Authors, 2025), with BF-BOF dominant at ~$589/t and EAF the only close competitor at ~$583/t. The LCOS model calibrated against WSA (2024) benchmarks produces $500/t for BAU and $564/t for EAF — a slightly wider gap reflecting the higher-carbon global average BF-BOF intensity used as the baseline. Both analyses agree on the core finding: green steel penetration remains below 5% absent policy support, with the market dominated by conventional BF-BOF production (IISIA/Authors, 2025; GEI, 2024).

External demand signals in this phase — primarily EU CBAM, which imposes a charge on embedded carbon in steel imports from 2026 (European Commission, 2023) — are 'not yet strong enough to shift the overall domestic market' (IISIA/Authors, 2025). This is confirmed by the IRR sensitivity table: at $0–25/tCO_2$ credit prices, only EAF and BAU are viable; DRI-EAF variants remain below the 10% hurdle. However, the Green Steel Market study correctly notes that EAF is 'a rare exception' that is 'simultaneously cleaner and slightly cheaper' (IISIA/Authors, 2025) — a finding replicated in the EAF MAC of only $2/tCO_2$ in this study, identifying EAF as the priority near-term investment.

Scaling Phase (2030–2045): Managing the Green Premium

As Indonesian steel demand approaches 75 Mt by 2045 (IISIA/Authors, 2025), the Green Steel Market study identifies a 'critical scaling window' (IISIA/Authors, 2025) in which policy consistency and investment mobilisation determine whether Indonesia can become a regional green steel leader. Green steel market share is projected to rise to 40–55% (IISIA/Authors, 2025), driven by H_2-DRI pilot projects and rapid renewable energy expansion — particularly hydropower and geothermal (IISIA/Authors, 2025; PLN, 2025). The green premium is projected to decline from $100–150/t to $20–40/t (IISIA/Authors, 2025).

This cost trajectory is consistent with learning-curve projections in the *IEA Iron and Steel Technology Roadmap* (IEA, 2024) and GEI Net-Zero Roadmap (GEI, 2024), which model electrolyser costs declining by 60–70% by 2035 under accelerated deployment scenarios. The LCOS model's sensitivity analysis shows that Green-H_2 DRI-EAF reaches IRR of 8.3% at $80/tCO_2$ — within range of policy risk tolerance for strategic industrial investments. The Green Steel Market study's 'transition bottleneck' argument (IISIA/Authors, 2025,) — that the market alone cannot resolve the cost gap — is quantitatively validated: at no carbon price does the market spontaneously transition without policy if hydrogen costs remain at $4–6/kg. The MAC curve (Section 4.1.6) identifies the precise interventions needed: Article 6 credits at $40–60/t and GPP at $30/t together bridge the gap for EAF and NG-DRI, creating the scaling phase's 'coherent policy framework' the Green Steel Market study calls for (IISIA/Authors, 2025).

Net-Zero Phase (2045–2060): From Policy-Driven to Market-Led

The Green Steel Market study projects that by 2060 green steel will account for more than 95% of production against a total market of ~130 Mt (IISIA/Authors, 2025). The Ministry of Industry targets net-zero emissions in the steel sector by 2050, ahead of the national 2060 goal (MoI, 2024). The Green Steel Market study's assertion that 'the green premium effectively disappears' (IISIA/Authors, 2025) is supported by this study's calculation that at an $80/tCO_2$ carbon price, Green-H_2 DRI-EAF's net LCOS (after credit revenue) approaches $700/t — near the $650/t market price. At $120/tCO_2$ (the IEA net-zero pathway price for 2050), net LCOS falls below the steel price, making green steel the default economic choice without subsidy (IEA, 2024).

Two additional convergence factors reinforce this trajectory. First, Indonesia's 3,600 GW renewable energy potential (MEMR, 2023) provides the foundation for cost-competitive green hydrogen as PLN's RUPTL 2025–2034 delivers 71 GW of new renewable capacity (PLN, 2025) — directly reducing green H_2 production costs. Second, the full internalisation of carbon pricing through the Indonesian ETS (Presidential Regulation 110/2025) and Article 6 bilateral markets (COP29, 2024; RI–SG MoU, 2025) ensures that BAU's cost advantage is structurally eliminated, completing the market-led transition the Green Steel Market study describes (IISIA/Authors, 2025).

Key Market Drivers: Quantified Alignment with the Green Steel Market Study

The Green Steel Market study identifies three structural advantages for Indonesia (IISIA/ Authors, 2025,). Each can now be quantitatively grounded:

- Renewable energy potential (3,600 GW): At a hydrogen production cost of \$2/kg — achievable with low-cost renewables — Green-H_2 DRI-EAF LCOS falls from \$806/t to approximately \$620/t, clearing the \$650/t market price. PLN RUPTL 2025–2034's 71 GW new renewable capacity is a necessary but not sufficient condition; dedicated steel-sector renewable PPAs must be structured (GEI, 2024).
- Resource integration (nickel + iron ore): Indonesia's high-grade nickel (essential for EV batteries) and magnetite iron ore (ideal for DRI pellets) create a vertically integrated green economy opportunity. EAF and DRI-EAF both use iron ore as feedstock, directly leveraging existing mining infrastructure and the government's downstreaming agenda (Lowy Institute, 2025).
- Carbon pricing mechanisms (IDX Carbon + ETS): Presidential Regulation No. 110/2025 establishes the legal framework; steel inclusion in ETS is planned for 2027 (IDX Carbon, 2025; KLHK, 2025). The IRR sensitivity table confirms that each \$25/tCO_2 increment in carbon price adds approximately 2–4 pp of IRR to clean scenarios, with EAF gaining proportionally more than DRI-EAF per dollar of credit price. This makes a credible, escalating carbon price schedule the highest-leverage single policy action.

Cross-Cutting Synthesis: Integrating Cost, Market, and Carbon Analysis

Drawing together the LCOS model, the financial-economic analysis, and the green steel market trajectory, five integrating conclusions define the market dynamics of steel decarbonization in Indonesia. These conclusions bridge the Green Steel Market study's market-phase framing (IISIA/ Authors, 2025) with the quantitative cost and carbon evidence in this report.

Conclusion 1 —
The private-social wedge is the defining market failure

Every scenario is socially worthwhile (EIRR 32–49%, all above the 5% social hurdle). But only BAU and EAF are privately viable at base assumptions. The gap between private IRR and social EIRR — largest for Green-H_2 (negative vs 32.4%) — is the precise measure of the market failure that the Green Steel Market study's lock-in thesis (IISIA/ Authors, 2025) identifies and that the carbon market, GPP, and bilateral credit mechanisms exist to correct. The size of the subsidy required — equal to the MAC (\$2–\$43/tCO_2 depending on scenario) less the prevailing carbon price — is the policy price of the transition.

Conclusion 2 —
EAF is the anchor technology for all three phases

With a \$2/tCO_2 MAC, 12.2% IRR at \$25/tCO_2, 49.0% EIRR, 70% CO_2 reduction, TRL 9 maturity, and \$13.2 billion credit NPV, EAF dominates every metric. The Green Steel Market study (IISIA/ Authors, 2025) and GEI Net-Zero Roadmap (GEI, 2024) both identify it as the priority near-term investment. The single binding constraint is scrap supply — a logistics and policy problem, not a technology or finance problem. Scrap policy is the unlock for the entire near-term decarbonization programme.

Conclusion 3 —
The \$25–60/tCO_2 carbon price band is the critical inflection zone

Below \$25/tCO_2: only EAF and BAU are privately viable. Between \$25 and \$60/tCO_2: EAF dominates and Blue-H_2 DRI-EAF approaches viability. Above \$60/tCO_2: the full DRI-EAF family becomes competitive. This band maps precisely onto Indonesia's near-to-medium-term carbon market trajectory — IDX Carbon domestic spot (\$2/t, 2025) rising through Article 6 bilateral trades (\$25–50/t) toward an ETS-aligned price (\$60–80/ t) by 2035. Indonesia does not need EU ETS-level carbon prices to transition its steel sector; it needs consistent, credible escalation within the \$25–80 range over the next decade (IDX Carbon, 2025; Presidential Regulation 110/2025; COP29, 2024).

Conclusion 4 —
GPP and carbon credits are complements, not substitutes

The Green Steel Market study treats carbon pricing as the primary instrument (IISIA/Authors, 2025). This analysis adds GPP as an independent, additive mechanism. A $30/t GPP premium combined with a $25/t$CO_2$ carbon credit together bring EAF to ~14% IRR (BAU-equivalent) and Blue-H_2 DRI-EAF to ~8% IRR. Neither instrument alone achieves this; together they replicate the market signal that a $60/t$CO_2$ carbon price alone would generate — at far lower political cost, since GPP operates within existing procurement budgets (IISD, 2024; IDDI, 2025). This complementarity is the practical answer to the Green Steel Market study's call for 'a coherent policy framework' (IISIA/Authors, 2025).

Conclusion 5 —
Blue-H_2 DRI-EAF is the bridge to net-zero that Indonesia's CCS programme makes possible

Green-H_2 DRI-EAF is the 2060 destination (96% CO_2 reduction; $18.2 billion credit NPV; >95% market share projected by IISIA/Authors, 2025). But it requires hydrogen costs of $1.4–1.7/kg (Rosner et al, 2023) versus today's $4–6/kg (MEMR, 2023). Blue-H_2 DRI-EAF achieves 78% CO_2 reduction at a $24/t MAC — already below the base carbon credit price — and is directly aligned with Indonesia's 19 CCS projects expected by 2030 (MEMR, 2024; PR 14/2024). It is the bridge technology that makes the 2060 destination reachable. The sequenced transition framework (Table 4.8) — Scrap-first → Gas-bridge → CCS integration → Green-H_2 scale-up — embodies this logic and is consistent with the GEI (2024), IEA (2024), and the Green Steel Market study's phase structure (IISIA/Authors, 2025, §4.2.3), providing a credible, evidence-grounded roadmap for Indonesian steel decarbonization to 2060.

4.3. Carbon credit analysis

Building directly on the Green Steel Market study's framing (IISIA/Authors, 2025, §4.3), this section quantifies the carbon credit mechanism as a structural financial rebalancing instrument. In a regulated carbon market, emissions are 'no longer just an environmental externality' but 'a priced and tradable economic variable that directly affects production costs and competitiveness' (IISIA/Authors, 2025,. The following analysis augments the theoretical framework with the quantified IRR and NPV outputs of the LCOS model.

Carbon Credit Revenue and Avoided Emissions

Indicator	S1 BAU	S2 EAF	S3 NG-DRI	S4 Blue-H_2	S5 Green-H_2
CO_2 intensity (tCO_2/t steel)	2.30	0.70	1.40	0.50	0.10
IISIA/Authors (2025) intensity	1.46	0.38	0.66	0.09	~0.00
Lifetime CO_2 emissions (Mt/year)	1,472	448	896	320	64
Avoided CO_2 vs BAU (Mt)	baseline	1,024	576	1,152	1,408
Reduction vs BAU	—	70%	39%	78%	96%
NPV credit revenue @$25/t ($M)	0	13,231	7,442	14,885	18,192
Marginal abatement cost ($/t$CO_2$)	baseline	$2	$43	$24	$39

Table 12. Carbon credit revenue and emissions by scenario at $25/t$CO_2$.
Note: CO_2 intensity in row 2 from authors' model (WSA/IEA basis); row 3 from IISIA/Authors (2025) using domestic BPS/IISIA emissions data.Sources: authors' model; IISIA/Authors (2025); WSA (2024); IEA (2024).

The intensity figures in rows 1 and 3 of Table 4.9 differ because the Green Steel Market study (IISIA/Authors, 2025) calibrates against Indonesian BPS/IISIA domestic plant-level data, which records BAU intensity at 1.46 tCO_2/t — consistent with the Indonesian steel sector's relatively efficient BF-BOF fleet — while the present model uses the WSA (2024) global average of 2.30 tCO_2/t.

Both are legitimate: the lower figure reflects the specific Indonesian plant mix; the higher figure is the global comparator used in CBAM and carbon credit baseline-setting. The Green Steel Market study's EAF intensity (0.38 tCO_2/t) and Green-H_2 near-zero (0.00 tCO_2/t) are consistent with IEA (2024) and MIT EPPA (2023) benchmarks.

BAU from Cost Advantage to Structural Liability

The Green Steel Market study argues that BAU's carbon liability 'transforms from baseline competitive option to structurally disadvantaged pathway' once carbon pricing is operational (IISIA/Authors, 2025). The quantitative model confirms this trajectory. Without carbon pricing, BAU earns a \$8.0 billion financial NPV and 14.1% IRR — the best of all five scenarios. Under the base \$25/tCO_2 credit price, BAU earns zero credit revenue (it is the counterfactual baseline). The Green Steel Market study projects BAU emissions rising from ~48 Mt CO_2 in 2025 to ~140 Mt CO_2 by 2060 (IISIA/Authors, 2025), which at a \$60/tCO_2 carbon liability (achievable by 2035 given IDX Carbon trajectories) translates into an annual carbon cost of approximately \$8.4 billion — erasing the current cost advantage entirely. CBAM exacerbates this: the EU carbon price of ~\$75/tCO_2 (2025 average) applied to 2.30 tCO_2/t embedded emissions equals ~\$173/t implicit tariff, far exceeding the \$150/t gross margin at current steel prices. This confirms the Green Steel Market study's 'stranded asset risk' warning (IISIA/Authors, 2025), supported by the GEI Net-Zero Roadmap's scenario modelling (GEI, 2024) and recent Mongabay investigative reporting on Indonesia's regulatory gap (Mongabay, 2026).

Transitional Pathways

The Green Steel Market study (IISIA/Authors, 2025) identifies scrap-based EAF (0.38 tCO_2/t) and gas-based DRI (0.66 tCO_2/t) as 'early winners' in a carbon market, generating surplus credits that become additional revenue. This analysis quantifies the EAF credit stream at \$13.2 billion NPV at the \$25/t base price — reducing its effective LCOS from \$564/t to \$509/t. At \$50/tCO_2, EAF's credit revenue NPV doubles to approximately \$26 billion, pushing its LCOS net of credits to approximately \$454/t, below BAU — the decisive crossing point at which the market realigns without further subsidy.

The Green Steel Market study correctly identifies the stranded asset risk for NG-DRI (IISIA/Authors, 2025): as the emissions cap tightens toward net-zero by 2050, 0.66 tCO_2/t may exceed allowable thresholds, converting NG-DRI from credit seller to credit buyer. This analysis estimates that NG-DRI crosses the credit-neutral threshold when Indonesia's sectoral cap reaches approximately 0.66 tCO_2/t — projected around 2040–2045 under a linear convergence from current BAU. The H_2-ready DRI design recommendation (IEA, 2024; GEI, 2024) is therefore not merely a cost-optimisation choice but a stranded-asset risk-management strategy: it allows the NG-DRI fleet to switch to hydrogen feed before the carbon liability becomes prohibitive.

Deep Decarbonization Pathways

The Green Steel Market study introduces the concept of a 'credit monopoly' effect (IISIA/Authors, 2025): as the cap tightens toward net-zero, only ultra-low-emission producers remain below the regulatory threshold and can generate credits. By 2050–2060, Blue-H_2 and Green-H_2 DRI-EAF producers become the primary—potentially sole — credit generators within the sector, each tonne of steel generating up to 1.46 tCO_2 of credits relative to the historical BAU baseline.

The quantitative model places this in dollar terms. At \$25/tCO_2, Green-H_2 DRI-EAF earns \$18.2 billion NPV in credit revenue over 20 years. At \$80/tCO_2 — the EU ETS 2023–2025 average—this rises to approximately \$58 billion. At the \$913/t LCOS cited in the Green Steel Market study (IISIA/Authors, 2025), a \$58 billion credit NPV against \$194 billion total cost NPV implies a net LCOS of approximately \$700/t — approaching parity with today's \$650/t steel price, precisely validating the Green Steel Market study's projection that the green premium 'effectively disappears' as carbon pricing matures (IISIA/Authors, 2025). This corroborates the IEA Iron and Steel Roadmap's (2024) finding that a functioning carbon price of \$80–130/tCO_2 is the single most important enabler of green steel competitiveness in emerging economies.

IRR Sensitivity to Carbon Credit Price

Credit price	S1 BAU IRR	S2 EAF IRR	S3 NG-DRI	S4 Blue-H_2	S5 Green-H_2	Best
$0/t$CO_2$	14.1%	6.8%	0.0%	(3.2%)	< 0%	S1 only
$25/t (base)	14.1%	12.2%	3.8%	4.0%	< 0%	S1, S2
$50/t$CO_2$	14.1%	16.4%	6.8%	8.8%	2.4%	S2 dominates
$80/t$CO_2$	14.1%	20.9%	9.8%	13.3%	8.3%	S2, S4
$120/t$CO_2$	14.1%	26.1%	13.2%	18.4%	14.3%	All viable

Table 13. — IRR by carbon credit price. Yellow = base case. Green = above 10% hurdle; red = below. Sources: authors' model; EU ETS benchmark per Bloomberg NEF (2025).

This table directly operationalises the Green Steel Market study's 'cross-cutting policy insight' (IISIA/Authors, 2025): 'the effectiveness of carbon markets depends on both price levels and policy design.' In the absence of carbon pricing, only BAU is viable. Under moderate pricing ($25–50/t), EAF becomes dominant. Under high pricing ($80–120/t), the full DRI-EAF technology family becomes privately attractive. The precise thresholds are: EAF at ~$15/t$CO_2$; Blue-$H_2$ DRI-EAF at ~$60/t$CO_2$; NG-DRI-EAF at ~$80/tCO_2; and Green-H_2 DRI-EAF at ~$120/t$CO_2$. These numbers translate policy intentions into investable decision criteria for both the private sector and government.

CHAPTER 5 STRATEGIC IMPLICATIONS FOR POLICY INNOVATIONS

5.1. Policy Imperative: Bridging the Green Premium and Protecting Competitiveness

The transition toward green iron and steel in Indonesia is constrained not by technological feasibility, but by a persistent misalignment between production costs, market incentives, and policy design. The core manifestation of this misalignment is the "green premium"—the additional cost associated with producing low-carbon steel relative to conventional coal-based production.

The LCOS analysis demonstrates that conventional production remains the dominant cost benchmark (~USD 589/ton), while hydrogen-based steel remains significantly more expensive (>USD 900/ton). Under these conditions, firms are economically incentivized to continue investing in carbon-intensive production, resulting in a high-emission equilibrium. This structural outcome is not merely theoretical; it is reinforced by empirical evidence. As noted by an industry representative:

"The main burden lies in the initial capital expenditure. Transitioning to green steel requires entirely new invesment; exiting plants cannot simply switch thecnologies."— Industry stakeholder (Indonesian Iron and Steel Association / IISIA)

Policy Design and the Persistence of the Green Premium

Existing policy instruments in Indonesia have not effectively addressed the cost differential between green and conventional steel. Fiscal incentives are primarily structured as corporate income tax reductions for firms adopting environmentally friendly technologies. This limitation is reflected in KADIN perspectives:

"When companies invest in expensive mitigation technologies but receive no meaningful incentives—either for the investment itself or through product pricing—the additional cost is passed on, making the product uncompetitive."
— Industry representative (KADIN Indonesia)

This confirms that current incentives improve financial conditions only indirectly and fail to address the per-ton cost disadvantage of green steel. As a result, decarbonization remains a secondary consideration in investment decisions. More importantly, the current incentive structure fails to directly target the green premium, which is driven by high costs of clean energy, low-carbon inputs, and advanced technologies. The absence of cost-focused instruments—such as renewable energy subsidies, scrap support, or long-term energy contracts—means that green steel remains structurally uncompetitive in the market.

Weak Demand Signals and Market Formation Constraints

The persistence of the green premium is further reinforced by the lack of demand-side policy instruments. There is currently no requirement for the use of green steel in public infrastructure, nor a functioning GPP framework. Stakeholder interviews highlight the absence of a domestic market:

"There is currently no market for green steel in Indonesia. Demand exists primarily in Europe, not domestically."— Energy transition expert (Institute for Essential Services Reform / IESR)

"Domestic consumers still prioritize price over sustainability; awareness of green steel remains low." — Government stakeholder (Ministry of Industry / Kemenperin)

These findings indicate that producers face high investment risks due to uncertain demand and lack of price premiums, delaying market formation. This creates a critical gap: producers face high upfront investment costs, but lack certainty of market demand

As a result, firms face significant risks in adopting low-carbon technologies, even when supply-side incentives are available. This weak demand signal delays the formation of a viable domestic market for green steel and slows down cost reduction through scale.

Distorted Competitive Environment

The competitiveness challenge is further exacerbated by policy gaps in trade and certification. First, green certification systems exist but remain voluntary, limiting their effectiveness. Firms that invest in low-carbon production incur higher costs, but receive no price premium or market advantage.

“Whether a producer is green or not, they face the same demand in the current market.” — Industry stakeholder (IISIA)

Second, imported steel—often produced under lower environmental standards—continues to enter the domestic market without carbon-related penalties. Combined with the absence of carbon pricing, this creates a distorted competitive environment in which high-emission products remain cheaper, and low-emission products are economically disadvantaged.

“The domestic industry is under severe pressure from low-priced imports, which significantly undermine competitiveness.” — Industry association representative (IISIA)

This distortion undermines both environmental objectives and industrial competitiveness.

Carbon Pricing Gap and Missing Economic Signals

Although Indonesia has established a legal foundation for carbon pricing, implementation remains limited. The current planned carbon price (~USD 2/tCO_2) is far below the level required to influence production decisions. This weak signal is reflected in business perceptions:

“From a business perspective, decarbonization is often perceived as an additional cost rather than a source of economic value.”— Industry representative (KADIN Indonesia)

As demonstrated in the LCOS and carbon credit analysis, carbon prices below ~USD 50/tCO_2 have a negligible impact, and meaningful shifts occur only at higher price levels. In the absence of effective carbon pricing, environmental costs are not internalized, there is no economic differentiation between green and conventional steel, and the green premium persists. This weakens the entire transition ecosystem and delays investment in low-carbon technologies.

Institutional Constraints: MRV and Policy Credibility

A further constraint lies in the limited development of Indonesia’s Measurement, Reporting, and Verification (MRV) system. Current gaps in emissions data, reporting standards, and verification mechanisms reduce policy credibility and create uncertainty for market actors. Stakeholders highlight institutional weaknesses:

“Renewable energy certificates are not yet fully recognized internationally due to concerns about credibility, traceability, and verification.” — Energy policy expert (IESR)

“Institutional fragmentation and sectoral coordination challenges hinder effective policy implementation.” — Government stakeholder (Ministry of Industry / Kemenperin)

This has two key implications. Domestically, it limits the effectiveness of carbon pricing and regulatory enforcement; internationally, it weakens the ability of Indonesian steel products to comply with requirements such as the CBAM. In this context, MRV is not only a technical requirement, but a precondition for competitiveness in global markets.

5.2. A Five-Pillar Policy Framework for Green Steel Protection and Competitiveness

The analysis in this study shows that the transition to green steel in Indonesia is constrained not only by cost differentials, but by fragmented and misaligned policy instruments. While multiple policy tools exist—ranging from fiscal incentives to certification systems and trade regulations—their current design does not collectively address the core challenge of the transition: bridging the green premium while maintaining competitiveness. Empirical evidence confirms that these instruments operate in isolation, with limited interaction across cost structures, demand formation, and market regulation.

"Policies across ministries are still fragmented; coordination challenges make implementation less effective." — Government stakeholder (Ministry of Industry / Kemenperin)

This fragmentation reduces overall policy effectiveness and reinforces the persistence of high-carbon production pathways.

Pillar 1: Coordinating Regulatory Signals and Investment Horizons

A key barrier identified in both the modelling and empirical evidence is the lack of coherent and credible investment signals. Although fiscal incentives for environmentally friendly technologies exist, they are not structured to prioritise decarbonization outcomes. This misalignment is reflected in KADIN views:

"Companies respond primarily to investment scale and economic returns, not enviromental criteria, because incentives are not structured around emissions reduction," —Industry representative (KADIN Indonesia)

Current incentive schemes allocate only ~10% weighting to environmental criteria, require high overall eligibility thresholds (≥80%), and primarily function through corporate income tax reductions. As a result, firms are incentivized to optimize for investment size or employment generation rather than emissions reduction. This weakens the role of policy as a driver of structural change and contributes to continued investment in carbon-intensive production.

A strengthened policy and legal framework is therefore essential to anchor expectations. Clear timelines, sectoral targets, and enforceable emissions benchmarks reduce uncertainty and enable firms to align capital allocation with long-term transition pathways. Without such signals, even well-designed financial incentives risk being underutilized, as firms defer investment decisions in anticipation of policy changes.

Pillar 2: Establishing Market Credibility through Standards and Classification

The analysis also highlights a critical gap in the institutionalisation of green standards. While Indonesia has introduced several regulations related to green material, these remain largely voluntary and are not effectively linked to economic incentives. Stakeholder evidence underscores this limitation:

"Green certification exists, but because it is not mandatory and not linked to pricing or procurement, it does not influence market behavior." — Energy policy expert (IESR)

In practice, firms adopting low-carbon technologies incur higher production costs, but do not receive corresponding market benefits, and face competition from lower-cost, high-emission alternatives. This disconnect prevents emissions performance from being translated into price signals or competitive advantage. Without mandatory standards or integration with procurement and trade policies, green certification remains largely symbolic. By defining what constitutes "green steel" and aligning these definitions with international requirements, policymakers can enable price differentiation, facilitate participation in export markets, and support the functioning of carbon markets and procurement systems. Without such systems, low-carbon producers are unable to fully capture the economic benefits of their emissions advantage.

The effectiveness of the policy framework is further constrained by institutional limitations, particularly in MRV systems. Current challenges include incomplete emissions data, inconsistent reporting standards, and weak verification mechanisms.

Pillar 3: Addressing the Green Premium through Targeted Financial Support

The persistence of the green premium is further reinforced by the absence of direct cost-reduction instruments. Existing policies do not adequately address key cost drivers such as electricity prices for EAF production, availability and pricing of scrap inputs, and access to affordable low-carbon energy. This gap is clearly reflected in IISIA insights:

“The main issue is cost—energy, raw materials and technology all increase production costs significantly for green steel.” —Industry stakeholder (IISIA)

As a result, the cost gap identified in the LCOS analysis remains largely unchanged in practice. Carbon pricing, which could theoretically address this gap, is currently set at a level (~USD 2/tCO_2) that is too low to influence production decisions. By lowering upfront investment costs and supporting early deployment, financial instruments can unlock private investment, accelerate learning effects, and reduce long-term system costs.

Pillar 4: Managing Trade Exposure and Preventing Carbon Leakage

The competitiveness of domestic producers is further undermined by gaps in trade and industrial policy. Indonesia continues to import large volumes of steel, often produced under lower environmental standards and lower cost structures. At the same time, domestic producers face higher costs when adopting low-carbon technologies, and there are no effective mechanisms to internalize the carbon content of imports. Stakeholders highlight this imbalance:

“Domestic producers face higher costs due to decarbonization efforts, but imports are not subject to the same environmental constraints.” — Industry association representative (IISIA)

In addition:

“There is no mechanism yet to account for the carbon content of imported steel.” —Goverment stakeholder (Ministry of Industry / Kemenperin)

Existing policies, such as the Domestic Component Level (TKDN) requirement, focus primarily on local content rather than emissions performance. Consequently, they do not incentivize green production, and do not provide protection for low-carbon domestic producers.

This creates an uneven playing field, where decarbonization efforts may reduce competitiveness rather than enhance it. Trade and industrial protection measures are therefore necessary to stabilize the transition environment. By aligning domestic standards with international regimes and ensuring that imported products face comparable carbon constraints, policymakers can maintain a level playing field, and prevent the relocation of emissions-intensive production. Such measures are particularly important during the intermediate phase of transition, when cost differentials remain significant.

Pillar 5: Creating Demand to Anchor Market Transformation

Another critical gap lies in the absence of demand-side policy instruments. There is currently no mandatory requirement for green steel in public procurement or infrastructure projects. This constraint is clearly articulated by IESR:

“Without government demand—especially through public procurement—there is no strong incentive for producers to shift toward green steel.” — Energy transition expert (IESR)

As a result, weak and uncertain demand for green steel, limited incentives for firms to scale production, and delayed cost reductions through economies of scale. Without a reliable demand signal, supply-side measures alone are insufficient to drive market transformation.

Public policy therefore plays a critical role in market creation. Instruments such as green public procurement can provide stable and predictable demand, early revenue streams for low-carbon producers, and signals to private buyers. By acting as a lead purchaser, the government can reduce market uncertainty and accelerate the transition from niche production to large-scale deployment.

5.3. Sequencing the Transition: A Phased Policy Approach

The transition to green steel in Indonesia is not only shaped by cost dynamics and technological readiness, but also by the timing, coherence, and institutional capacity of policy implementation. The LCOS and carbon pricing analysis demonstrate that different technologies become viable at different cost thresholds. However, empirical evidence from Indonesia shows that current policy instruments are not yet aligned with these evolving requirements.

“We are still in an early stage where many policies are being discussed, but implementation is not yet fully operational.” — Government stakeholder (Ministry of Industry / Kemenperin)

This misalignment underscores that effective decarbonization depends not only on what policies are adopted, but on when and how they are deployed in relation to market conditions. As such, the transition must be approached as a phased and adaptive process, where policy intensity and design evolve alongside cost structures and institutional readiness.

Early Phase (2025–2030): Enabling Low-Cost Transition and Avoiding Lock-In

In the near term, the transition is constrained by both economic and institutional limitations. The LCOS results indicate that only scrap-based EAF is cost-competitive, while deeper decarbonization pathways remain prohibitively expensive. At the same time, empirical evidence shows that Indonesia’s policy framework is not yet equipped to drive even low-cost transition pathways effectively. Key constraints include:

- Weak carbon pricing signals (~USD 2/tCO_2), insufficient to influence production decisions
- Indirect fiscal incentives (CIT-based), which do not reduce per-unit production costs
- Absence of demand-side policies, such as mandatory green procurement
- Voluntary certification systems, limiting market differentiation

Stakeholders highlight the weakness of early-stage policy signals:

“The current carbon price is too low to influence industrial decisions—it is not yet a real economic consideration for producers.” — Government stakeholder (Ministry of Industry / Kemenperin)

In addition, foundational systems required for transition remain underdeveloped:

“We still lack a robust system for emissions data and verification, which is critical for any carbon market to function effectively.” — Energy policy expert (IESR)

These gaps imply that even in the early phase—where relatively low-cost solutions are available—the policy environment does not fully support their adoption. As a result, the primary objective in this phase is not only to enable cost-effective transition, but to build the institutional and policy foundations required for subsequent stages. This includes:

- strengthening Measurement, Reporting, and Verification (MRV) systems,
- establishing credible emissions baselines, and
- initiating regulatory frameworks for carbon markets and green standards

Without these foundations, later-stage policies—particularly carbon pricing and certification—will lack credibility and effectiveness.

Intermediate Phase (2030–2045): Actively Bridging the Cost Gap

As the transition progresses, the limitations of the existing policy framework become more pronounced. Steel demand expands, and exposure to international carbon constraints intensifies. However, empirical evidence suggests that current policies remain misaligned with the scale of transformation required.

During this phase, the LCOS analysis indicates that the green premium persists, particularly for hydrogen-based technologies, and carbon pricing must rise significantly to influence competitiveness. Yet, current policy instruments are not structured to deliver this shift. Specifically, carbon pricing remains underdeveloped and politically constrained, trade policies do not account for carbon intensity of imports, and industrial policies (e.g., TKDN) prioritize local content over emissions performance.

“There is still no clear roadmap that links industrial policy, energy transition, and carbon pricing into a single coordinated strategy.” — Policy expert (IESR)

At the same time, firms face uncertainty in scaling up low-carbon technologies:

“Industry players are hesitant to invest in new technologies because the policy direction is not yet clear and consistent.” — Industry representative (KADIN Indonesia)

This creates a structural bottleneck. While the need for transition becomes more urgent, the policy framework lacks the capacity to bridge the cost gap and realign market incentives.

In addition, the absence of integrated policy design introduces risks of inefficient sequencing continued reliance on transitional technologies (e.g., gas-based DRI) without long-term alignment, underinvestment in hydrogen and renewable infrastructure, and fragmented adoption across firms and subsectors.

This phase therefore requires a shift from incremental policy development to active policy scaling, including:

- strengthening carbon pricing trajectories,
- introducing carbon-based trade measures, and
- linking certification systems with procurement and financing

Without such scaling, the transition risks stagnation, with partial emissions reductions but no pathway to net-zero compatibility.

Late Phase (2045–2060): Transition to Market-Led Competitiveness

In the long term, the effectiveness of the transition depends on the maturity and credibility of policy institutions established in earlier phases. The LCOS analysis suggests that the green premium diminishes as technology costs decline and carbon pricing becomes more stringent. However, achieving this outcome is contingent on sustained policy development.

Empirical evidence highlights that key institutional components—particularly MRV systems—are currently underdeveloped. Without robust MRV, carbon markets cannot function effectively, emissions caps cannot be enforced reliably, and international credibility remains limited.

“Indonesia’s certification and tracking systems are not yet fully aligned with international standards, which may create barriers in export markets.” — Energy transition expert (IESR)

In addition, global market requirements are becoming more stringent:

“Export markets are increasingly demanding verifiable emissions data; without it, products may face restrictions.” — Industry association representative (IISIA)

This has direct implications for competitiveness, especially in relation to external policies such as the CBAM, which require verifiable emissions data.

In this phase, policy priorities shift toward system optimization, including:

- ensuring the integrity of carbon markets,
- maintaining alignment with international standards, and
- managing the economic impacts of industrial restructuring

If earlier phases fail to establish strong institutional foundations, this phase may be characterized by:

- delayed cost convergence,
- limited participation in global low-carbon markets, and
- continued reliance on policy support rather than market-driven competitiveness.

5.4. Strategic Policy Insight

The results of this study indicate that the future competitiveness of Indonesia's steel sector is not determined solely by cost efficiency or technological capability, but by the degree to which policy frameworks reshape cost structures, market incentives, and competitive conditions. The LCOS and carbon pricing analyses show that, under current conditions, low-carbon technologies remain economically disadvantaged. Empirical evidence from Indonesia further demonstrates that this disadvantage is not only market-driven, but also policy-induced and institutionally reinforced.

Policy as the Determinant of Market Outcomes

A central finding of the analysis is that policy instruments directly influence the relative cost position of different production pathways. However, current policy design in Indonesia does not sufficiently alter these cost structures. Existing fiscal incentives are primarily structured as corporate income tax reductions, do not directly reduce per-unit production costs, and assign limited weight to environmental performance (~10%).

The LCOS analysis shows that low-carbon technologies remain economically disadvantaged under current conditions. Empirical evidence confirms that this disadvantage is reinforced by policy design that does not sufficiently alter cost structures.

"From the industry perspective, decarbonization is still seen primarily as an additional cost, not as a business opportunity." —Industry representative (KADIN Indonesia)

As a result, the cost differential identified in the LCOS analysis—particularly the green premium for hydrogen-based steel—remains largely unchanged in practice. This confirms that without targeted cost-reduction mechanisms, policy does not materially affect competitiveness. in this context, the persistence of conventional production is not simply a function of market efficiency, but a reflection of policy design that fails to address underlying cost drivers.

The Risk of Passive Transition

If policy intervention remains limited or inconsistent, the transition is likely to be driven primarily by external pressures, particularly from international markets. In this scenario, exporters adjust selectively to meet foreign regulatory requirements, domestic markets remain dominated by conventional production, and the overall transition proceeds in a fragmented and reactive manner.

"Countries that move earlier will have an advantage in capturing emerging green markets." — Energy policy expert (IESR)

However, without proactive policy alignment, Indonesia risks falling behind:

"If we are too slow to adapt, we may lose competitiveness and become dependent on external standards set by others." — Policy stakeholder (Kemenperin)

Such a pathway carries significant risks. It may lead to loss of export competitiveness due to delayed compliance, increased exposure to carbon-related trade barriers, and inefficient allocation of capital across technologies. Moreover, a passive transition increases the likelihood that decarbonization occurs under compressed timelines, requiring more abrupt and costly adjustments in later stages.

"At the moment, many actions are driven by external requirements rather than a fully integrated national strategy."— Policy expert (IESR / Kemenperin consultation)

The study's modelling results suggest that weak policy signals lead to a persistence of high-emission production. Stakeholder perspectives confirm that market outcomes are highly dependent on policy strength.

"If there is no strong policy push, industry will continue with the existing production model because it is the most economically viable." — Industry stakeholder (IISIA)

This indicates that market behavior is not self-correcting in the context of decarbonization. Instead, it responds directly to the presence—or absence—of policy incentives.

The Cost of Delay

The timing of policy intervention has direct implications for both economic and environmental outcomes. Delayed action allows the continuation of investment in carbon-intensive assets, which extends the lifespan of high-emission infrastructure, and increases the volume of future emissions that must be mitigated. This creates a cumulative cost effect. The longer the transition is delayed, the higher the eventual cost of decarbonization, and the greater the risk of stranded assets.

"If we delay the transition, the cost will not disappear—it will only become larger and more difficult to manage in the future." —Energy transition expert (IESR)

In addition, international pressures are intensifying:

"Global markets are moving faster, and if domestic policies do not keep pace, our products may face barriers in export markets." — Industry association representative (IISIA)

The sequencing analysis further suggests that early, targeted interventions—particularly those that enable low-cost pathways such as scrap-EAF—can reduce long-term transition costs by establishing initial momentum and avoiding lock-in.

From Cost Burden to Competitive Positioning

While the green premium is often framed as a barrier, the analysis indicates that it should be understood as a transitional condition rather than a permanent constraint. As carbon pricing increases and technology costs decline, the relative cost position of low-carbon steel improves. At sufficiently high carbon prices, the relationship reverses, high-emission production becomes cost-disadvantaged, low-emission production gains additional revenue through carbon credits, and competitiveness shifts toward cleaner technologies. This dynamic suggests that early investment in low-carbon pathways can provide forward-looking advantages, particularly in export-oriented segments of the industry.

Policy Coherence as a Precondition for Transition

A recurring finding across the analysis is that individual policy instruments are insufficient in isolation. Carbon pricing without supporting measures does not close the cost gap. Subsidies without market creation do not ensure demand. Trade measures without domestic alignment risk distortion. Effective transition therefore depends on policy coherence, defined as the alignment of price signals (carbon pricing), cost support (financial incentives), market creation (demand-side policies), and competitive conditions (trade measures). The absence of such coherence leads to fragmented outcomes, where progress in one area is offset by constraints in another. Stakeholders emphasize that current conditions create an uneven playing field for domestic producers.

"Local producers that attempt to decarbonise face higher costs, while imported products are not subject to the same requirements."— Industry association representative (IISIA)

This imbalance reinforces the advantage of high-emission production and discourages investment in low-carbon technologies.

"What is needed is a comprehensive approach—linking incentives, regulation, and market creation into a single framework."— Industry stakeholder (KADIN Indonesia)

CONCLUSION

The competitiveness challenge facing Indonesia's steel decarbonization is not fundamentally a technological problem, but a market and policy coordination problem. The analysis demonstrates that low-carbon steel pathways already generate substantial economic and social value, yet most of that value remains uncaptured by private investors under current market conditions. This creates a persistent divergence between what is rational for society and what is rational for firms. As long as carbon costs remain weakly internalized, demand for low-carbon materials remains uncertain, and imported carbon-intensive products face limited constraints, conventional production will continue to outperform cleaner alternatives in purely commercial terms despite its growing long-term liabilities. The green premium therefore reflects not an inherent inefficiency of green steel, but a failure of existing market structures to reward emissions reductions and future competitiveness.

The transition is unlikely to follow a single technological pathway. Instead, Indonesia's decarbonization trajectory will be determined by a sequence of technologies whose competitiveness changes over time. Scrap-based EAF emerges as the most economically efficient and immediately deployable option, offering the strongest combination of cost competitiveness, emissions reduction, and financial viability. However, EAF alone cannot deliver full sectoral decarbonization due to constraints in scrap availability. As a result, hydrogen-ready DRI-EAF pathways become strategically important, not because they are the cheapest options today, but because they preserve future flexibility and avoid locking the industry into carbon-intensive assets. In this sense, the transition is best understood as a process of managing technological succession rather than selecting a single winning technology.

At the market level, Indonesia's steel industry is entering a period in which carbon performance increasingly becomes a determinant of competitiveness. Historically, competitive advantage was shaped by production costs, resource availability, and economies of scale. Going forward, access to export markets, compliance with climate-linked trade measures, and the ability to capture value from carbon markets will become equally important. The emergence of mechanisms such as CBAM signals a structural shift in global trade, where emissions intensity becomes a tradable attribute alongside product quality and price. Under these conditions, decarbonization should not be viewed solely as an environmental obligation, but as a strategic industrial response to changing market rules. The cost of inaction is therefore not only higher emissions, but the gradual erosion of Indonesia's competitive position in international markets.

No single policy instrument is capable of resolving the competitiveness challenge on its own. Carbon pricing, fiscal incentives, trade measures, certification systems, and GPP each address different dimensions of the green premium. Their effectiveness depends on their interaction rather than their individual strength. Carbon markets create economic value for emissions reductions; procurement policies create demand certainty; standards establish market credibility; trade measures protect against carbon leakage; and targeted financial support lowers investment risks. The transition succeeds only when these instruments operate as an integrated policy ecosystem. The the key challenge for Indonesia is not the absence of policy tools, but the need to align them into a coherent framework capable of reshaping investment decisions and market expectations.

Ultimately, the future of Indonesia's steel industry will be determined by how effectively it converts decarbonization from a cost burden into a source of competitive advantage. The evidence presented in this study indicates that the transition is economically achievable, technologically feasible, and socially beneficial. However, these outcomes are not automatic. They depend on deliberate policy choices that reduce the gap between private incentives and public value. The strategic question is therefore no longer whether Indonesia can decarbonize its steel sector, but whether it can do so quickly enough to capture emerging market opportunities while avoiding the risks of carbon-intensive lock-in. In an increasingly carbon-constrained global economy, competitiveness and decarbonization are no longer competing objectives; they are becoming inseparable conditions for long-term industrial success.

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