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Effects of Carbon Border Adjustment Mechanisms on Emissions, Industrial Competitiveness and Carbon-Capture Investment in Developing and Emerging Economies

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Abstract: The definitive phase of the European Union Carbon Border Adjustment Mechanism (CBAM) commenced on 1 January 2026 for cement, aluminium, fertilisers, iron and steel, hydrogen and electricity. The policy is intended to equalise carbon costs and reduce leakage, but its distributional consequences are asymmetric because developing and emerging economies often combine carbon-intensive production, limited measurement-reporting-verification capacity, expensive capital and strong dependence on a narrow set of exports. This study develops an integrated trade-carbon-cost framework linking multi-regional input-output and computable-general-equilibrium channels with product-level carbon footprints, price-elasticity analysis and plant-level carbon capture and storage (CCS) investment thresholds. The legal baseline incorporates the 50-tonne de minimis rule, the 2026-2034 phase-in, recognition of carbon prices paid in the country of origin and the published Q2-2026 certificate price of EUR75.28/tCO2. World Bank exposure rankings are combined with six literature-calibrated industrial archetypes: blast-furnace steel, cement clinker, primary aluminium, ammonia, grey hydrogen and coal-based electricity. Results show that first-year gross charges are modest because only 2.5% of the full obligation is phased in, but the effective carbon signal rises sharply after 2029. At a 2030 carbon price of EUR107/tCO2, modelled gross border costs reach 19.3% of steel value, 37.7% of clinker value, 24.9% of ammonia value and 48.7% of electricity value before detailed benchmark adjustments and domestic carbon-price credits. Under a central export-demand elasticity of 1.5, these shocks imply volume losses of approximately 23%, 38%, 28% and 45%, respectively. Marginal CCS parity emerges between 2031 and 2034 depending on sector, while long-horizon discounted analysis shows that CBAM alone is insufficient to finance high-cost capture in steel and cement without concessional finance, shared transport-storage infrastructure or low-carbon product premiums. The paper proposes a five-layer policy architecture integrating MRV, domestic carbon pricing, industrial transition finance, technology transfer and just-transition safeguards. The principal contribution is a transparent decision rule that connects international trade exposure directly to plant-level carbon-capture investment timing.

Keywords: *Carbon Border Adjustment Mechanism; Carbon Capture and Storage; Industrial Competitiveness; Embedded Emissions; Developing Economies; Climate Finance; Just Transition.*

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I. INTRODUCTION

Carbon-border adjustment has moved from a theoretical instrument to an operational element of climate and trade policy. Regulation (EU) 2023/956 established the EU CBAM, while the 2025 simplification regulation introduced a mass-based threshold that exempts most small importers without materially reducing emissions coverage. The definitive regime began on 1 January 2026. Importers above 50 tonnes per year of cement, iron and steel, aluminium and fertilisers require authorised-declarant status; electricity and hydrogen remain in scope regardless of quantity. The first annual declaration and

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surrender for 2026 imports are due in 2027, and certificate prices are linked to EU Emissions Trading System allowance prices. [1-7]

For developing and emerging economies, the main concern is not the average macroeconomic effect but the concentration of risk in specific products, plants, regions and workforces. A country may experience a negligible change in national gross domestic product while a single aluminium smelter, fertiliser complex, steelworks or cement cluster loses a large share of its European market. World Bank exposure indices consequently distinguish trade exposure, output exposure and economy-wide exposure, identifying countries such as Mozambique, Ukraine, Egypt, India, Uzbekistan, Kazakhstan, South Africa, Georgia, Tunisia and Indonesia as priority cases under different metrics. [8,18,19]

The policy can transmit through four channels. First, a direct carbon-cost channel raises the landed price of high-emission goods. Second, a demand and trade-diversion channel shifts EU purchases toward cleaner suppliers or domestic production. Third, an investment channel changes the relative economics of efficiency, fuel switching, renewable power, hydrogen and CCS. Fourth, a distributional channel reallocates income among exporters, importers, workers, consumers and governments. General-equilibrium studies normally capture the first two channels, while engineering studies evaluate the third; few frameworks connect all four at a plant decision level. [9-17,24-38]

This paper addresses that gap by developing an integrated decision framework with three questions. What is the magnitude of product and country exposure as CBAM phases in? At what carbon-price and phase-in combination does carbon capture become cheaper than continuing to pay the border charge? Which policy package can preserve legitimate industrial development while maintaining climate integrity? Because the definitive regime has only recently begun, the analysis is explicitly ex ante and scenario-based rather than claiming causal effects that cannot yet be observed. Its novelty is the direct conversion of border-carbon exposure into a time-dependent industrial investment signal.

II. LITERATURE REVIEW AND CONCEPTUAL FOUNDATION

➢ *Carbon Leakage, Competitiveness and Border Adjustment*

The economic justification for a border adjustment is the risk that asymmetric climate policy relocates production, investment or market share without reducing global emissions. The literature distinguishes operational leakage, investment leakage and fossil-fuel-price leakage. Meta-analysis indicates that leakage and competitiveness effects are usually limited at the economy-wide level but can be substantial for emissions-intensive and trade-exposed sectors. Border adjustments, output-based rebates and free allocation can reduce leakage, but they differ in environmental effectiveness, administrative burden, fiscal incidence and consistency with trade rules. [24-35]

An effective mechanism must compare like with like: imported and domestic products should face comparable carbon costs, while actual carbon prices paid abroad should be credited. However, default emission values, incomplete supply-chain boundaries and product re-routing can generate strategic behaviour. Clean firms in carbon-intensive countries may gain if they can document actual emissions below punitive defaults; high-emission firms may face price compression or market exit. This heterogeneity is central to the analytical model developed below. [5,6,15,31-38]

➢ *Developing-Country Exposure and Climate Justice*

UNCTAD and subsequent modelling studies find that aggregate global emissions reductions from a unilateral CBAM are modest relative to the potential trade and income redistribution. Vulnerability is higher where CBAM sectors account for a large share of exports, production or fiscal revenue and where firms lack access to low-cost finance, renewable power, scrap, high-grade ore, geological storage or verified emissions data. Least-developed-country impacts may be small in aggregate, yet the same economies have the least administrative capacity and the greatest sensitivity to a single plant closure. [8-19]

The climate-justice debate therefore concerns both responsibility and capability. Developing economies have contributed less to historical emissions, require continued industrialisation and often face a higher weighted average cost of capital. A border measure that raises the cost of exports without recycling finance can transfer adjustment costs to jurisdictions with limited fiscal space. Conversely, exemption without decarbonisation conditions can weaken incentives and leave exposed producers vulnerable to future border measures in other markets. The policy problem is to combine environmental equivalence with differentiated implementation support. [13-18,21-23,67,68]

➢ *Carbon Capture as an Industrial Competitiveness Option*

CCS is especially relevant where emissions arise from chemical reactions or reducing agents rather than combustion alone. Cement calcination, natural-gas and coal-based ammonia, grey hydrogen and portions of integrated steelmaking have residual emissions that are difficult to eliminate through efficiency or electrification. The IEA, IPCC and Global CCS Institute consequently include capture, transport and geological storage in pathways for net-zero heavy industry, although cost, energy penalty, infrastructure access, capture rate and long-term liability remain critical constraints. [39-50]

Published avoidance costs vary by stream concentration, plant configuration, energy price and infrastructure. High-purity process streams can be captured at comparatively low cost; dilute flue gases and retrofits can exceed EUR100/tCO_2. Shared pipeline and storage hubs lower transport costs and reduce the minimum efficient scale. Steel also has alternative routes, including scrap-electric arc furnaces and hydrogen direct reduction, so CCS should be compared with full process transformation rather than treated as the universal solution. For cement and some chemical plants, however, capture remains one of the few deep-abatement options. [40-54]

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➢ *Methodological Gap*

Trade models generally represent technology through sector averages, while plant-level engineering studies rarely include market elasticity, export dependence or carbon-border phase-in. Multi-regional input-output databases provide embodied-emissions linkages but cannot by themselves determine whether a plant should pay a border charge, switch technology or install capture. The present framework links these levels through a common product unit, a consistent carbon price and an explicit investment parity rule. [55-66]

III. MATERIALS AND METHODS

➢ *Research Design and System Boundary*

The study employs an integrated ex ante assessment combining: (i) country-sector exposure screening; (ii) product-level carbon-footprint accounting; (iii) CBAM liability scenarios; (iv) constant-elasticity competitiveness analysis; (v) plant-level CCS cost comparison; and (vi) distributional and just-transition interpretation. The system boundary follows the CBAM principle of embedded emissions up to the point at which the covered product leaves the production installation, rather than a complete cradle-to-grave life cycle. Full life-cycle emissions are retained as a sensitivity where indirect electricity and upstream inputs may enter future scope. [1-6,20,63-66]

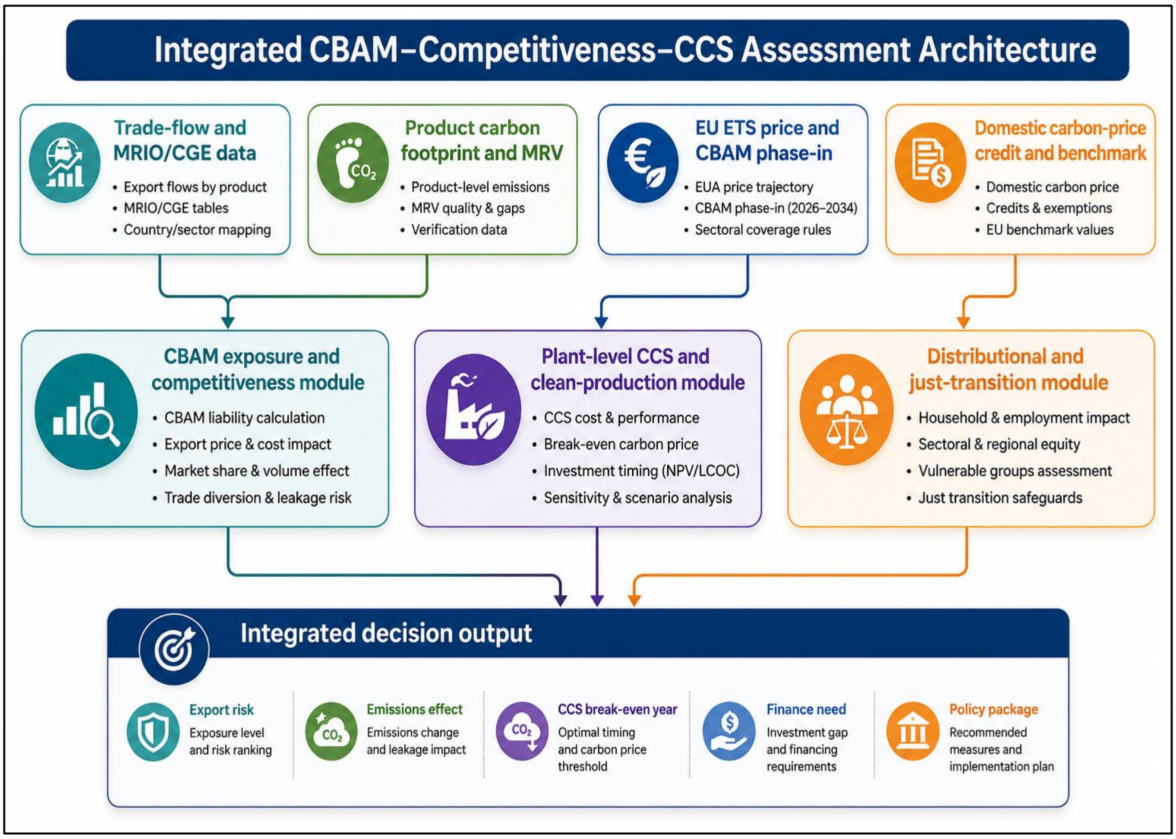

Fig 1 Integrated Analytical Architecture Linking Trade Exposure, Product Carbon Intensity, CBAM Pricing, Industrial Abatement and Distributional Outcomes.

➢ *Data Sources and Calibration*

The legal baseline uses the consolidated CBAM Regulation, the simplification amendment, definitive-period benchmark rules, Commission guidance and the December 2025 transitional review. The Q2-2026 certificate price of EUR75.28/tCO_2 is used as the observed starting point. The phase-in schedule is represented by the proportion of the full carbon obligation exposed as free EU ETS allocation is withdrawn: 2.5% in 2026, 5% in 2027, 10% in 2028, 22.5% in 2029, 48.5% in 2030, 61% in 2031, 73.5% in 2032, 86% in 2033 and 100% from 2034. [1-7]

Country screening follows the World Bank methodological note using 2022 mirror trade data, product-level emissions intensity and EU trade dependence. Sector intensities and CCS costs are calibrated to IEA, JRC, IEAGHG, Global CCS Institute and peer-reviewed techno-economic studies. The purpose is not to reproduce an official compliance calculator; actual liability depends on CN code, verified installation data, precursor treatment, official benchmark adjustment, eligible carbon price paid and certificate timing. [8,20,39-54]

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Table 1 Definitive-Period CBAM Design Variables Used in the Analysis

Variable	2026 analytical treatment
Covered sectors	Cement; aluminium; fertilisers; iron and steel; hydrogen; electricity
De minimis rule	50 tonnes/year for cement, iron/steel, aluminium and fertilisers; not applied to electricity or hydrogen
Price basis	EU ETS-linked certificate price; Q2-2026 observed value EUR75.28/tCO2
Carbon price credit	Verified price effectively paid in the country of origin is deducted
Financial timing	2026 embedded emissions accrue under the definitive regime; first declaration/surrender occurs in 2027
Phase-in	2.5% in 2026, rising to 100% in 2034
Emission scope	Direct emissions for all sectors; relevant indirect emissions included according to sector-specific rules
Verification	Actual embedded emissions require accredited verification under definitive-period rules

➢ *Trade-Exposure Metric*

For country c and sector s, annual gross exposure is the product of EU-bound quantity, product carbon intensity and the phase-adjusted carbon price. Normalising by export value gives an ad valorem exposure ratio. Normalising by sector output or national GDP gives output and macroeconomic exposure, respectively.

GCE(c,s,t) = Q(EU,c,s,t) x EI(c,s,t) x P(C,t) x phi(t) (1)

AER(c,s,t) = GCE(c,s,t) / [Q(EU,c,s,t) x V(c,s,t)] (2)

Here Q is exported quantity, EI is verified embedded emissions per unit, P(C,t) is the certificate price and phi is the phase-in share. The net obligation is reduced by the recognised carbon price paid in the origin country and by the official free-allocation adjustment. The reported scenario values are gross upper-bound exposure indicators before those two deductions.

➢ *Product Competitiveness and Trade Response*

The border cost per unit is divided by the product price to obtain a price wedge, tau. A constant-elasticity import-demand function estimates the retained EU export volume. The central elasticity is 1.5, with 0.75 and 3.0 used as low- and high-response sensitivities.

Q1 / Q0 = (1 + tau) ^ (-eta) (3)

This reduced-form relationship captures substitution toward cleaner suppliers, EU production or downstream alternatives. It does not claim that the entire border charge is passed through. Producer absorption, currency movements, contractual renegotiation and product differentiation can change incidence.

➢ *Carbon-Capture Investment Module*

For each industrial archetype, captured emissions equal baseline emissions multiplied by the effective capture rate after accounting for the energy penalty. The annualised CCS strategy cost includes capture, compression, transport, storage and residual CBAM on uncaptured emissions. A marginal parity condition occurs when the phase-adjusted border-carbon signal equals the levelised cost of CO2 avoided.

C(CCS,t) = E0 x r x AC(CCS) + E0 x (1-r) x P(C,t) x phi(t) (4)

P(C,t) x phi(t) >= AC(CCS) (5)

The parity rule is deliberately simple and transparent. A bankable decision would additionally include capital timing, production utilisation, domestic sales, low-carbon product premiums, tax incentives, shared infrastructure, decommissioning risk and the probability of future scope expansion. Discounted comparisons use a 10% real rate, representing the comparatively high financing conditions faced by many emerging-market industrial projects.

➢ *Input-Output, CGE and Distributional Linkage*

The model can be embedded in a multi-regional input-output system by treating CBAM as an import-margin shock on covered products and tracing upstream embodied emissions through the Leontief inverse. In a CGE model, the same shock enters bilateral trade costs, production nests and government revenue, allowing endogenous substitution, exchange-rate adjustment and welfare effects. The plant-level CCS module returns a lower emission coefficient and higher capital-service requirement to the sector account. Distributional analysis separates skilled and unskilled labour, capital income, government revenue and consumer prices, while a regional module identifies communities dependent on a single installation. [9-12,36,55-62]

➢ *Uncertainty and Limitations*

Monte Carlo or Latin-hypercube sampling can be applied to carbon price, product price, emission intensity, elasticity, capture cost, capture rate and discount rate. The present deterministic results use central values to make the mechanism auditable. The largest uncertainties are future EU ETS prices, final sector benchmarks, recognition of third-country carbon prices, plant-specific emissions, pass-through and technology cost in jurisdictions without CO2 transport and storage networks.

IV. RESULTS

➢ *Policy Baseline and Carbon-Price Escalation*

The definitive regime creates a financial obligation from 2026 but deliberately phases the burden in over eight years. The Q2-2026 published certificate price is EUR75.28/tCO2; multiplied by the 2.5% phase share, the immediate effective signal is only EUR1.88/tCO2 before benchmark adjustment. By 2030, the scenario price of EUR107/tCO2 and the 48.5% phase share produce an effective signal of EUR51.90/tCO2. At EUR145/tCO2 and full phase-in in 2034, the signal becomes more than seventy times the 2026 value. [5-7]

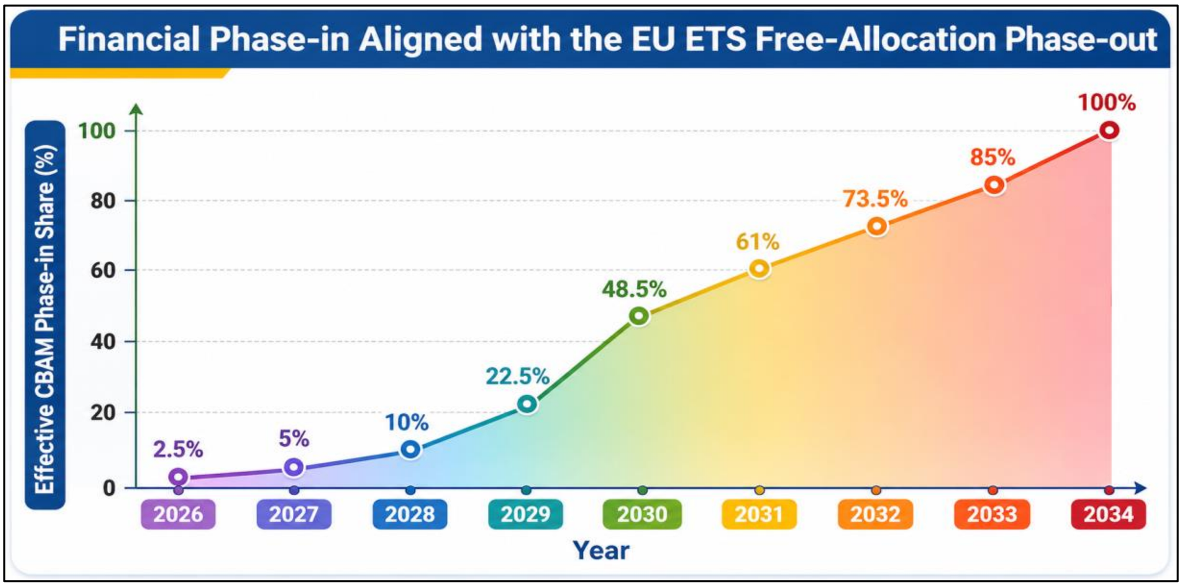

Fig 2 CBAM Financial Phase-in Used in the Scenario Model. The Plotted Share is the Complement of the Remaining EU ETS Free-Allocation Factor.

➢ *Country-Sector Exposure*

World Bank exposure analysis shows that vulnerability is not confined to the largest exporters. Mozambique is highly exposed through aluminium; Egypt through fertilisers and other covered products; Ukraine and Georgia through carbon-intensive metals; and India through the combination of trade scale and emission intensity. South Africa, Kazakhstan, Uzbekistan, Tunisia and Indonesia also appear among priority countries under aggregate or sector metrics. The ranking should be interpreted as screening, because a clean facility can perform far better than its national average and a high-emission facility far worse. [8,13-19]

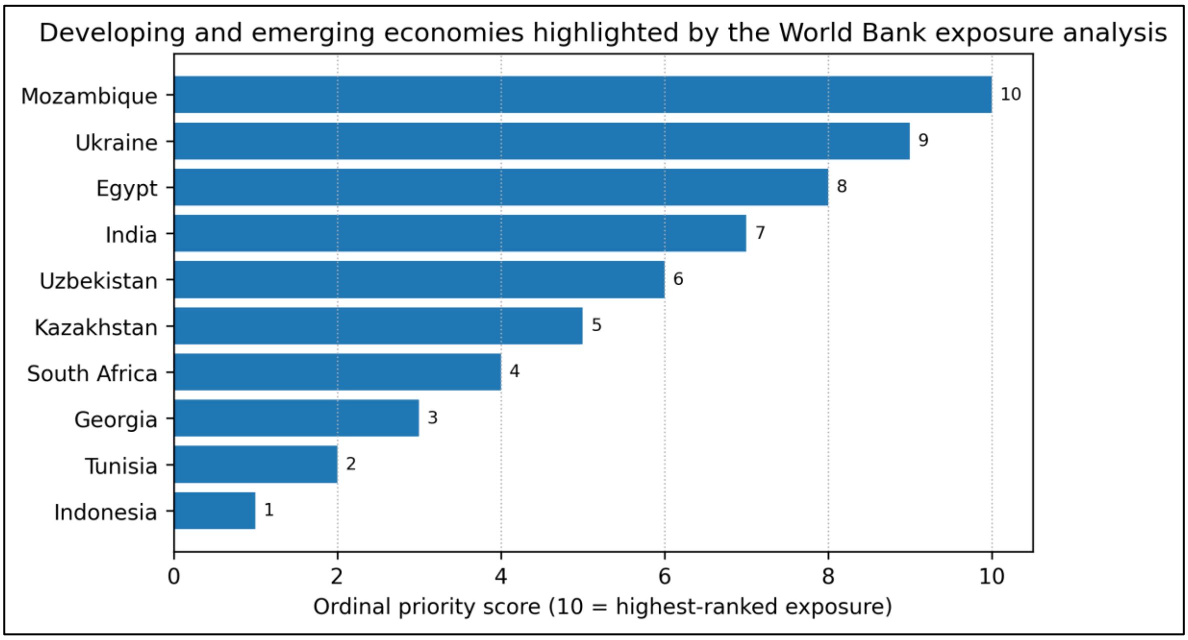

Fig 3 Ordinal Priority Ranking Reconstructed from the World Bank Aggregate Exposure Discussion. Bar Length Represents Rank Order, Not a Monetary Estimate.

Table 2 Illustrative Country-Sector Transmission Channels

Economy	Main exposed channel	Priority response
Mozambique	Primary aluminium and dependence on a small number of large exporters	Plant MRV, clean electricity contracts, grid attribution and concessional retrofit finance
Egypt	Fertilisers, ammonia and energy-intensive industry	Gas-efficiency upgrades, CCS-ready ammonia, domestic carbon-price credit and export certification
India	Large steel and aluminium export base with heterogeneous plant intensity	Facility-level differentiation, green power, scrap/DRI pathways, CCS clusters and SME support

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South Africa	Coal-intensive electricity and metals	Renewable grid expansion, just-transition finance, green iron and verified product footprints
Ukraine/Georgia	High EU trade dependence and carbon-intensive metals	Reconstruction finance, modern furnaces, MRV interoperability and transitional guarantees
Indonesia	Coal-based metals and high default-value risk	Actual emissions reporting, power decarbonisation, anti-circumvention compliance and technology transfer

➢ *Product-Level Competitiveness Effects*

Table 3 reports the literature-calibrated industrial archetypes. Product prices are indicative 2025-2026 reference values, not forecasts. Aluminium is modelled on direct emissions because indirect electricity emissions are not uniformly charged across all aluminium goods in the initial definitive scope; a full life-cycle sensitivity would be much larger for coal-powered smelters. The gross liability excludes official benchmark adjustment and carbon-price credits, so it is an exposure indicator rather than an invoice.

Table 3 Industrial Archetype Assumptions

Sector	**Product value (EUR/unit)**	**Embedded emissions (tCO2/unit)**	**CCS/abatement cost (EUR/tCO2)**	**Marginal parity year**
Iron and steel (BF-BOF/HRC)	620	2.30	95	2033
Cement clinker	110	0.80	100	2033
Primary aluminium (direct scope)	2900	1.70	120	2034
Ammonia/fertiliser	500	2.40	65	2031
Grey hydrogen	2500	9.00	80	2032
Coal-based electricity	80	0.75	75	2032

At the low 2026 phase share, gross charges are below 2% of product value for every archetype. The risk accelerates after 2029. In 2030, the modelled gross cost equals 19.3% of steel value, 37.7% of clinker value, 3.0% of aluminium value on direct emissions, 24.9% of ammonia value, 18.7% of grey-hydrogen value and 48.7% of coal-electricity value. Under the central elasticity, the corresponding retained export volumes are approximately 76.8%, 61.9%, 95.6%, 71.6%, 77.3% and 55.2% of baseline.

Table 4 Modelled Gross Exposure and Central Trade Response

Sector	**2026 EUR/unit**	**2026 % value**	**2030 EUR/unit**	**2030 % value**	**2030 volume loss**
Iron and steel (BF-BOF/HRC)	4.33	0.70%	119.36	19.3%	23.2%
Cement clinker	1.51	1.37%	41.52	37.7%	38.1%
Primary aluminium (direct scope)	3.20	0.11%	88.22	3.0%	4.4%
Ammonia/fertiliser	4.52	0.90%	124.55	24.9%	28.4%
Grey hydrogen	16.94	0.68%	467.06	18.7%	22.7%
Coal-based electricity	1.41	1.76%	38.92	48.7%	44.8%

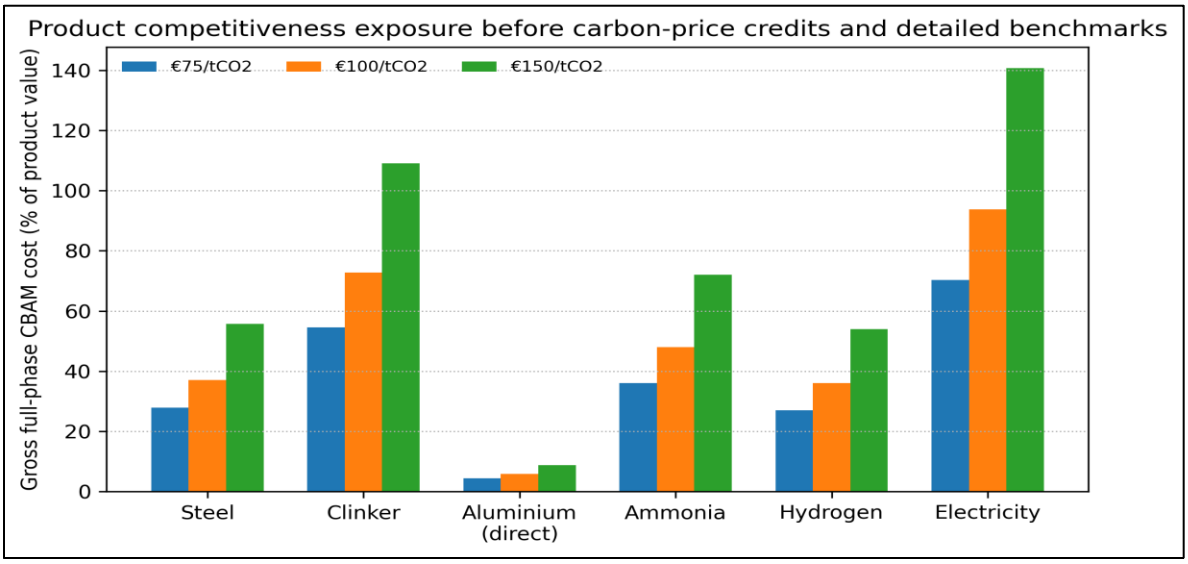

Fig 4 Full-Phase Gross Carbon-Cost Exposure Under Alternative Certificate Prices. Official Liability will Differ after Benchmark and Origin-Carbon-Price Adjustments.

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➢ *Carbon-Capture Investment Thresholds*

The decisive variable for plant investment is not the headline EU ETS price alone but the phase-adjusted price. An EUR100/tCO2 certificate price in 2028 produces an effective signal of only EUR10/tCO2 because 90% of the equivalent EU free-allocation protection remains. Consequently, a rational exporter may delay a large capture retrofit even while acknowledging that full-phase exposure will be material. This creates a risk of under-investment followed by a late and disorderly transition.

The central cost assumptions generate marginal parity in 2031 for ammonia, 2032 for hydrogen and coal power, 2033 for steel and cement, and 2034 for aluminium process-abatement. These are marginal comparisons: they indicate when one additional tonne of avoided CO2 costs less than the corresponding border charge. They do not by themselves guarantee a positive project NPV.

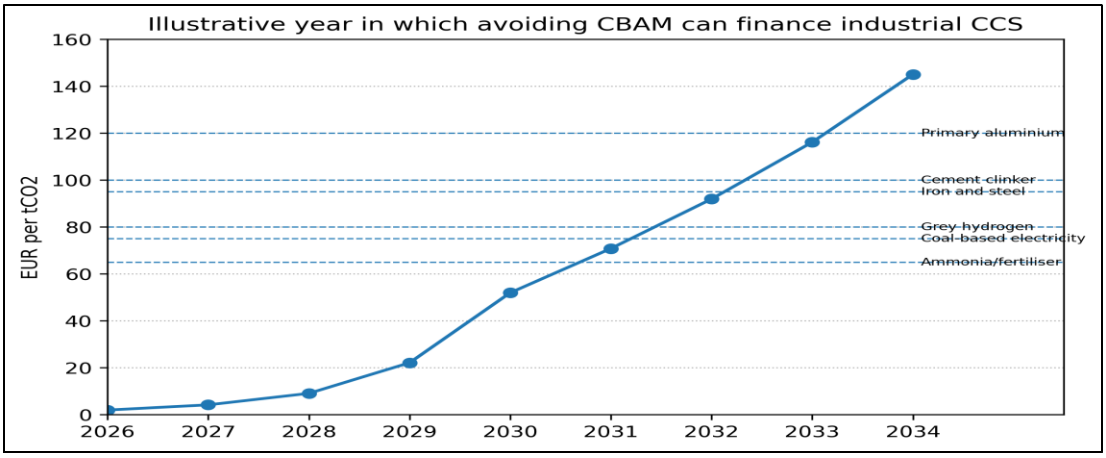

Fig 5 Phase-Adjusted Border-Carbon Signal and Sectoral Levelised Abatement-Cost Thresholds.

➢ *Pay-CBAM versus Invest-in-CCS*

Long-horizon discounted comparison produces a more nuanced result. For the representative export plants, paying CBAM remains cheaper through 2040 for steel and cement under the central assumptions because capture costs are high and the early phase-in is weak. Ammonia capture becomes economically superior, saving about EUR92 million in discounted 2026-2040 cost, while coal-power capture is approximately at parity and grey hydrogen is close to parity. The result changes materially with lower-cost finance, higher product premiums, utilisation of captured CO2, domestic carbon pricing, tax credits or shared infrastructure.

Table 5 Discounted 2026-2040 Strategy Cost for Representative Exporters (EUR Million)

Sector	Pay CBAM	CCS + residual CBAM	CCS saving (+) / premium (-)
Iron and steel (BF-BOF/HRC)	1458	1680	-222
Cement clinker	507	653	-146
Primary aluminium (direct scope)	216	291	-76
Ammonia/fertiliser	761	669	92
Grey hydrogen	570	599	-29
Coal-based electricity	951	942	9

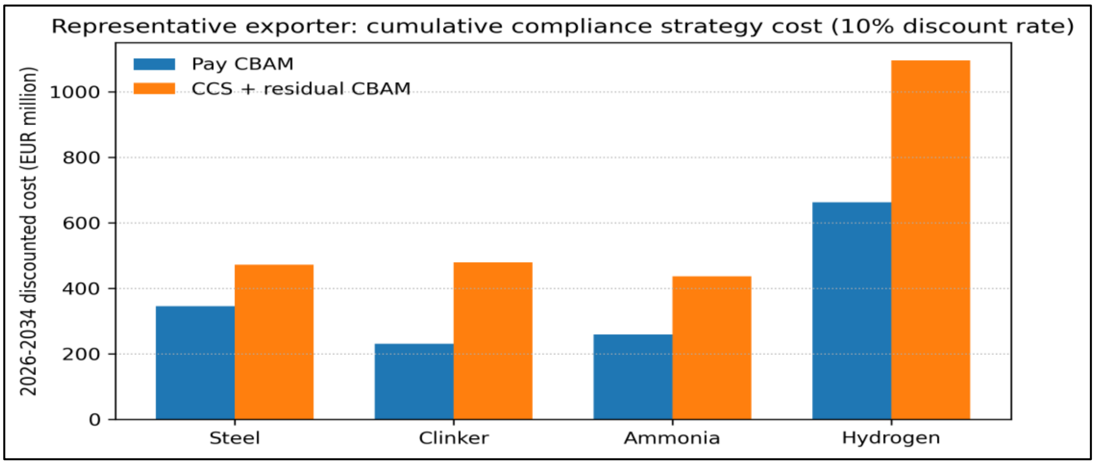

Fig 6 Long-Horizon Discounted Strategy Cost. CCS is Financially Preferred Only where the Shaded CCS Bar is Lower than the Pay-CBAM Bar.

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➢ *Emissions and Macroeconomic Effects*

The emissions effect depends on whether the mechanism causes genuine process improvement or merely reroutes trade. Quantitative trade modelling finds that CBAM can reduce emissions embodied in direct EU imports more than total global emissions because carbon-intensive goods may be redirected to non-EU markets. Including input-output linkages reduces the apparent effect because indirect emissions are transmitted through precursors and production networks. The mechanism therefore performs best when paired with wider carbon pricing, clean-technology deployment and credible product-level MRV. [9-12,36-38,55-59]

At macroeconomic level, the EU Commission's transitional review models an aggregate GDP effect for least-developed countries below 0.01% by 2035 relative to a no-CBAM baseline. That result is compatible with the severe plant-level effects reported here: a small macro average can conceal a major shock to one export enclave. Governments should therefore combine CGE results with plant inventories, employment mapping and fiscal exposure. [5,8-19]

➢ *Distributional and Just-Transition Effects*

The burden is likely to fall first on exporter margins because EU importers can use procurement contracts to demand verified emissions and pass compliance costs upstream. Over time, incidence may shift to EU consumers, workers in exporting regions, electricity customers or governments that subsidise transition. Small and medium-sized suppliers face disproportionate measurement and verification costs even where the 50-tonne importer threshold excludes some transactions. Women, contract workers and informal service providers can be affected indirectly when a large plant reduces production. [5,13-19,67]

Table 6 Distributional Risk and Safeguard Measures

Affected group	Primary risk	Safeguard
Export workers	Reduced shifts, closure or automation during retrofit	Wage insurance, retraining, social dialogue and local supplier development
SME suppliers	MRV and verification cost; loss of EU buyers	Shared digital MRV platform, vouchers and pooled verification
Consumers	Domestic carbon pricing raises energy and material prices	Targeted transfers and recycling of carbon revenue
Governments	Loss of export, tax and foreign-exchange revenue	Transition funds, guarantees and fiscal-risk planning
Communities	Regional dependence on a single steel, cement, aluminium or fertiliser plant	Place-based diversification and infrastructure investment
Clean first movers	Unable to monetise lower intensity because national defaults dominate	Actual-data certification, green procurement and product premiums

V. DISCUSSION

➢ *CBAM is a Dynamic Investment Signal, Not a Static Tariff*

The first key finding is temporal. The 2026 headline price can overstate the immediate burden because the charge is heavily phased, while a static 2026 compliance response can understate the strategic burden because the phase share rises non-linearly. Firms should therefore evaluate the entire 2026-2034 path. A plant that waits until the charge is fully material may face long engineering lead times, unavailable contractors, congested storage networks and higher financing costs.

The second finding is that product carbon intensity matters more than national income classification. CBAM rewards cleaner installations within high-emission countries if actual data are verified. This creates an opportunity for developing economies to avoid being represented by national defaults. Investment in meters, laboratory systems, mass-balance reconciliation, accredited verifiers and digital product passports can have a faster payback than major process retrofits.

➢ *CBAM Alone Does Not Guarantee CCS Investment*

The model shows that marginal annual parity can occur before the full project becomes financially attractive. Capture investments are capital-intensive, apply to total plant output rather than EU exports alone, and may require pipelines and storage that a single exporter cannot provide. A government that expects CBAM to automatically trigger CCS may therefore be disappointed. The investment case improves when the plant serves multiple carbon-constrained markets, receives a green premium, earns domestic carbon credits, benefits from tax incentives or joins a shared industrial cluster.

Sector strategy must also remain technology-neutral. For steel, hydrogen DRI, scrap-EAF, biomass and material efficiency may outperform retrofitted capture depending on local resources. For aluminium, power decarbonisation and inert-anode technology may matter more than flue-gas capture. For cement and ammonia, CCS can be comparatively central because of process emissions and concentrated streams. The framework is intended to compare these options on a common EUR/tCO2 and product-cost basis. [39-54]

➢ *Carbon Pricing in the Exporting Country*

Recognition of an origin-country carbon price changes the fiscal incidence without necessarily changing the exporter's total carbon cost. Instead of transferring the entire payment to the EU through CBAM certificates, the exporting government can retain revenue and recycle it into industrial decarbonisation, worker support or household compensation. The design must be credible, transparent and compatible with the Commission's deduction rules. A nominal tax with broad exemptions, free rebates or weak enforcement may not receive full recognition. [1-7,21-23]

➢ *Implications for Africa, Asia and Latin America*

African economies require plant-specific rather than continent-wide responses. Hydropower-based aluminium can be relatively clean, while coal-based grids create large indirect exposure. Gas-based fertiliser may have lower intensity than coal-based production but still faces substantial process emissions. Asian emerging economies combine scale, coal

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dependence and growing domestic demand, which can enable technology learning but also permit trade diversion. Latin American producers may gain from renewable electricity, biomass, high-quality ore and geological storage, provided traceability and infrastructure are available.

VI. POLICY OPTIONS AND IMPLEMENTATION FRAMEWORK

➢ *Five-Layer Competitiveness-Compatible Climate Strategy*

A credible response should not weaken climate commitments by subsidising unabated emissions. It should instead reduce the cost of verified decarbonisation. Figure 7 organises the policy package into five mutually reinforcing layers.

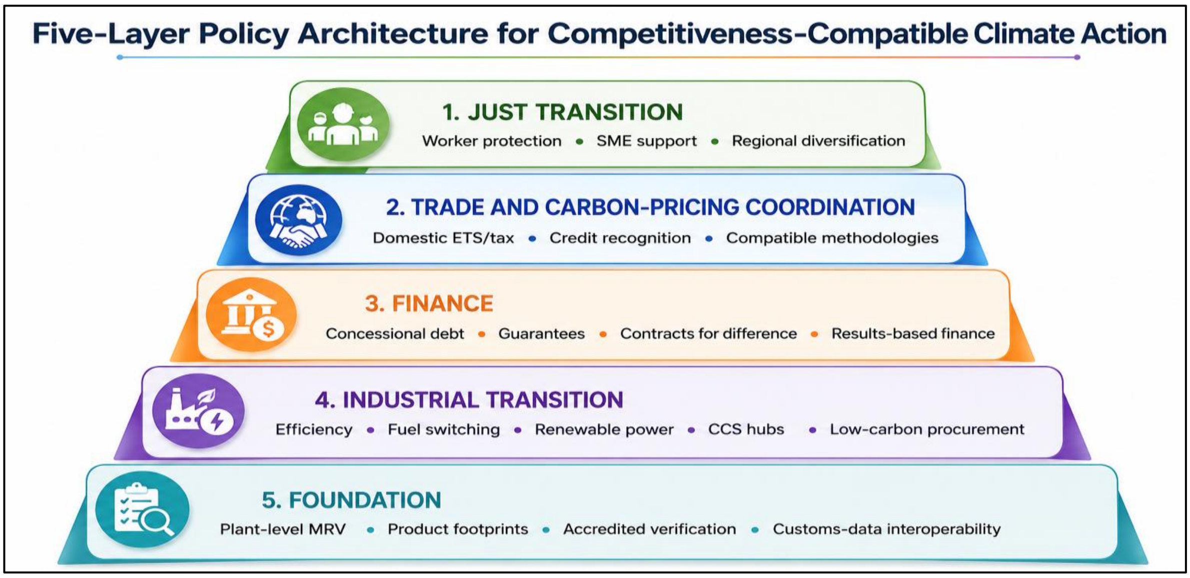

Fig 7 Five-Layer Policy Architecture for CBAM-Exposed Developing and Emerging Economies.

Table 7 Recommended Policy Package

Policy instrument	Design principle	Expected effect
National CBAM readiness unit	Customs, trade, environment, energy, standards and industry agencies share one product database	Reduces fragmented compliance and identifies exposed plants early
Digital product MRV	Metered fuel/electricity data, mass balance, emission factors, verifier workflow and audit trail	Allows clean facilities to use actual values and avoid punitive defaults
Domestic carbon price	Predictable tax or ETS with targeted transition support and transparent revenue recycling	Retains carbon revenue locally and creates an investment signal recognised at the border
Industrial decarbonisation facility	Concessional loans, guarantees, viability-gap grants and contracts for difference	Closes the gap between early CBAM savings and high upfront abatement cost
Shared CCS infrastructure	Open-access hubs, regulated tariffs and long-term storage liability rules	Reduces transport/storage cost and enables smaller plants
Technology-transfer partnership	Licensing, engineering support, training and local manufacturing conditions	Accelerates deployment and builds domestic capability
Green public procurement	Carbon-intensity thresholds and long-term offtake for low-carbon materials	Creates a bankable product premium
Just-transition compact	Worker representation, retraining, social protection and regional diversification	Prevents decarbonisation costs from being concentrated on vulnerable groups

➢ *Climate-Finance and Technology-Transfer Mechanism*

The proposed financing mechanism has three windows. The readiness window funds inventories, MRV, accreditation and feasibility studies. The investment window blends development-bank debt, guarantees and grants for first-of-a-kind industrial projects. The infrastructure window finances shared renewable power, hydrogen, CO_2 transport and storage. Disbursement should be linked to independently verified tonnes of embedded emissions reduced, while preserving safeguards for additionality, leakage and long-term storage integrity.

Potential sources include multilateral development banks, climate funds, bilateral partnerships, Article 6 cooperation, export-credit agencies and a negotiated share of carbon-border-related public revenue. Article 6 units should not be double counted against product emissions unless the relevant accounting treatment is explicitly accepted; the safer design is to use results-based climate finance to lower project cost while reporting the actual lower product intensity under CBAM. [21-23,39,43-50,68]

➢ *Implementation Roadmap*

Table 8 Indicative Implementation Roadmap

Period	Government action	Firm action
0-12 months	Map CN codes, exposed trade, installations, jobs and verification capacity	Establish emissions baseline, assign CBAM owner, engage EU importers and correct data gaps
12-24 months	Launch national MRV portal, verifier accreditation and transition-finance facility	Complete energy/abatement studies, secure renewable power and screen CCS/alternative routes
2028-2030	Introduce or strengthen domestic carbon pricing; develop shared infrastructure	Take final investment decisions before the 2030 phase-share jump; negotiate green offtake
2031-2034	Scale industrial clusters and just-transition programmes	Commission deep-abatement projects and optimise product portfolio
Post-2034	Integrate with wider international carbon-border and product standards	Operate at verified near-zero intensity and monetise clean-product advantage

VII. CONCLUSION

The EU CBAM has entered its definitive phase, but its industrial consequences will unfold gradually and unevenly. The immediate 2026 burden is limited by the 2.5% phase share, while the strategic burden rises sharply after 2029 and reaches full exposure in 2034. Developing and emerging economies with concentrated exports, high carbon intensity and weak MRV are most vulnerable, even where aggregate GDP effects appear small.

The integrated scenario analysis finds that the 2030 gross price wedge can materially erode competitiveness in steel, clinker, ammonia, hydrogen and coal-based electricity. Cleaner firms can protect market access by reporting actual verified emissions, while firms relying on national defaults risk losing both price and volume. Carbon capture becomes marginally competitive between 2031 and 2034 in the calibrated sectors, but a border charge alone does not make every project bankable. Steel and cement require lower-cost capital, shared infrastructure, green premiums or additional policy support; ammonia and high-concentration process streams offer earlier opportunities.

Governments should respond with a competitiveness-compatible climate strategy rather than exemptions that preserve high-emission production. The priority sequence is: establish plant-level MRV; secure recognition of domestic carbon prices; deploy efficiency and clean power; prepare CCS or alternative process routes; provide blended finance and shared infrastructure; and protect affected workers and communities. The paper's central contribution is a practical decision rule linking trade exposure to the timing of industrial decarbonisation investment. Applied with facility data, the framework can support national CBAM readiness programmes, corporate capital planning and international climate-finance negotiations.

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