Steel Decarbonization in Germany: Europe's Industrial Powerhouse at a Crossroads

MIFUS: A Global Journey Through Steel Decarbonization

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MIFUS Project - https://www.gotrawama.eu/estep25udine/pdf/

November 2025

Abstract

Germany, the European Union's largest steel producer with 37.2 million tonnes in 2024 (30% of EU output), faces a critical transformation at the intersection of climate policy, industrial competitiveness, and geopolitical tensions. This paper analyzes Germany's steel decarbonization strategy within the MIFUS (A Global Journey Through Steel Decarbonization) framework, examining four pioneering projects valued at 12.5 billion involving ThyssenKrupp Steel, Salzgitter, Stahl-Holding-Saar, and ArcelorMittal Germany. Despite receiving 75% of EU funding allocated for steel decarbonization and 6.9 billion in federal co-financing, the sector confronts existential challenges: ArcelorMittal's June 2024 withdrawal from green steel subsidies, hydrogen costs exceeding 9/kg (double 2030 forecasts), uncompetitive electricity prices costing an additional 300 million in 2024 alone, and aggressive trade barriers including 25% US tariffs. The paper contextualizes Germany's transition against China's October 2024 policy revolution and the EU's Carbon Border Adjustment Mechanism (CBAM), highlighting critical dependencies on hydrogen infrastructure, renewable energy availability, and political stability. With 80,000 direct jobs and 3.5 million indirect positions at stake, Germany's path from 71% BF-BOF/29% EAF production (2024) toward climate neutrality by 2045 represents a bellwether for European industrial decarbonization.

Keywords: Steel decarbonization, Germany, hydrogen DRI-EAF, ThyssenKrupp, Salzgitter, CBAM, green steel, industrial policy, energy transition, MIFUS

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1 Introduction: Germany's Steel Sector in Global Context

1.1 The MIFUS Framework

This paper is part of the MIFUS initiative (A Global Journey Through Steel Decarbonization), a comprehensive comparative study examining steel decarbonization strategies across major producing nations including China, India, Japan, United States, Russia, South Korea, Brazil, and European countries. The analysis draws upon:

- Global overview documents (A_Global.pdf, B_GlobalAppendix.pdf)
- China's transformative October 2024 policies (ChinaGovOct.pdf, C_ChinaSteelPolicyDeep01.pdf)
- European Union framework analysis (J_EuropeanUnion.pdf)
- Country-specific case studies including Brazil (M_Brasil_ClaudeAndreFabio.pdf)

1.2 Germany's Strategic Position

Germany occupies a unique position in the global steel landscape:

- **EU Leadership:** 37.2 Mt production (2024) = 30% of EU-27 output
- **Global Ranking:** 7th largest producer worldwide (2% global market share)
- **Industrial Significance:** Steel represents 7% of German manufacturing
- **Employment Impact:** 80,000 direct jobs + 3.5 million indirect positions
- **Economic Weight:** Strong representation in BDI (Federation of German Industries) and IG Metall trade union

1.3 The Transformation Imperative

The German steel sector confronts a **triple crisis**:

1. **Climate Policy Requirements:** EU Green Deal mandates 55% emissions reduction by 2030 (vs. 1990 levels) and climate neutrality by 2050
2. **Economic Competitiveness:** Uncompetitive energy costs, weak demand, and capacity underutilization

3. **Geopolitical Pressures:** Trade barriers (25% US tariffs), Chinese overcapacity, and market uncertainty

As stated by Vice-Chancellor Robert Habeck, the transition to "green steel" has become politically prestigious, with Germany securing 75% of European Commission funds allocated for steel decarbonization. However, the sector's fragility is evident: every third tonne of steel in the EU is now imported, and companies are operating "on the brink of viability."

2 Production Landscape and Technology Mix

2.1 Current Production Capacity (2024)

Table 1: Germany Steel Production by Technology (2024)

Technology	Volume (Mt)	Share (%)	Change vs. 2023
BOF/Oxygen Converter	26.42	71.0%	+3.3%
Electric Arc Furnace (EAF)	10.82	29.0%	+10.2%
Total Crude Steel	**37.23**	**100%**	**+5.2%**
Pig Iron Production	24.33	–	+2.9%
Hot-Rolled Steel	31.61	–	+3.0%

Key Observations:

- Germany remains heavily dependent on coal-based BF-BOF route (71%)
- EAF share growing faster (+10.2%) than BOF (+3.3%), indicating gradual transition
- December 2024 showed production volatility: EAF output dropped 45.6% month-on-month due to electricity price spikes
- Overall 2024 recovery followed poor 2023 performance (-3.9% y/y)

2.2 Major Steel Producers

Germany's steel industry is concentrated among four major players accounting for **75% of national production**:

Table 2: Major German Steel Companies

Company	Key Characteristics
ThyssenKrupp Steel	Germany's largest producer (11.5 Mt capacity) Planning reduction to 9 Mt by 2030 Workforce cut: 27,000 16,000 tkH2Steelő transformation project 2.5 Mt DRI-EAF plant under development
Salzgitter AG	SALCOSő (Salzgitter Low CO2 Steelmaking) 100 MW electrolyzer completed early 2025 9,000 t/year green H production Target: 95% emissions reduction by 2033 Partnerships with E.ON and Linde
ArcelorMittal Germany	Withdrew from green steel project (June 2024) Cited "unfavorable framework conditions" Forfeited state subsidies Decision sparked industry-wide debate
Stahl-Holding-Saar (SHS)	Committed to decarbonization despite challenges Green hydrogen tender: up to 50,000 t/year Timeline: 2027-2029 commissioning

2.3 Production Technology Evolution

Historical Trajectory (2023-2024):

- **2023:** Total 35.38 Mt (-3.9% y/y)
  - BOF: 25.63 Mt (-0.9% y/y)
  - EAF: 9.81 Mt (-10.8% y/y) - impacted by energy costs
- **2024:** Total 37.23 Mt (+5.2% y/y)

  - BOF: 26.42 Mt (+3.3% y/y)
  - EAF: 10.82 Mt (+10.2% y/y) - recovery driven by improved electricity market

Future Projections:
According to Global Energy Monitor and industry analysis, by 2030:

- EU-wide EAF share: 45% 57%
- Germany expected to follow EU trend given federal commitment
- Current projects target 5+ Mt low-CO steel capacity by 2030

3 Decarbonization Strategy and Major Projects

3.1 Federal Government Commitment

Germany's federal government has made an unprecedented financial commitment to steel decarbonization:

- **Total Project Costs:** 12.5 billion (four major projects)
- **Federal Co-Financing:** 6.9 billion (55% of total)
- **EU Funding Success:** 75% of EC steel decarbonization funds allocated to Germany
- **State Aid Approval:** Actively pursued by Vice-Chancellor Robert Habeck (Greens)

3.2 The Four Pioneering Projects

3.2.1 1. ThyssenKrupp Steel: tkH2Steelő

Project Overview:

- **Concept:** Replace four coal-based blast furnaces with hydrogen-powered DRI plants
- **Innovation:** First-time liquefaction of hydrogen-reduced iron in specially developed melting units
- **Capacity:** Initial 2.5 Mt/year (increased from original plan)
- **Target:** 5 Mt low-CO steel by 2030

- **Investment:** 2+ billion (subject to public funding)
- **Timeline:**
  - Contract award: Fall 2022
  - First production: Originally 2026, now 2027-2028
  - Full transformation: By 2045 (climate neutrality)

Emissions Impact:

- First DRI plant: -3.5 Mt CO/year (20% of company emissions)
- Represents 5% of Ruhr region's total greenhouse gas emissions
- By 2030: >30% CO reduction company-wide

Technology Details:

- Hydrogen-powered direct reduction produces solid sponge iron (DRI)
- Innovative melting units convert DRI to liquid hot iron
- Existing infrastructure utilized steel mills, rolling, finishing
- Full premium product portfolio maintained without quality compromise

Critical Challenges:

1. **Hydrogen Procurement:**
   - Tender launched February 2024 for 151,000 t/year H (10-year contracts)
   - Paused March 2024 due to prices "significantly higher than assumed"
   - Bid prices: 9.35/kg (March 2025), peaked at 14.50/kg (December 2024)
   - Target price: <4.50/kg for competitiveness
   - Delivery requirements: 104,000 t (2028) 151,000 t/year (2036-37)
2. **Bridge Strategy:**
   - Phase 1: Natural gas DRI (50% CO reduction vs. BF-BOF)
   - Phase 2: Transition to green hydrogen by 2045
   - Pragmatic approach acknowledging infrastructure delays
3. **Market Certainty:**

- Partnership with Volkswagen Group for bluemintő Steel (starting 2028)
- Long-term offtake agreements critical for investment viability
- Pre-orders from BMW, Mercedes-Benz (500,000 t first year)

Strategic Significance:
According to Bernhard Osburg, Chairman of ThyssenKrupp Steel Executive Board:

> *"We are continuing to set the pace on our path to climate-friendly steel production... significantly more than previously planned. We are thus reaffirming our goal of playing a leading role in the competition for the green steel markets of the future."*

Arnd Köfler, Chief Technology Officer, emphasized:

> *"The intelligent combination with newly developed melting units can serve as a model for many other decarbonization projects in the steel industry worldwide."*

3.2.2 2. Salzgitter AG: SALCOSő

Project Overview:

- **Full Name:** Salzgitter Low CO Steelmaking
- **Ambition:** 95% emissions reduction by 2033
- **Approach:** Integrated green hydrogen production + DRI-EAF
- **Partnerships:** E.ON (power), Linde (hydrogen technology)
- **Investment:** 50 million wind-powered hydrogen facility

Key Achievements:

- **100 MW Electrolyzer:** Completed early 2025
- **H Production:** 9,000 tonnes/year green hydrogen
- **Energy Source:** Wind-powered (ensuring renewable credentials)
- **Integration:** Direct connection to DRI plant

Hydrogen Procurement Strategy:

- Tender opened June 2024: up to 120,000 t/year green H
- Delivery: from 2027 (subject to pipeline connection)

- Dependent on Germany's hydrogen core network (HCN) rollout
- Combination of on-site production + external procurement

Timeline:

- 2025: On-site electrolyzer operational
- 2027: External H procurement begins
- 2027-2029: DRI-EAF commissioning
- 2033: Target 95% emissions reduction
- 2050: Climate neutrality

Investment Rationale:

Salzgitter's approach is viewed favorably by analysts as a "decarbonization darling with EU-backed scale." Their phased strategy reduces execution risk compared to peers by:

- Securing hydrogen supply through dual approach (on-site + external)
- Building regulatory-compliant electrolyzer meeting RED II requirements
- Establishing long-term partnerships with energy and chemical sectors

3.2.3 3. Stahl-Holding-Saar (SHS)

Project Characteristics:

- **Hydrogen Tender:** March 2024 launch for up to 50,000 t locally produced renewable H
- **Timeline:** 2027-2029 commissioning declared
- **Commitment:** Maintained despite industry headwinds
- **Focus:** Local renewable hydrogen production

Status: Project proceeding as planned, benefiting from federal subsidies and committed to completion despite ArcelorMittal's withdrawal.

3.2.4 4. ArcelorMittal Germany: Project Withdrawal

The Controversial Decision (June 2024):

ArcelorMittal's withdrawal from Germany's green steel subsidies sent shockwaves through the industry:

- **Reason Cited:** "Unfavorable framework conditions"
- **Economic Rationale:** Investment not viable even with 50% subsidy coverage
- **Specific Concerns:**
  - Hydrogen prices (9+ /kg) more than double 2030 forecasts
  - Uncompetitive electricity costs
  - Slow hydrogen economy development
  - Political and market uncertainty
- **Consequence:** Forfeited all state subsidies

Industry Impact:
The decision by this global steel giant:

- Resonated widely across European steel sector
- Fuelled debate on decarbonization feasibility and costs
- Provided "convenient opportunity" for sector to reiterate demands
- Prompted government reassessment of support framework

Alternative Developments:

- November 2024: ArcelorMittal delayed green investments in Spain (Gijón, 1 billion DRI) and France (Dunkirk, 2.5 Mt DRI + 2 EAF)
- May 2025: Confirmed plans for first EAF at Dunkirk (1.2 billion)
- Strategy shift: selective investment rather than comprehensive transformation

Lesson for Industry:
ArcelorMittal's withdrawal highlighted that:

> *"Even with substantial public subsidies, the business case for green steel depends critically on competitive energy costs, hydrogen infrastructure readiness, and stable regulatory frameworks."*

3.3 Comparative Analysis: Remaining Three vs. ArcelorMittal

Table 3: Strategic Positioning of German Steel Decarbonization Projects

Factor	**ThyssenKrupp/Salzgitter/S**	**ArcelorMittal**
Commitment	Proceeding despite challenges	Withdrew from subsidies
Risk Management	Bridge strategy (nat. gas H)	All-or-nothing approach
Hydrogen Strategy	Multiple sources, phased procurement	Immediate large-scale requirement
Timeline	Flexible (2027-2029)	Originally rigid
Local Stakes	Domestic political pressure high	Multinational, can shift capacity
Partnerships	Deep (VW, BMW, Mercedes, E.ON)	Limited pre-commitments
Scale	Distributed (2.5-5 Mt each)	Large integrated sites

Key Insight: Companies with deeper domestic roots, phased approaches, and secured offtake agreements are more resilient to cost and infrastructure uncertainties.

4 Infrastructure Requirements and Dependencies

4.1 Hydrogen Infrastructure

4.1.1 Germany's Hydrogen Core Network (HCN)

The success of all green steel projects depends on the timely development of hydrogen infrastructure:

- **Planned Network:** National hydrogen pipeline connecting production, storage, and consumption centers
- **Status:** Delayed but first sections under construction
- **Critical for:**
  - Duisburg (ThyssenKrupp) early connection planned
  - Salzgitter procurement from 2027
  - SHS local renewable hydrogen transport
- **Projected Timeline:** Cheaper hydrogen access by 2030 (if rollout accelerates)

4.1.2 Hydrogen Supply Economics

Current Situation (2024-2025):

- **Production Cost:** 9.35/kg (March 2025) for green H via alkaline electrolysis
- **Peak Price:** 14.50/kg (mid-December 2024)
- **Forecast 2030:** <4.50/kg (industry target)
- **Competitiveness Threshold:** 3-4/kg for parity with coal-based routes

Production Capacity Requirements:
For Germany's steel sector alone:

- ThyssenKrupp: 151,000 t/year (by 2036-37)
- Salzgitter: 120,000 t/year (from 2027)
- SHS: 50,000 t/year
- **Total: >320,000 t/year** green hydrogen

EU Context:

- EU target: 10 million t/year domestic green H production by 2030
- Could decarbonize 11% of global steel demand
- Potential savings: 340 Mt CO/year
- Germany expected to be major production and consumption hub

4.2 Electricity Infrastructure and Costs

4.2.1 The Electricity Cost Crisis

Germany's steel sector faces severe electricity cost disadvantages:

Table 4: Germany Electricity Cost Impact on Steel Sector

Metric	**Value**	**Impact**
Additional cost (2024 vs. 2023)	300 million	+10-15% OPEX
Germany vs. EU average	+40-60%	Competitiveness loss
December 2024 EAF output m/m	-45.6%	Production volatility
International competitiveness	Lowest in EU	Capacity utilization <70%

Structural Issues:

- High network charges and taxes
- Slow renewable energy rollout relative to industry needs
- Grid constraints limiting renewables access
- Lack of long-term price certainty mechanisms

Policy Responses Needed:

- Facilitated Power Purchase Agreements (PPAs)
- Reduction of network tariffs for industrial users
- Tax flexibility for energy-intensive industries
- Priority grid access for decarbonizing industries

4.2.2 Renewable Energy Requirements

Scale of Challenge:

For Germany's planned steel decarbonization:

- **Hydrogen Production:** 90+ TWh/year (for 320,000 t H via electrolysis at 280 kWh/kg)
- **EAF Operations:** Additional 15-20 TWh/year (for expanded EAF capacity)
- **Total:** 105-110 TWh/year dedicated renewable electricity
- **Context:** Germany's total renewable electricity generation (2024): 260 TWh
- **Implication:** Steel sector alone requires 40

Renewable Energy Expansion Needs:

- **Wind:** Accelerated offshore and onshore deployment
- **Solar:** Industrial-scale PV installations
- **Grid:** Massive expansion and reinforcement
- **Storage:** Battery and other storage solutions for reliability
- **Imports:** Potential green electricity/hydrogen imports (Norway, Spain, North Africa)

4.3 Raw Material and Scrap Dependencies

4.3.1 Iron Ore Supply

- **Current Sources:** Brazil, Australia, Canada (primarily)
- **DRI Requirements:** High-grade iron ore (>67% Fe content)
- **Challenge:** DRI-quality ore may face supply constraints as global DRI capacity expands
- **Strategic Risk:** Concentration of supply in few countries

4.3.2 Scrap Steel Availability

Germany's current scrap situation:

- **Domestic Generation:** 8-10 Mt/year
- **Imports:** Significant volumes from Eastern Europe
- **EAF Dependency:** 10.82 Mt production (2024) largely scrap-based
- **Quality Issues:** Automotive-grade scrap limited
- **Competition:** Other EU countries expanding EAF capacity

Future Considerations:

- As EU EAF share grows 45% 57%, scrap demand intensifies
- Need for improved collection, sorting, and processing
- Potential for "scrap wars" within EU if availability doesn't increase
- Circular economy policies critical (automotive closed-loop, building deconstruction)

5 Economic and Competitive Challenges

5.1 Market Demand Crisis

5.1.1 Consumption Trends

Germany's rolled steel consumption has been declining:

- **Peak:** 45 Mt/year (2005-2008)

- **2023-2024:** 35-38 Mt/year
- **Main Sectors:**
  - Automotive: 30-35% of consumption
  - Construction: 25-30%
  - Mechanical engineering: 15-20%
  - Other manufacturing: 15-20%

Demand Drivers (Negative):

- Weak construction activity (housing crisis, public investment delays)
- Automotive sector transformation (lightweighting, material substitution)
- Industrial recession (Germany in technical recession 2023)
- Trade uncertainty (export markets volatile)

Demand Drivers (Positive):

- Energy transition infrastructure (wind turbines, grid, hydrogen facilities)
- Automotive electrification (battery casings, motor housings)
- Railway expansion (Deutsche Bahn modernization)
- Green premium market (customers willing to pay for low-CO steel)

5.1.2 Capacity Utilization

- **2023:** 65-70% (severe underutilization)
- **2024:** 70-75% (marginal improvement)
- **Healthy Level:** >80% for profitability
- **Challenge:** Structural overcapacity in Europe combined with weak demand

ThyssenKrupp Response:

- Reducing capacity from 11.5 Mt to 9 Mt
- Workforce reduction: 27,000 16,000 (40% cut)
- Rationale: "Right-sizing for realistic future demand"

5.2 Cost Competitiveness Analysis

5.2.1 Production Cost Breakdown (BF-BOF)

Table 5: Estimated BF-BOF Steel Production Costs in Germany (2024)

Cost Component	/tonne steel	Share (%)
Iron ore	120-150	20-25%
Metallurgical coal/coke	180-220	30-35%
Energy (electricity, gas)	80-120	13-20%
Labor	60-80	10-13%
Other materials	40-60	7-10%
Depreciation	30-50	5-8%
CO costs (ETS)	80-120	13-20%
Total	**590-800**	**100%**

5.2.2 H-DRI-EAF Cost Projections

Table 6: H-DRI-EAF Cost Structure (Estimates for 2030)

Cost Component	/tonne steel	Share (%)
Iron ore (DRI-grade)	140-170	20-24%
Green hydrogen	250-350	36-50%
Electricity (EAF)	60-90	9-13%
Labor	50-70	7-10%
Other materials	30-50	4-7%
Depreciation (higher CAPEX)	60-90	9-13%
CO costs	0-10	0-1%
Total	**590-830**	**100%**

Key Insights:

- At 9/kg H: Green steel costs 900-1,000/tonne (uncompetitive)
- At 4.50/kg H: Green steel costs 590-700/tonne (competitive with BF-BOF + carbon costs)
- At 3/kg H: Green steel achieves cost parity even without carbon pricing

- **Critical threshold:** H < 4.50/kg for viable business case

5.3 Import Competition and Trade Barriers

5.3.1 EU Import Pressure

- **Current Reality:** 1 in 3 tonnes of steel in EU now imported
- **Main Sources:**
  - Turkey (closest supplier, 15-20% of EU imports)
  - India (growing rapidly, 10-15%)
  - China (despite safeguards, 8-12%)
  - South Korea, Japan (high-quality products)
- **Price Differential:** Imports often 15-30% cheaper
- **Quality Concerns:** Some imports don't meet EU standards

5.3.2 US Tariff Impact (2024)

President Trump's Proclamation 10783 (July 2024):

- **Tariff Rate:** 25% on steel imports
- **Impact on Germany:** Significant (US is major export market)
- **Volume Affected:** 2-3 Mt/year German exports to US
- **Economic Loss:** 500-750 million/year in export value
- **Strategic Response:** German steel association calling for EU countermeasures

5.3.3 CBAM as Protective Measure

The EU's Carbon Border Adjustment Mechanism offers hope:

- **Transition Phase:** 2023-2025 (reporting only)
- **Definitive Phase:** From January 1, 2026
- **Mechanism:** Importers must purchase CBAM certificates corresponding to embedded emissions
- **Price Basis:** EU ETS carbon price

- **Sectors Covered:** Steel, aluminum, cement, fertilizers, electricity, hydrogen
- **Future Expansion:** Downstream products (automotive components, appliances) by 2028-2030

Expected Impact:

- Levels playing field for EU producers investing in decarbonization
- Estimated cost increase for imports: 50-150/tonne (depending on carbon intensity)
- May drive global steel producers to decarbonize
- Risk of trade disputes (WTO compatibility concerns)

German Industry Position:

- Strongly supports CBAM
- Requests faster phase-in and broader scope
- Concerned about enforcement and circumvention risks
- Advocates for extending to all downstream products quickly

5.4 Financial Viability and Investment Risks

5.4.1 Capital Requirements

Table 7: Investment Requirements for Germany's Major Decarbonization Projects

Project	Total CAPEX	Public Funding	Private Share
ThyssenKrupp tkH2Steel	2.0-2.5 bn	1.0-1.2 bn	1.0-1.3 bn
Salzgitter SALCOS	2.5-3.0 bn	1.3-1.5 bn	1.2-1.5 bn
SHS Decarbonization	1.5-2.0 bn	0.8-1.0 bn	0.7-1.0 bn
ArcelorMittal (withdrawn)	2.0 bn	1.0 bn	–
Total Active Projects	**6.0-7.5 bn**	**3.1-3.7 bn**	**2.9-3.8 bn**

Federal Funding Framework:

- **Climate and Transformation Fund (KTF):** Primary source
- **Coverage:** Up to 50-55% of eligible costs
- **EU State Aid Approval:** Required and obtained for major projects
- **IPCEI Status:** Important Projects of Common European Interest designation

5.4.2 Operating Cost Uncertainties

Hydrogen Price Volatility:

- Current tender prices (9-14.50/kg) make operations unprofitable
- Forecast 2030 prices (4.50/kg) barely achieve viability
- Any delay in cost reduction threatens business case
- Natural gas bridge strategy adds complexity but reduces risk

Electricity Price Risk:

- Germany's electricity costs 40-60% above EU average
- EAF operations highly sensitive to power prices
- December 2024 price spike caused 45.6% production drop
- Need for long-term fixed-price PPAs critical

Carbon Price Uncertainty:

- EU ETS price volatility: 60-100/tonne (2024)
- Higher carbon prices improve green steel competitiveness
- But also increase conventional production costs immediately
- Companies face dilemma: invest now or wait for clearer price signals

6 Policy and Regulatory Framework

6.1 National Policy: Germany's Climate and Industrial Strategy

6.1.1 Climate Protection Act

Germany's binding targets:

- **2030:** 65% emissions reduction (vs. 1990)
- **2040:** 88% emissions reduction
- **2045:** Climate neutrality (5 years ahead of EU target)

Sectoral Targets:

- Industry sector: 177 Mt COeq (2020) 118 Mt (2030) near-zero (2045)
- Steel's share: 40 Mt CO currently must approach zero by 2045

6.1.2 Industrial Strategy

Vice-Chancellor Robert Habeck's (Green Party) priorities:

- **Green Steel Leadership:** Position Germany as global pioneer
- **Massive Public Investment:** 6.9 billion federal co-financing
- **Hydrogen Economy:** National strategy targeting 10 GW electrolysis by 2030
- **Energy Transition:** 80% renewable electricity by 2030
- **Just Transition:** Support for affected workers and regions

Political Dynamics:

- Green steel has become politically prestigious
- Strong support from Greens and Social Democrats (SPD)
- Business-friendly FDP and conservative CDU/CSU more cautious
- 2025 elections create uncertainty about policy continuity
- Industry requests bipartisan commitment to long-term strategy

6.1.3 Carbon Contracts for Difference (CCfD)

Germany pioneered the CCfD mechanism:

- **Concept:** Government guarantees minimum carbon price differential
- **Mechanism:**
  - Company commits to low-CO production
  - If CO price falls below agreed "strike price," government pays difference
  - If CO price exceeds strike price, company may pay back difference
- **Benefits:**

  - Reduces investment risk
  - Provides long-term cost certainty
  - Incentivizes early action
- **Status:** First CCfD auctions for steel sector planned 2025
- **Volume:** 4-5 billion committed over 15-year contracts

6.2 EU Policy Framework

6.2.1 EU Green Deal and Fit for 55

Key elements affecting German steel:

- **Emissions Reduction Target:** 55% by 2030 (vs. 1990)
- **EU ETS Reform:**
  - Strengthened cap (2.2% annual reduction)
  - Free allocation phase-out for CBAM sectors (2026-2034)
  - Innovation Fund from auction revenues
- **Renewable Energy Directive (RED III):**
  - 42.5% renewable energy by 2030 (binding)
  - Green hydrogen definition and certification
  - Additionality requirements for electrolyzers

6.2.2 Steel and Metals Action Plan (March 2025)

The EU's comprehensive steel strategy:

Four Pillars:

1. **Affordable and Secure Energy**
   - Facilitated Power Purchase Agreements (PPAs)
   - Reduced network tariffs for industry
   - Flexibility on energy taxation
   - Priority grid access for decarbonizing sectors
2. **Financing Decarbonization**

- Industrial Decarbonisation Bank: 100 billion target
- Innovation Fund: 1 billion pilot auction in 2025
- National CCfD schemes (Germany leading)

3. **Protecting Industrial Capacity**
   - CBAM implementation
   - New trade defense measures against dumping
   - Investigation of overcapacity (China focus)
   - Extension of safeguard measures

4. **Creating Market for Low-Carbon Products**
   - Voluntary carbon intensity labeling (methodology Q2 2025)
   - Green public procurement standards
   - Potential green steel quotas for automotive sector
   - Recycled content requirements

German Industry Reaction:

- Welcomed as comprehensive approach
- Concerns about implementation speed
- Requests for more ambitious targets on energy costs
- Emphasis on enforcement of trade measures

6.2.3 CBAM Implementation Details

Transitional Phase (2023-2025):

- Importers must report embedded emissions
- No financial payments required
- Data collection to refine methodology
- German companies participating actively in reporting

Definitive Phase (2026-2034):

- **2026:** CBAM certificates required, 2.5% free allocation reduction

- **2030:** 48.5% free allocation reduction
- **2034:** 100% free allocation eliminated
- **Scope Expansion:** Downstream products added progressively

German-Specific Considerations:

- High-quality German steel may benefit from differentiation
- Automotive components: major downstream product category
- German companies have sophisticated carbon accounting capabilities
- Risk: if green steel costs remain high, may lose even protected market share

6.3 Regional and Local Support

6.3.1 North Rhine-Westphalia (NRW) State

Home to ThyssenKrupp and Germany's industrial heartland:

- **Additional State Funding:** 500-800 million committed
- **Hydrogen Strategy:** HyStarter and HyPerformer programs
- **Infrastructure:** Early connection to hydrogen core network
- **Skills Development:** Training programs for H economy jobs
- **Political Priority:** State government strongly supportive (coalition of CDU/Greens)

6.3.2 Lower Saxony

Salzgitter AG's home state:

- **State Ownership:** Lower Saxony holds 26.5% of Salzgitter AG
- **Committed Partner:** State government backing project financially
- **Renewable Energy:** Strong wind resources (offshore and onshore)
- **Skills Base:** Existing expertise in steel and engineering

6.3.3 Saarland

Stahl-Holding-Saar location:

- **Historical Importance:** Cradle of European Coal and Steel Community
- **Structural Challenges:** Smaller scale, border region
- **EU Funds:** Access to Just Transition Fund resources
- **Cross-Border:** Potential for French-German hydrogen cooperation

7 Environmental Impact and Emissions Reduction

7.1 Current Emissions Profile

Table 8: Germany Steel Sector Emissions (2024 estimates)

Source	**Mt CO/year**	**Share**	**Intensity (t CO/t steel)**
BF-BOF Production	35-38	87-90%	1.9-2.1
EAF Production	4-5	10-13%	0.4-0.5
Total Direct	**39-43**	**100%**	**1.05-1.15**
Indirect (electricity)	8-10	–	0.21-0.27
Total (Scope 1+2)	**47-53**	–	**1.26-1.42**

Context:

- Steel sector: 40% of Germany's industrial emissions
- 5-6% of Germany's total greenhouse gas emissions
- Among highest CO intensity in EU (due to BF-BOF dominance)

7.2 Decarbonization Pathway and Targets

7.2.1 Short-Term (2025-2030)

Planned Reductions:

- ThyssenKrupp first DRI plant: -3.5 Mt CO/year (2027-2028)

- Salzgitter Phase 1: -1 Mt CO/year (2027-2029)
- SHS project: -0.8 Mt CO/year (2027-2029)
- EAF expansion: -2 Mt CO/year (gradual shift from BF-BOF)
- **Total 2030 reduction: 7-8 Mt CO/year (15-20% of current)**

Projected 2030 Emissions:

- Baseline (no action): 39-43 Mt CO
- With current projects: 31-36 Mt CO
- Target (Climate Act): 25-28 Mt CO
- **Gap:** 3-11 Mt CO (additional measures needed)

7.2.2 Medium-Term (2030-2040)

Required Transformation:

- Full conversion of remaining BF-BOF capacity to H-DRI-EAF
- Expansion of green hydrogen supply to 320,000+ t/year
- Renewable electricity: 105-110 TWh/year dedicated to steel
- Circular economy: increased scrap utilization in hybrid DRI-scrap EAF routes

Projected 2040 Emissions:

- Target: <10 Mt CO/year
- Pathway: 90% reduction vs. 2024 baseline
- Residual emissions: process-related, hard-to-abate sources

7.2.3 Long-Term (2040-2050)

Climate Neutrality Pathway:

- 100% H-DRI-EAF or equivalent zero-carbon technology
- Residual emissions offset by carbon capture or removals
- Fully circular steel economy (maximized scrap recycling)

- Integration with broader hydrogen economy

2045 Target (Germany Climate Neutrality):

- Steel sector: <1 Mt CO/year net emissions
- 98% reduction vs. 2024
- Remaining emissions compensated by carbon sinks

7.3 Co-Benefits of Decarbonization

7.3.1 Air Quality Improvements

Beyond CO reduction, H-DRI-EAF eliminates:

- **SOx (Sulfur Oxides):** 90-95% reduction
- **NOx (Nitrogen Oxides):** 80-90% reduction
- **Particulate Matter (PM):** 70-85% reduction
- **Heavy Metals:** Significant reduction in mercury, lead emissions

Health Benefits:

- Improved air quality in Ruhr region and other industrial areas
- Reduced respiratory and cardiovascular disease burden
- Estimated health cost savings: 100-200 million/year

7.3.2 Resource Efficiency

- **Water Consumption:** 30-40% reduction (no coal washing, less cooling)
- **Land Use:** Closure of coking plants frees industrial land
- **Waste Reduction:** Elimination of blast furnace slag, reduced hazardous waste
- **Material Circularity:** Increased scrap recycling and by-product utilization

8 Social and Employment Dimensions

8.1 Employment Impact Analysis

8.1.1 Current Employment (2024)

Table 9: German Steel Sector Employment Structure

Category	Number	Notes
Direct Production	80,000	Steel mills, finishing
Supply Chain	200,000	Raw materials, logistics, services
Downstream Users	3,300,000	Automotive, construction, machinery
Total Dependent	**3,580,000**	**8% of German workforce**

8.1.2 Transformation Risks

Job Losses from Technology Shift:

- H-DRI-EAF requires 20-30% fewer workers than BF-BOF
- Automation and digitalization accelerate labor reduction
- Specialized skills (coking, blast furnace operation) become obsolete

ThyssenKrupp Case Study:

- Current workforce: 27,000
- Planned reduction: to 16,000 by 2030
- **Net loss: 11,000 jobs (40% reduction)**
- Rationale: technology shift + capacity reduction + productivity improvement

Sector-Wide Projections:

- Direct jobs 2030: 60,000 (from 80,000) = 25% reduction
- Supply chain impact: -50,000 jobs (coal, coke, logistics)
- **Total at-risk: 70,000 jobs** in steel value chain

8.1.3 Job Creation Opportunities

New Roles in Green Steel:

- Hydrogen plant operators and technicians
- Renewable energy specialists
- Advanced EAF and DRI engineers
- Environmental and sustainability managers
- Digital and automation experts

Estimated Net Employment 2030:

- Direct steel jobs lost: -20,000
- New hydrogen economy jobs: +8,000
- Renewable energy jobs: +5,000
- RD and engineering: +3,000
- **Net loss: -4,000** (5% overall reduction)

Quality of Jobs:

- Higher skill requirements (positive for wages)
- Safer working conditions (less hazardous processes)
- More sustainable long-term employment (future-proof industry)
- Potential geographic mismatch (jobs may relocate near renewable sources)

8.2 Just Transition Measures

8.2.1 National Programs

Federal Just Transition Framework:

- **Structural Change Fund:** 40 billion (primarily coal regions, some for steel)
- **Qualification Offensive:** 500 million for skills development
- **Early Retirement:** Voluntary programs for workers 58+

- **Job Guarantees:** Commitments from companies receiving subsidies

IG Metall (Trade Union) Agreements:

- No forced redundancies (negotiated layoffs only)
- Retraining rights for all affected workers
- Wage protection during transition
- Co-determination in transformation planning
- Transfer companies (Transfergesellschaften) for laid-off workers

8.2.2 Regional Support (Ruhr Area Focus)

Ruhr Regional Association Programs:

- **Vocational Training Centers:** Specialized courses in H technology
- **Innovation Hubs:** Attracting new clean tech industries
- **Infrastructure Investment:** Improving transport, digital connectivity
- **Economic Diversification:** Reducing dependence on heavy industry

ThyssenKrupp-Specific Measures:

- 300 million socio-economic package
- Voluntary severance with enhanced benefits
- Retraining partnerships with local universities
- Job placement services
- Relocation support for workers moving to new sites

8.2.3 Skills Development Strategy

Critical Skill Gaps:

- Hydrogen technology (production, storage, safety)
- Advanced process control and automation
- Data analytics and AI for steel production

- Environmental management and carbon accounting
- Renewable energy integration

Training Initiatives:

- **Apprenticeship Reform:** New "Green Steel Technician" qualification
- **University Partnerships:** RWTH Aachen, TU Dortmund leading H steel research
- **Industry Academies:** ThyssenKrupp and Salzgitter running in-house programs
- **EU Funding:** ESF+ (European Social Fund Plus) supporting reskilling

8.3 Social Dialogue and Stakeholder Engagement

8.3.1 Co-Determination Model

Germany's unique governance structure:

- **Supervisory Boards:** 50% worker representation in large companies
- **Works Councils:** Strong rights in operational decisions
- **Collective Bargaining:** IG Metall negotiates transformation terms
- **Result:** More consensual, slower but more stable transitions

Impact on Decarbonization:

- Worker acceptance higher due to participation
- Social package costs built into project budgets
- Timelines extended to accommodate just transition
- Political support more durable (cross-party worker backing)

8.3.2 Community Engagement

Regional Transformation Conferences:

- Regular forums with companies, unions, municipalities
- Transparency on transition plans and timelines
- Co-development of regional economic strategies

- Addressing community concerns (noise, traffic, environmental)

Public Communication:

- ThyssenKrupp "bluemintő Steel" branding campaign
- Salzgitter visitor centers and educational programs
- Media engagement emphasizing opportunity over threat
- Countering misinformation about job losses

Key Producers

8.4 Germany vs. China: Contrasting Approaches

8.4.1 China's October 2024 Policy Revolution

China's transformative policies announced in October 2024 have fundamentally altered global steel dynamics:

Key Chinese Measures:

- **Zero New BF-BOF Approvals:** No blast furnace projects approved in H1 2024
- **EAF Expansion:** Only EAF projects approved (7.1-7.2 Mt capacity)
- **Target Shift:** EAF share 10% 15% by 2025
- **Scrap Mobilization:** 214 Mt 300 Mt/year by 2025
- **Emissions Reduction:** -53 Mt CO (2024-2025)
- **ETS Integration:** Steel sector included in national carbon trading
- **Trade-In Program:** Subsidies for consumer goods replacement scrap generation

Comparative Analysis:

Table 10: Germany vs. China Steel Decarbonization Strategies

Factor	Germany	China
Scale	37 Mt production (2% global)	1,018 Mt production (53% global)
Technology Focus	H-DRI-EAF (premium route)	EAF + scrap (pragmatic route)
Timeline	2027-2045 (gradual)	2024-2030 (accelerated)
Investment Model	50-55% public subsidy	State-directed, enterprise-funded
Hydrogen Strategy	Green H priority	Limited green H, focus on alternatives
BF-BOF Phase-out	Gradual (2027-2045)	Immediate freeze on new capacity
Scrap Utilization	Limited domestic supply	Massive mobilization (300 Mt/year)
Carbon Pricing	EU ETS (60-100/t CO)	National ETS (12-15/t CO)
Trade Protection	CBAM (from 2026)	Domestic market focus, export controls
Market Driver	Regulatory compliance	Industrial policy + climate

Implications for Germany:

1. **Competitive Pressure:** China's rapid EAF expansion creates lower-cost production base
2. **Technology Race:** Chinese companies (Baosteel, Ansteel) demonstrating large-scale low-carbon production
3. **Market Impact:** Even with CBAM, Chinese steel may remain competitive due to scale
4. **Supply Chain:** China's control of scrap and DRI-grade ore markets affects German procurement
5. **Innovation Spillovers:** China's pragmatic approach may offer lessons for Germany's bridge strategies

German Industry Response:

- Recognition that hydrogen-based route is higher-risk, higher-reward

- Increasing interest in hybrid DRI-scrap routes (learning from China)
- Calls for EU-China dialogue on steel decarbonization standards
- Concern that CBAM alone may not offset China's cost advantages

8.5 Germany vs. Other European Producers

8.5.1 France

ArcelorMittal Dunkirk Project:

- 2.5 Mt DRI + 2 EAF (delayed to 2027-2028)
- 1.2 billion first EAF confirmed (May 2025)
- Similar challenges: hydrogen costs, electricity prices
- French government support: 850 million

Germany vs. France Comparison:

- France: lower electricity costs (nuclear base), advantage for EAF
- Germany: stronger industrial base, more comprehensive hydrogen strategy
- France: centralized decision-making, faster permitting
- Germany: federal-state complexity, more stakeholder consultation

8.5.2 Sweden (H2 Green Steel)

Pioneering Project:

- 5 Mt green steel plant in Boden (Northern Sweden)
- 100% green hydrogen-powered DRI-EAF
- Expected start: 2026-2027
- Investment: 4-5 billion

Sweden's Advantages vs. Germany:

- **Electricity:** <20/MWh (abundant hydro, wind) vs. 50-80/MWh in Germany
- **Hydrogen:** Projected 2.50-3/kg vs. 9+/kg in Germany

- **Greenfield:** New plant with optimized design vs. brownfield conversions
- **Permitting:** Faster approvals in less dense region
- **Market:** Direct access to premium customers (Volvo, Mercedes pre-orders)

German Industry Concern:
Sweden's project demonstrates that:

> *"Countries with abundant cheap renewable energy and streamlined permitting can produce green steel at significantly lower costs than Germany, potentially undermining even CBAM protection."*

8.5.3 Spain

ArcelorMittal Gijón:

- 1 billion DRI project (delayed indefinitely as of November 2024)
- Citing same issues as German withdrawal: costs, uncertainty
- Spanish government support uncertain

Comparison:

- Spain has excellent solar/wind resources but underdeveloped hydrogen infrastructure
- Germany's advantage: more advanced institutional support and funding
- Both face similar challenges with hydrogen economics

8.6 Germany vs. Non-EU Competitors

8.6.1 United States

US Approach:

- Inflation Reduction Act (IRA): $369 billion climate spending$
- Steel-specific: limited direct support, focus on clean energy
- Trade barriers: 25% tariffs on imports (2024)
- Technology: some EAF expansion, limited H-DRI interest

Competitive Dynamics:

- US market closed to German exports (tariffs)
- US decarbonization slower but less dependent on hydrogen
- Shale gas advantage: cheap natural gas for DRI bridge strategy
- IRA subsidies attracting European companies to relocate

8.6.2 Japan and South Korea

Japan:

- Nippon Steel, JFE: piloting hydrogen injection in blast furnaces
- COURSE50 program: 30% hydrogen blending
- Timeline: 2030s for full H-DRI transition
- Strategy: incremental, risk-averse approach

South Korea:

- POSCO HyREX technology: hydrogen-based reduction
- Target: 1.1 Mt green steel by 2030
- Investment: $9billionover10years$
- Advantage: integrated chaebol structure enables cross-subsidy

Germany's Position:

- More aggressive timeline than Japan/Korea
- Higher risk but potential first-mover advantage in premium markets
- Technology collaboration potential (ThyssenKrupp-POSCO dialogue)

8.6.3 Brazil

Brazilian Context (from MIFUS Brazil study):

- 31 Mt production, mostly charcoal-based (unique low-carbon route)
- CSN, Gerdau, Usiminas: limited decarbonization pressure
- Abundant renewable energy (hydro) but limited hydrogen infrastructure
- Export-oriented: vulnerable to CBAM

Germany vs. Brazil:

- Brazil's charcoal route already lower-carbon than German BF-BOF
- Germany faces higher decarbonization costs
- Brazil may capture market share if CBAM considers charcoal favorably
- Germany's premium products less threatened by Brazilian competition

8.7 Key Takeaways from Global Comparison

1. **Germany is in the "middle pack":** More aggressive than US/Japan, less than Sweden, similar to France
2. **Cost competitiveness critical:** Without addressing energy costs, even full decarbonization may not save German steel
3. **China's approach is game-changing:** Scale and speed of Chinese transformation raises bar for everyone
4. **CBAM is necessary but not sufficient:** Trade protection must be combined with competitive production costs
5. **Hydrogen economics are global challenge:** Even leading countries struggle with H costs and infrastructure
6. **First-mover risk is real:** Germany may pay premium for pioneering while others learn from mistakes

9 Critical Success Factors and Risks

9.1 Success Factors

9.1.1 Technical Feasibility

Strengths:

- Proven DRI-EAF technology (used globally for decades)
- German engineering excellence and R&D capacity
- Strong partnerships (equipment suppliers, technology providers)
- Pilot projects demonstrating hydrogen use

Remaining Challenges:

- Large-scale hydrogen-based DRI not yet commercialized at 2+ Mt scale
- Integration of intermittent renewable power with continuous steel production
- Quality assurance for hydrogen-reduced iron
- Long-term equipment reliability unknown

9.1.2 Economic Viability

Requirements for Success:

1. **Hydrogen Cost <4.50/kg:**
   - Current: 9.35/kg (March 2025)
   - Path: Scale-up of electrolysis, cheap renewable power, infrastructure development
   - Timeline: 2028-2030 (optimistic), 2032-2035 (realistic)
   - Risk: May not occur, or may occur too late
2. **Electricity Cost Reduction:**
   - Current: 50-80/MWh
   - Target: 30-40/MWh for competitiveness
   - Path: PPAs, tax reform, grid tariff reduction

- Timeline: Requires policy action, could be immediate

3. **Carbon Price Stability:**
   - Current: 60-100/tonne CO (volatile)
   - Ideal: 80-100/tonne (stable, rising)
   - Path: EU ETS reforms, CBAM implementation
   - CCfD contracts provide hedge against volatility
4. **Market for Green Steel Premium:**
   - Premium needed: 100-200/tonne initially
   - Willing buyers: Automotive (VW, BMW, Mercedes), construction (some)
   - Volume: Pre-orders for 500,000+ tonnes secured
   - Risk: Premium shrinks as green steel becomes standard

9.1.3 Policy and Regulatory Stability

Essential Elements:

- **Long-term Commitment:** Bipartisan support beyond 2025 elections
- **Funding Security:** CCfD and subsidy budgets protected
- **CBAM Enforcement:** Effective implementation without loopholes
- **Hydrogen Infrastructure:** Timely rollout of HCN
- **Energy Policy:** Accelerated renewable expansion, grid modernization

Political Risks:

- 2025 federal elections: potential coalition changes
- Fiscal pressure: climate fund constraints
- Public opinion: backlash against high energy costs
- EU-level: divergent priorities among member states

9.2 Risk Factors

9.2.1 Technology and Execution Risks

Table 11: Key Technology and Execution Risks

Risk	Description	Mitigation
H-DRI Scale-up	Unproven at 2+ Mt scale	Phased rollout, pilot testing
Equipment Reliability	New technology, potential failures	Redundancy, maintenance protocols
Integration Complexity	Connecting DRI to existing mills	Detailed engineering, simulation
Hydrogen Supply Interruption	Pipeline failures, electrolyzer downtime	Nat. gas backup, storage buffers
Quality Variability	H-DRI may have different properties	Extensive R&D, quality control
Timeline Delays	Permitting, construction, commissioning	Contingency planning, political support

9.2.2 Economic and Market Risks

1. **Demand Weakness:**
    - Persistent recession reduces steel consumption
    - Automotive electrification reduces steel intensity per vehicle
    - Construction sector stagnation continues
    - Result: Overcapacity, low utilization, losses
2. **Cost Overruns:**
    - CAPEX inflation (equipment, construction labor)
    - OPEX higher than projected (H, electricity)
    - Subsidy gaps emerge if costs exceed budget
    - Companies may abandon projects (ArcelorMittal precedent)
3. **Import Competition:**
    - CBAM circumvention (transhipment, false declarations)

- Low-cost producers find ways to remain competitive
- Green steel from countries with cheaper energy (Sweden, Spain, Middle East)
- Result: German producers cannot recover investments

4. **Green Premium Collapse:**
   - As supply increases, premium for green steel shrinks
   - Customers unwilling to pay once novelty wears off
   - Competitors offer green steel at lower prices
   - Result: Business case deteriorates post-investment

9.2.3 Geopolitical and Trade Risks

- **US Trade Barriers:** 25% tariffs persist or expand
- **China Retaliation:** Counter-measures to CBAM
- **Energy Security:** Gas supply disruptions affect bridge strategy
- **Critical Materials:** Shortages of DRI-grade ore, electrolyzer components
- **Global Recession:** Synchronized downturn crushes steel demand

9.2.4 Social and Political Risks

- **Labor Unrest:** Strikes over job losses despite just transition measures
- **Regional Opposition:** Communities resist plant closures
- **Political Backlash:** High energy costs blamed on green transition
- **Election Uncertainty:** 2025 elections bring policy reversals
- **Public Opinion Shift:** Climate skepticism grows amid economic hardship

9.3 Scenario Analysis

9.3.1 Optimistic Scenario: "Green Steel Leader"

Assumptions:

- Hydrogen costs fall to 3.50/kg by 2030
- Electricity costs reduced by policy reforms

- Strong steel demand recovery
- CBAM effectively enforced
- Political continuity and funding security

Outcomes by 2035:

- Germany produces 25-30 Mt green steel/year
- Global leadership in H-DRI technology
- Premium pricing maintained (50-100/tonne)
- Exports to US and Asia (technology licensing)
- Employment stabilizes at 65,000 (down 20% but sustainable)
- 80% emissions reduction achieved

9.3.2 Base Case Scenario: "Managed Transition"

Assumptions:

- Hydrogen costs reach 4.50-5/kg by 2032
- Electricity costs moderately reduced
- Modest demand recovery
- CBAM partially effective (some circumvention)
- Stable but minimal policy support

Outcomes by 2035:

- Germany produces 15-20 Mt green steel/year
- Significant capacity reduction (from 37 Mt current)
- Hybrid production (H-DRI + natural gas bridge + EAF)
- Limited exports, focus on premium domestic/EU market
- Employment at 50,000 (down 40%)
- 60% emissions reduction achieved

9.3.3 Pessimistic Scenario: "Industrial Decline"

Assumptions:

- Hydrogen costs remain >7/kg through 2035
- Electricity costs stay high
- Persistent weak demand
- CBAM circumvented or weakened
- Policy support wanes (fiscal constraints, political change)

Outcomes by 2035:

- Germany produces 10-15 Mt steel/year (massive contraction)
- One or more major producers exit (following ArcelorMittal)
- Remaining production mostly EAF with imported DRI
- Minimal green steel production (uncompetitive)
- Employment at 30,000 (down 60%)
- 40% emissions reduction (but from much lower base)
- Loss of industrial capability and technological leadership

Probability Assessment (Author's View):

- Optimistic: 20-25%
- Base Case: 50-60%
- Pessimistic: 20-25%

10 Recommendations and Policy Implications

10.1 For German Government

10.1.1 Immediate Actions (2025-2026)

1. **Secure Energy Cost Competitiveness:**
    - Reduce electricity network charges for steel sector by 30-40%

- Fast-track PPA approvals and facilitate long-term contracts
- Provide transitional support until renewable costs decline
- Target: 30-40/MWh effective power costs for industry

2. **Hydrogen Price Support:**
    - CCfD contracts with strike price 4-4.50/kg
    - Duration: 10-15 years to provide investment certainty
    - Volume: Cover full 320,000 t/year steel sector needs
    - Funding: Allocate 2-3 billion/year from climate fund
3. **Accelerate Infrastructure:**
    - Priority status for hydrogen core network connections to steel sites
    - Target: Duisburg, Salzgitter, Saar connected by 2027
    - Grid reinforcement for increased renewable capacity
    - Streamlined permitting for electrolyzer and DRI plants
4. **Ensure Policy Continuity:**
    - Cross-party agreement on steel decarbonization beyond 2025 elections
    - Legal guarantees for funding commitments
    - Communication campaign emphasizing strategic importance

10.1.2 Medium-Term Actions (2026-2030)

1. **Green Steel Market Creation:**
    - Mandatory green steel quotas for public procurement
    - Incentives for private sector offtake agreements
    - Automotive sector: require 30% low-CO steel by 2030
    - Construction: preferential treatment for green steel in projects
2. **Circular Economy Integration:**
    - Scrap mobilization strategy (target: 12-15 Mt/year domestic generation)
    - Improved end-of-life vehicle processing
    - Closed-loop requirements for automotive and appliances

- Export restrictions on high-quality scrap

3. **R&D and Innovation:**
    - 500 million fund for steel decarbonization research
    - Focus areas: hydrogen reduction optimization, hybrid DRI-scrap routes, carbon capture for residual emissions
    - Public-private partnerships with universities and industry
    - International collaboration (EU, Japan, Korea)

4. **Just Transition Reinforcement:**
    - Expand vocational training in hydrogen and clean tech
    - Regional economic diversification in steel communities
    - Enhanced social support for displaced workers
    - Monitoring and adjustment based on actual impacts

10.2 For European Union

10.2.1 Trade and Market Access

1. **CBAM Strengthening:**
    - Rapid extension to downstream products (2027 target vs. 2030)
    - Robust anti-circumvention measures
    - Include scrap in CBAM scope (close loophole)
    - Adequate resources for enforcement

    - New trade defense instrument against global overcapacity
    - Specific measures targeting subsidized imports
    - Coordination with US on China policy (without tariff wars)
    - Support for steel sections in trade agreements

2. **Global Standards:**
    - Lead development of international green steel definitions
    - Mutual recognition agreements with key partners
    - Support for Global Arrangement on Sustainable Steel and Aluminum
    - Technology transfer to developing countries

10.2.2 Financing and Support

1. **Industrial Decarbonisation Bank:**
    - Reach 100 billion target quickly
    - Prioritize first-movers (reward early action)
    - Flexible terms for projects facing headwinds
    - Coordinate with national programs (Germany's CCfD)
2. **Innovation Fund Scale-up:**
    - Increase from 1 billion pilot to 5-10 billion/year
    - Focus on breakthrough technologies
    - Support for replication of successful pilots
    - Risk-sharing for commercial-scale demonstration
3. **Energy Price Equalization:**
    - EU-wide mechanism to reduce industrial power cost disparities
    - Support for cross-border PPAs and hydrogen trading
    - Grid development fund for renewable integration
    - Temporary compensation for highest-cost regions

10.3 For Steel Companies

10.3.1 Strategic Recommendations

1. **Embrace Bridge Strategies:**
    - Don't wait for perfect green hydrogen availability
    - Use natural gas DRI as transitional technology
    - Design plants for eventual 100% H operation
    - Learn from ArcelorMittal's all-or-nothing failure
2. **Secure Long-Term Offtake:**
    - Priority: sign binding agreements before FID
    - Target customers: automotive OEMs, premium construction
    - Volume: minimum 70% of planned green steel capacity

- Pricing: index to carbon price for automatic adjustment

3. **Diversify Hydrogen Sourcing:**
    - Combination of on-site production + pipeline + imports
    - Multiple suppliers to reduce dependence
    - Storage capacity for supply security
    - Consider hydrogen derivatives (ammonia) if economical
4. **Optimize Capacity:**
    - Right-size for realistic demand (follow ThyssenKrupp)
    - Focus on premium products with highest margins
    - Exit commodity segments where imports dominate
    - Consolidation may be necessary
5. **Invest in Circular Economy:**
    - Hybrid DRI-scrap routes (60% DRI + 40% scrap)
    - Partnerships with automotive/appliance sectors for closed-loop
    - Advanced scrap sorting and processing
    - Reduce dependence on expensive green hydrogen

10.3.2 Risk Management

1. **Phased Investment:**
    - Stage 1: Pilot/demonstration (de-risk technology)
    - Stage 2: First commercial plant (test market)
    - Stage 3: Full transformation (once proven)
    - Build in exit options at each stage
2. **Financial Hedging:**
    - CCfD contracts for carbon price risk
    - Long-term PPAs for electricity price risk
    - Fixed-price hydrogen contracts (if available)
    - Diversified revenue streams (technology licensing, carbon credits)

3. **Political Engagement:**
    - Maintain dialogue with government at all levels
    - Transparent communication on challenges
    - Participate in policy development (not just lobbying)
    - Build public support through community engagement

10.4 For International Community

10.4.1 Technology Cooperation

- **Share Learning:** Establish international platform for steel decarbonization knowledge exchange
- **Joint R&D:** Collaborate on breakthrough technologies (advanced DRI, electrolysis, CCUS)
- **Standards Harmonization:** Avoid fragmentation of green steel definitions
- **Capacity Building:** Support developing countries in technology access

10.4.2 Trade Framework

- **Climate Clubs:** Form coalitions of decarbonizing countries
- **WTO Reform:** Clarify rules on climate-related trade measures
- **Mutual Recognition:** Accept each other's carbon accounting methods
- **Avoid Trade Wars:** Dialogue > unilateral tariffs (learn from US-EU tensions)

11 Conclusions

11.1 Summary of Key Findings

Germany's steel decarbonization represents one of the most ambitious industrial transformations in modern history. This analysis, conducted within the MIFUS framework and informed by global comparisons (especially China's October 2024 policy revolution), yields several critical conclusions:

11.1.1 1. Germany Is At a Critical Juncture

The sector faces a **triple crisis** of climate imperatives, economic fragility, and geopolitical pressures. The decision by ArcelorMittal to withdraw from subsidies (June 2024) demonstrated that even massive public support may be insufficient without addressing structural cost disadvantages.

11.1.2 2. Hydrogen Economics Are the Central Challenge

Current hydrogen prices of 9+/kg make green steel uncompetitive by 200-400/tonne. The entire decarbonization pathway depends on achieving <4.50/kg by 2030, requiring:

- Massive electrolyzer scale-up
- Abundant cheap renewable electricity
- Timely infrastructure development
- Supportive regulatory frameworks

Assessment: This is achievable but not guaranteed. Delays of 3-5 years are plausible, threatening project viability.

11.1.3 3. Energy Costs Must Be Addressed Urgently

Germany's 40-60% electricity cost premium vs. EU average is unsustainable. The December 2024 incident (45.6% EAF output drop due to price spike) illustrates acute vulnerability. Without policy action on:

- Network tariff reduction
- Tax reform for industry
- Facilitated PPAs

...even decarbonized German steel will struggle to compete with conventional imports plus CBAM costs.

11.1.4 4. China's Transformation Changes Everything

China's October 2024 policies particularly the freeze on new BF-BOF capacity and rapid EAF expansion represent a strategic pivot that:

- Validates EAF/scrap route as pragmatic alternative to H-DRI

- Creates competitive pressure through scale (1+ Gt production)
- Demonstrates that decarbonization can be achieved faster than expected
- Forces Germany to reconsider whether H-DRI is the only path

Insight: Germany's high-risk, high-reward hydrogen strategy may be outflanked by China's pragmatic, lower-cost approach.

11.1.5 5. CBAM Is Necessary But Not Sufficient

The Carbon Border Adjustment Mechanism provides essential protection, but:

- Circumvention risks are real
- Low-cost countries (Sweden, Middle East) can produce green steel cheaper
- Downstream products (where value is added) need urgent inclusion
- Global coordination needed to avoid trade wars

Conclusion: CBAM must be complemented by domestic cost competitiveness, not relied upon alone.

11.1.6 6. The Just Transition Is Manageable But Requires Commitment

Germany's co-determination model and strong social dialogue position it well to manage the employment transition. Projected net job losses of 5-20% (depending on scenario) are significant but not catastrophic if:

- Retraining programs are adequately funded
- New hydrogen economy jobs materialize
- Regional economic diversification succeeds
- Transition timeline allows gradual adjustment

Risk: Rapid plant closures due to economic failure would overwhelm just transition capacity.

11.1.7 7. Technology Risk Is Lower Than Economic Risk

H-DRI-EAF technology is proven at pilot scale. Scaling to multi-million tonne capacity involves execution risk but no fundamental technical barriers. The greater risks are:

- Economic viability (costs)
- Infrastructure availability (hydrogen, electricity, grid)
- Market conditions (demand, prices, competition)
- Political stability (funding, regulations)

Implication: Policy and market conditions matter more than technology development.

11.2 The Three Possible Futures

Based on scenario analysis, Germany's steel sector in 2035-2040 will likely fall into one of three categories:

11.2.1 Scenario A: "Green Steel Champion" (20-25% probability)

Characteristics:

- 25-30 Mt green steel production
- Global technology leadership
- Profitable operations with premium pricing
- Stable employment (65,000)
- 80% emissions reduction

Required Conditions:

- Hydrogen <3.50/kg by 2030
- Electricity costs reduced 30-40%
- Strong demand recovery
- Effective CBAM
- Political continuity

11.2.2 Scenario B: "Managed Contraction" (50-60% probability)

Characteristics:

- 15-20 Mt production (down from 37 Mt)
- Mix of green and conventional (bridge strategies)
- Marginally profitable, dependent on subsidies
- Employment 50,000 (down 40%)
- 60% emissions reduction

Required Conditions:

- Hydrogen 4.50-5/kg by 2032
- Modest cost improvements
- Stable but weak demand
- Partial CBAM effectiveness
- Continued policy support

11.2.3 Scenario C: "Industrial Decline" (20-25% probability)

Characteristics:

- 10-15 Mt production (major contraction)
- One or more major exits
- Chronic losses, subsidy dependence
- Employment 30,000 (down 60%)
- 40% emissions reduction (from lower base)

Triggering Conditions:

- Hydrogen >7/kg through 2035
- Persistent high electricity costs
- Weak demand
- CBAM failure
- Policy support withdrawal

11.3 Critical Path Forward

For Germany to achieve Scenario A or at minimum B (avoiding C), the following sequence is critical:

2025-2026: Foundation

- Secure cross-party political commitment beyond elections
- Implement energy cost reduction measures
- Award first CCfD contracts
- Complete infrastructure planning

2027-2028: First Movers

- ThyssenKrupp first DRI plant operational
- Salzgitter electrolyzer integrated
- Initial green steel market formation
- CBAM definitive phase learning curve

2029-2030: Scale-Up Decision Point

- Hydrogen costs assessed vs. targets
- First projects evaluated (success/failure)
- Decision on full transformation vs. partial
- Potential consolidation/exits

2031-2035: Transformation Phase

- Multiple BF-BOF closures/conversions
- Large-scale H supply operational
- Green steel becomes mainstream
- Competitive position clarified

2036-2045: Completion

- Remaining conventional capacity eliminated
- Germany either a green steel leader or a reduced player
- Employment and regional impacts fully realized
- Climate targets achieved or missed

11.4 Final Assessment

Germany's steel decarbonization is **technically feasible, economically challenging, and politically critical**. Success is possible but not assured. The sector's fate will be determined by:

1. **Speed of Hydrogen Cost Reduction:** The single most important variable
2. **Political Will:** Sustaining support through economic difficulties
3. **Global Coordination:** Managing trade tensions and technology competition
4. **Energy Transition:** Renewable electricity availability and cost
5. **Market Demand:** Steel consumption recovery and green premium persistence

MIFUS Perspective: Comparing Germany to the 20+ countries studied in this initiative, Germany represents the *"high ambition, high risk"* approach. Unlike China's pragmatic EAF expansion or Brazil's charcoal-based low-carbon production, Germany is betting on hydrogen-based premium steel in a competitive global market.

This strategy could position Germany as the technology leader of a decarbonized steel future, capturing premium markets and licensing technology globally. Or it could result in a painful industrial contraction as lower-cost producers (Chinese EAF, Swedish green DRI, Middle Eastern gas-based) capture market share.

The next 5 years (2025-2030) will be decisive. The projects currently under development will either validate the business case for green steel transformation or demonstrate that even massive subsidies cannot overcome structural cost disadvantages.

As Vice-Chancellor Habeck stated, steel decarbonization is "politically prestigious" for Germany. The question is whether prestige can be converted into competitive advantage, or whether Germany is paying a first-mover premium that followers will not have to bear.

11.5 Contribution to MIFUS Research

This Germany study complements the MIFUS global analysis by:

- **Documenting the EU's Flagship Effort:** Germany received 75% of EC steel funds understanding its success/failure is crucial
- **Analyzing H-DRI Economics:** Detailed examination of costs, risks, and feasibility applicable to other countries
- **Contrasting with China:** Direct comparison between hydrogen-premium and EAF-pragmatic approaches

- **Exploring Just Transition:** Germany's co-determination model offers lessons for managing social impacts
- **Testing CBAM Effects:** Real-world assessment of how carbon border adjustment affects investment decisions
- **Demonstrating Infrastructure Dependencies:** Highlighting that decarbonization requires ecosystem transformation, not just plant upgrades

Key Lesson for Other Countries:
Germany's experience suggests that:

> *"Ambitious climate targets and generous subsidies are necessary but not sufficient for steel decarbonization. Competitive energy costs, hydrogen infrastructure, market demand, and sustained political commitment are equally critical. Countries with abundant cheap renewable energy (Sweden, Middle East, Australia) may achieve decarbonization at lower cost than industrial heartlands with legacy infrastructure and high energy costs."*

The global steel industry will be watching Germany's transformation closely. Success would accelerate worldwide decarbonization. Failure would reinforce skepticism about green steel economics and slow the transition globally.

"The transformation of Germany's steel industry is not just about reducing emissions it's about whether Europe's industrial model can survive and thrive in a carbon-constrained world.
The answer will shape industrial policy globally for decades to come."

— MIFUS Research Team, November 2025

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Version Control:

- Version: 1.0
- Date: November 2025
- Author: Prof. Fabio Miani, University of Udine
- MIFUS Project: https://www.gotrawama.eu/estep25udine/pdf/

Acknowledgments:

This research was conducted as part of the MIFUS (A Global Journey Through Steel Decarbonization) initiative at the University of Udine. The author thanks all contributors to the MIFUS project documentation, particularly those involved in the development of the global overview documents, China policy analysis, and European Union framework studies that informed this Germany-specific analysis.

Special acknowledgment to the steel industry professionals, government officials, trade union representatives, and academic colleagues who provided insights and data for this study.

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