GCC INDUSTRIAL EXPORT EXPOSURE TO THE EU CARBON BORDER ADJUSTMENT MECHANISM

Product-level trade and emissions analysis 2019 to 2025

Ashutosh Jaiswal

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Abstract

This working paper measures the conditional carbon-cost exposure of Gulf Cooperation Council exports to the European Union using 5,295 country-product-year observations covering 519 eight-digit commodity codes during 2019-2025. European Union import values and net mass are matched to corrected 2026 regulatory emissions defaults and product-specific free-allocation benchmarks. The matched basket reaches EUR 4.480 billion and 2.805 million tonnes in 2025. At an assumed certificate price of EUR 75 per tonne of carbon-dioxide equivalent, applying 2026 rules to that basket produces a conditional exposure interval of EUR 323.0-328.6 million, equivalent to 7.21-7.33% of recorded import value. Aluminium represents 80.2% of trade value; iron and steel account for 66.6% of the lower-end cost estimate. A full-phase-in scenario retaining the prescribed default mark-ups yields EUR 689.4-693.3 million. Historical product-code ambiguity materially widens earlier-year intervals, particularly for urea. The analysis identifies a concentration of exposure in specific country-*product combinations and quantifies the consequences of default-factor reliance. Results describe fixed-basket regulatory scenarios. Installation emissions, importer exemptions, carbon-price credits and contractual incidence remain unobserved. The paper provides a reproducible source-to-result calculation and a targeted agenda for replacing defaults with verified installation evidence.*

Keywords: CBAM; GCC; trade; emissions; product-level exposure; regulatory defaults.

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1. Introduction

Carbon pricing at the border creates a measurement problem for industrial exporters: a commercial portfolio must be translated into quantities of covered goods, emissions within a specified boundary, and a monetary obligation under a dated set of rules. The measurement is especially consequential when a portfolio contains both high-value metal products and lower-value bulk materials. A common carbon price can produce sharply different cost-to-value ratios across those products.

This paper examines Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates. It uses the importing side of the trade relationship to identify goods entering the EU from these origins. All historical years use the EU27_2020 geographical definition. The empirical period ends in 2025; the regulatory and data retrieval cutoff is 26 September 2026. The paper uses the retained September 2026 data and regulatory snapshot.

The central contribution is an auditable mapping from recorded commodity quantities to conditional exposure. Each result can be traced to a country, year, commodity code, emissions default and benchmark. Historical trade is held fixed when current rules are applied. This design allows the reader to examine changing portfolio exposure without assigning an unobserved historical trajectory to plant emissions. Official trade data provide observations [1], [2]; emissions defaults provide regulatory parameters [3], [4]; the monetary estimates are calculations under disclosed assumptions.

A. Research questions

The first question concerns the evolution of the covered trade basket: how much of the recorded value and physical mass originates in each country and sector, and how has that composition changed since 2019? The second concerns the concentration of conditional cost: which products account for the largest estimates after emissions factors and free-allocation benchmarks are applied? The third concerns measurement sensitivity:

how much do classifications, regulatory defaults and the assumed carbon price change the answer? The fourth concerns interpretation: what additional information would be required to translate portfolio exposure into exporter profitability or an actual customs liability?

These questions are addressed in sequence. Descriptive trade statistics establish the observed base. A transparent accounting model translates mass into default-based emissions equivalents and conditional costs. Sensitivity exercises vary assumptions that are visible in the model. A limitations analysis identifies the information outside the public-data design. The paper reports no causal coefficient linking CBAM to observed exports. The historical period contains no definitive-regime outcome with which to estimate such a coefficient.

B. Scope and terminology

The term GCC exports is operationalised as EU-recorded imports from GCC origins. Import valuation is the denominator used throughout. The term steel follows the regulatory iron-and-steel group, which also contains covered precursors and selected downstream articles. Fertilisers include the covered chemicals specified in the regulation. The four-sector restriction excludes electricity and hydrogen. Partially covered kaolinic clay is retained in a separate scope sensitivity because the eight-digit trade observation does not identify the covered calcined fraction.

The covered basket refers to observations that pass the product-scope and factor-matching rules described in Section 4. An absent country-product record is not assigned a fabricated trade flow. Published records with a positive value and a zero reported mass are retained and flagged. Monetary scenarios assign zero mass-based cost to their recorded zero quantity. This convention is disclosed because rounded or suppressed quantities can affect the interpretation of very small observations.

C. Contribution and practical use

The design offers three specific analytical outputs. First, it provides a seven-year trade panel with consistent geographic coverage. Second, it makes the regulatory calculation explicit at product level, including the difference between emissions before mark-ups and exposure after benchmark subtraction. Third, it preserves uncertainty arising from product definitions and missing production detail as calculation intervals.

[Inference] These outputs can support prioritisation of emissions-data collection. A large default-based estimate identifies a product for investigation; its economic interpretation depends on the installation evidence subsequently obtained. The ranking is particularly useful when a business has limited resources for supplier outreach or verification. A high-value aluminium account and a lower-value steel account can require different amounts of verification effort once the emissions boundary and benchmark are considered.

The remaining sections review related research, define the regulatory parameters, describe the dataset, establish the accounting model, present the results and examine their sensitivity. Technical appendices provide country-year and sector-year totals, product rankings, factor registers, worked examples and a reproducibility record. The companion research package contains the observation-level dataset and calculation code.

2. Related research and analytical positioning

A. Exposure indices and aggregate modelling

The World Bank methodological note by Maliszewska, Fischer, Jung and Chepeliev develops CBAM exposure indices that combine trade dependence and emissions intensity. Its competitiveness-oriented measures are designed to compare economies and sectors [9]. This paper uses a different denominator and a more explicit product calculation: recorded EU import value is paired with regulatory defaults and benchmarks. The two approaches address related questions with different exposure concepts. Their numerical results require matching the price, emissions boundary, trade year and denominator before comparison.

Abdou, Dudu, Gerling and Kadissi examine CBAM exposure in the Middle East and Central Asia using a regional financial-burden framework [10]. Their geographic and macroeconomic perspective is directly relevant to the motivation of the present study. The current exercise adds a GCC-focused seven-year product panel and uses the corrected default-value and benchmark framework available at the research cutoff. The paper does not treat an earlier regional estimate as a validation target because the regulatory vintage and aggregation differ.

Dechezleprêtre and co-authors analyse CBAM through an enhanced input-output model that incorporates supply-chain linkages [11]. That design can examine propagation through production networks. The present fixed-basket model isolates the initial quantity-to-cost calculation. It does not estimate changes in input

demand, downstream value added or economy-wide substitution. The exposure estimates therefore provide inputs that could be used in a behavioural model, subject to additional calibration.

B. Industrial emissions measurement

The Joint Research Centre report by Vidovic and co-authors develops estimates of emissions intensity for steel, fertilisers, aluminium and cement using a methodology aligned with CBAM reporting concepts [12]. Its relevance is methodological: product boundaries and production routes influence the conversion of physical output into embedded emissions. For the numerical calculation here, the corrected legal defaults and corresponding benchmark workbook are used directly. A literature estimate is not substituted for a legal default in the baseline.

UNCTAD studies the distributional implications of an EU border adjustment through a general equilibrium model with particular attention to developing economies [13]. The WTO's World Trade Report 2022 discusses carbon pricing, trade and international cooperation [14]. These publications frame the broader economic questions, while the present study confines its measured output to an explicitly defined export basket.

C. Interpretation of the literature

[Inference] Taken together, the reviewed approaches show why a single exposure number can be misunderstood. A share of national GDP, a share of worldwide sector exports and a share of EU import value answer different questions. An endogenous trade model also permits responses that a fixed-basket accounting exercise deliberately holds constant. This paper makes those boundaries explicit when presenting its contribution.

The literature review is targeted to the model's design and interpretation. It is not presented as a systematic review. No exhaustive search count, screening diagram or claim of comprehensive coverage is made. The references support the concepts actually used; the empirical estimates are generated from the retained data and code.

2.1. Research framework and interpretation

D. Four linked measurement stages

The empirical framework contains four stages: trade classification, physical quantity measurement, emissions assignment and monetary conversion. Each stage can alter the final estimate independently. A product outside the covered codes receives no modelled cost. A covered product requires a usable quantity. A quantity requires an emissions factor with the appropriate unit and boundary. A monetary estimate additionally requires a price, mark-up, benchmark and treatment of credits.

This sequence explains the analytical value of retaining a product-level panel. An aggregate sector multiplier hides differences in the mix of goods and in the quality of their matches. It can also confound changes in recorded prices with changes in physical quantities. The panel stores value and mass separately and makes the transformation to monetary exposure reproducible.

E. Mechanisms that are evaluated

The model evaluates arithmetic mechanisms: the effect of a higher certificate price, a different permitted product interpretation, a different default emissions intensity, and the removal of the free-allocation adjustment. These are conditional comparisons with all other included variables held constant. Their interpretation follows directly from the equations in Section 5.

The model does not estimate customer switching, plant closure, output expansion, technology adoption or the division of costs between buyers and sellers. Those outcomes require behavioural assumptions and evidence that are outside the dataset. In particular, a cost-to-value ratio cannot be interpreted as a percentage reduction in profit. Gross trade value includes items and valuation conventions that differ from firm revenue and operating margin.

F. Research propositions

Three propositions organise the descriptive analysis. First, the largest trade-value sector need not have the largest conditional emissions-cost estimate. Second, current country-specific defaults and fallback defaults can generate materially different exposure even when a common carbon price is used. Third, uncertainty about the composition of historical product codes can alter the apparent trend in exposure. The results section evaluates these propositions using recorded data and explicit mapping rules.

[Inference] A practical implication is that commercial importance and information priority should be assessed jointly. Trade value identifies the scale of the customer relationship. Conditional exposure identifies the scale of the modelled carbon-cost issue. The discrepancy between those rankings is an analytical finding that merits investigation; it does not establish a technology deficit at any named producer.

The distinction between a country's legal default and an individual installation's measured emissions is maintained throughout. The default assignment belongs to the regulatory calculation. It cannot establish which production route generated an actual shipment. Likewise, a fallback flag records the model's use of the official other-country table. It is not evidence that an exporter has failed to measure or disclose emissions.

3. Regulatory parameters and temporal boundary

A. Regulatory vintage

The calculation uses the consolidated CBAM regulation following the 2025 amendment, the definitive-period calculation framework, the free-allocation benchmarks and the July 2026 correction to default values [3]-[7]. The Commission's explanatory guidance is used to interpret the relationship between defaults and benchmarks [8]. The legal instruments remain the authority for the adopted parameters.

The historical trade period is 2019-2025. The definitive regime begins in 2026. Applying 2026 rules to an earlier basket is a counterfactual calculation. No historical tax payment is inferred from that operation. The 2025 basket is used as the principal recent-trade reference; it is not projected forward as a forecast of 2026 imports.

B. Price and adjustments

The base scenario assumes EUR 75 per tonne of carbon-dioxide equivalent. The Commission published EUR 75.36 for the first quarter of 2026 and EUR 75.28 for the second quarter [15]. EUR 75 is an analyst-selected rounded scenario parameter. It is neither a full-year realised price nor a prediction of subsequent quarterly prices.

The corrected defaults prescribe mark-ups of 10% in 2026 for cement, iron and steel and aluminium, and 1% for fertilisers. The schedule for the first three sectors rises to 20% in 2027 and 30% from 2028 under the instrument used here [4]. The 2026 calculation subtracts the relevant default benchmark multiplied by 0.975 and a cross-sectoral correction factor of one. The latter is established for 2026-2030 in Decision 2026/1862 [7].

C. Boundaries of the calculation

The numerical baseline includes no deduction for a carbon price paid in the country of origin. This is a scenario assumption reflecting the absence of payment-level evidence. It is not a finding that no eligible payments exist. The model also makes no importer-specific exemption adjustment. Public country-product aggregates do not reveal each importer's annual covered mass.

The legal threshold operates at importer level. Removing a country-product cell merely because its mass is below a threshold would apply the rule to the wrong unit. The analysis therefore reports a portfolio estimate before such adjustments and records the absence of importer-level information as a limitation.

D. Interpretation of the free-allocation adjustment

The benchmark is subtracted from the marked-up emissions factor. Multiplying the whole emissions estimate by 2.5% produces a different calculation. Figure 8 later quantifies that difference for an illustrative primary-aluminium benchmark. The cost becomes sensitive to the gap between the assigned emissions intensity and the benchmark, even when the free-allocation factor is close to one.

The full-phase-in scenario removes the benchmark deduction and retains the prescribed 2028-onward default mark-ups. It freezes the trade basket, default factors and carbon price. Its interpretation is a conditional endpoint under the specified schedule. Future legal amendments, technology changes and trade responses remain outside that endpoint.

4. Data and sample construction

A. Trade observations

The primary trade source is Eurostat Comext dataset DS-045409, retrieved through the official API in 42 country-year batches [1]. Each request fixes annual frequency, the EU27_2020 reporting area, import flow and one GCC partner, and retrieves value in euros and quantity in units of 100 kilograms. The seven years and six partners yield a consistent retrieval grid. The source reports an update timestamp of 15 September 2026 in the retained responses.

Eight-digit CN records are selected from the downloaded data. Higher-level HS totals are retained for reconciliation and are excluded from the analytical sum. This avoids counting a physical shipment at multiple levels of the product hierarchy. Quantities are converted to metric tonnes by dividing QUANTITY_IN_100KG by ten. The value field remains in current euros. No inflation adjustment is applied because the exposure ratio uses the same year's recorded trade-value denominator.

The empirical unit is a country-CN8-year record. The matched core contains 5,295 records and 519 distinct CN8 codes across the full period. The 2025 cross-section contains 805 records. The panel is unbalanced: observed commodity codes and trading relationships change over time. The analysis does not insert artificial zero-valued observations to create a balanced panel.

B. Product selection

The scope register follows the four selected regulatory sectors, including listed precursors and downstream goods. The independent scope check identifies no observed in-scope CN8 record left without an emissions match after the documented historical-code treatment. This coverage statement is limited to identifiable public records. Confidential or unspecified trade outside the selected codes cannot be assigned to products from the present data.

The partial kaolinic-clay code is excluded from the core. Its full recorded mass is used only in an upper inclusion sensitivity, with zero covered mass as the opposite endpoint. The design preserves the difference between partial legal scope and complete commodity-code coverage.

C. Valuation and origin

Eurostat's metadata describe extra-EU trade valuation and the use of partner-origin information [2]. The paper consistently calls the value measure recorded EU import value. Re-export activity and customs origin rules require particular care when interpreting a commercial hub. No value is assigned to a specific GCC company, plant or customer's revenue account.

No exporter-reported Comtrade mirror series enters the baseline. The verification uses independent aggregations within the Eurostat source, including product hierarchy and selected monthly-to-annual comparisons. A cross-source mirror comparison remains a useful extension; the paper does not claim that it has been completed.

D. Data retention

Raw API responses, official workbooks, legal texts and selected research documents were retained with filenames and SHA-256 hashes. The source register separates retrieved evidence from derived datasets. This permits subsequent revisions to be distinguished from changes in the calculation code. Appendix A defines the fields used in the analytical panel.

4.1. Emissions and benchmark matching

E. Source hierarchy for emissions

The corrected Commission workbook is the machine-readable emissions source [4]. For each product, the code selects the most specific applicable default row. A numeric country-specific value is used when available. If the country sheet omits a value or records a dash, the matching other-country row supplies the factor, following the corrected annex. The register records this fallback explicitly.

The factor labelled total emissions in the legal default table is used. For iron and steel and aluminium, the table reflects the direct-emissions scope used in this calculation. Fertiliser and cement defaults can include their applicable indirect component. A corporate scope 1-plus-scope 2 intensity is not inserted into a differently bounded product calculation. Published corporate sustainability metrics may support contextual discussion, but no such metric is used as shipment evidence here.

F. Benchmarks and route indicators

The default-based free-allocation calculation uses Column B of the benchmark workbook, which incorporates relevant precursor effects [5], [8]. Route indicators are matched to the route attached to the selected default. Time indicators are parsed separately: the 2026 calculation selects values applicable to 2026-2027. A route indicator and a year indicator can appear together in a benchmark cell.

Some default rows allow more than one benchmark interpretation. The model retains each compatible alternative and calculates lower and upper cost endpoints from the paired factor and benchmark. It does not

combine an emissions factor from one product interpretation with a benchmark from an incompatible route. The same pairing principle applies to white and grey clinker alternatives within an eight-digit trade code.

G. Historical nomenclature

Historical codes require explicit treatment because the current regulatory workbook does not contain every code observed since 2019. For unwrought aluminium, older undivided categories are matched to current categories with the same applicable default and primary or secondary benchmark relationship. For historical urea CN 31021010, the greater-than-45%-nitrogen description can span current solution and other-urea categories. The model retains the compatible current 31021012, 31021015 and 31021019 alternatives. The lower-nitrogen category is excluded from that envelope.

Other legacy items are mapped only within the same six-digit family and compatible default route. Where multiple current benchmark values remain possible, they are retained as alternatives. This is a conservative classification envelope; it is not a recovered shipment composition. The historical-code register makes these cases reviewable. A stable-code sensitivity removes legacy mappings to show their effect.

H. Frozen-factor interpretation

Every historical year is evaluated with the same regulatory-factor vintage. Consequently, changes in the modelled emissions equivalent reflect quantities and product composition under fixed factors. They do not measure actual decarbonisation between 2019 and 2025. The design avoids inventing plant-year emissions data, while preserving an informative comparison of the portfolios recorded in each year.

[Inference] The historical urea envelope illustrates the economic value of better product identification. A more precise composition record can narrow an exposure interval even when no production process changes. This is a measurement improvement whose magnitude can be distinguished from a physical reduction in emissions.

5. Accounting model and estimands

A. Definitions

Let c denote origin country, p the eight-digit product and t the observed trade year. Let Q denote tonnes and V recorded import value in euros. Let a identify a compatible regulatory alternative for a product. The alternative contains a default emissions intensity e and its matched benchmark b, each expressed in tonnes of carbon-dioxide equivalent per tonne of good. P is the assumed certificate price. The mark-up is m, the retained free-allocation factor is f and the cross-sectoral correction factor is k.

The physical conversion is $Q = q100 / 10$, where q100 is the published quantity in 100-kilogram units. The base default emissions equivalent is $E = Q \times e$. This is a modelled quantity obtained from trade mass and a regulatory parameter; it is not a measured installation inventory.

B. Conditional cost equations

For an individual alternative, the 2026-rule cost is $C(a) = Q \times P \times \max\{(1 + m)e(a) - fkb(a), 0\}$. The implemented values are $P = 75$, $f = 0.975$ and $k = 1$. The mark-up is 0.01 for fertilisers and 0.10 for the other three sectors. No origin-carbon-price credit or importer exemption enters this conditional scenario.

For each country-product-year observation, the lower endpoint is the minimum of C(a) over compatible alternatives and the upper endpoint is the maximum. Portfolio endpoints sum these observation-level endpoints. The resulting interval is an admissible scenario envelope. It has no probability coverage interpretation and is not a statistical confidence interval.

The base gross-carbon-price diagnostic is $G(a) = Q \times P \times e(a)$. It contains neither a default mark-up nor a benchmark deduction. The full-phase-in scenario is $F(a) = Q \times P \times (1 + m^*)e(a)$, with $m^* = 0.01$ for fertilisers and 0.30 for the other sectors. The latter follows the selected schedule while keeping quantities and intensities fixed.

C. Aggregation and ratios

Country totals, sector totals and country-sector totals are sums over mutually exclusive product observations. The cost-to-value ratio is $R = 100 \times \text{sum}(C) / \text{sum}(V)$. It is calculated after aggregation. Averaging individual product ratios would assign undue influence to small observations and can produce a different answer.

Product rankings use the lower endpoint of 2026-rule exposure, with the upper endpoint reported alongside it. The ranking convention is disclosed because interval overlap can make an exact ordering unstable. Concentration is measured as the share of total conditional cost accounted for by the largest country-product cells. These cells do not identify firms or installations.

D. Mathematical implications

With a fixed basket and no monetary credit, C scales linearly with P. Price sensitivity therefore requires no estimated elasticity. The benchmark subtraction also implies a threshold: a particular alternative has a zero conditional cost when (1 + m)e does not exceed fkb. Above that threshold, reducing the assumed emissions factor reduces cost at the rate QP(1 + m), holding all other terms constant. These properties are algebraic implications of the model.

The code applies the non-negative floor before aggregation. A negative net emissions expression for one product does not offset the positive expression for another. Appendix H supplies worked examples with sufficient numerical precision to reproduce the calculation independently.

Qctp = qctp,100kg / 10. (1)

Ectp(a) = Qctp ecp(a). (2)

ncp(a) = max{(1 + m)ecp(a) - fk bcp(a), 0}. (3)

Cctp(a) = Qctp P ncp(a). (4)

Clow = sumctp mina Cctp(a). (5)

Chigh = sumctp maxa Cctp(a). (6)

R = 100 C / sumctp Vctp. (7)

Fctp(a) = Qctp P(1 + m*)ecp(a). (8)

5.1. Uncertainty and sensitivity design

E. Three distinct sources of uncertainty

The first source is observable classification ambiguity. A trade code may combine white and grey clinker or may represent an older product definition with several compatible current categories. These cases generate the reported endpoint intervals. The alternatives are documented and can be changed when better composition evidence becomes available.

The second source is scenario uncertainty. The future certificate price, the relevant import period and the degree of physical emissions improvement are not known from the historical trade data. They are therefore varied explicitly. The EUR 50, EUR 75 and EUR 100 price scenarios provide a transparent scale comparison. A reduction in the model's intensity parameter is a sensitivity exercise; it is not a claim that a plant has achieved that reduction.

The third source is information that the present model cannot quantify. This includes deviations between plant actuals and defaults, unobserved importer exemptions, eligible foreign carbon payments, changes in commercial contracts and future trade responses. The reported classification interval does not cover all of these uncertainties. Its narrowness in a particular year must not be interpreted as high certainty about actual liability.

F. Robustness variants

Four variants are reported. The full matched core is the baseline. A current-benchmark-code variant excludes historical codes requiring a successor mapping. A country-specific-default variant removes observations that use any fallback emissions default. An unambiguous-match variant retains only observations with a single compatible parameter combination. Each variant reports both its retained trade value and its cost estimate.

These are sample-composition checks. Removing fallback-dependent observations can change the sector composition substantially. A lower total for that reduced sample cannot be interpreted as the amount that improved verification would save on the original portfolio. The omitted records still represent observed trade.

G. Mass and valuation checks

The panel contains no missing mass field among the matched records. It contains 141 records with positive value and zero reported mass over the full period. Their combined value is EUR 16,574. In 2025, the equivalent value is EUR 704 across 17 records. These observations are immaterial to the aggregate value calculation at the displayed precision, but their zero mass remains an explicit data-quality flag.

The hierarchy reconciliation compares the sum of eight-digit observations with published four-digit totals for unwrought aluminium, cement, nitrogenous fertilisers and seamless tubes across all 42 country-year batches. The differences are below one unit of the underlying quantity precision and arise only at floating-point scale. Six monthly-to-annual spot checks reproduce annual mass. One import-value comparison differs by EUR 1. Appendix B records those checks.

H. Statistical claims

The design is an accounting analysis of recorded observations. It does not estimate a sampling distribution, apply a treatment-control design or fit a causal panel regression. No p-values or confidence intervals are attached to the scenario totals. A Monte Carlo distribution would require defensible probability distributions for unobserved parameters; none is imposed. The deterministic intervals and sensitivity tables show exactly which assumptions generate their variation.

6. Results for the historical trade basket

A. Value and mass follow different paths

Recorded imports in the matched core increase from EUR 1.983 billion in 2019 to EUR 4.480 billion in 2025. The highest annual value is EUR 5.392 billion in 2022. The corresponding mass increases from 1.327 million tonnes in 2019 to 2.805 million tonnes in 2025; the 2022 mass is 2.868 million tonnes. Figure 1 displays these two measures separately.

The 2020 basket has a lower value than 2019 and a higher mass. The 2022 value peak also exceeds the 2025 value despite a much smaller difference in total tonnes. These observed patterns establish that a value-only trend would describe the portfolio differently from a quantity-based exposure calculation. They do not identify the causes of commodity-price movements or changes in product quality.

[Inference] The separation of value and mass is commercially important. A higher unit value reduces the cost-to-value ratio for an unchanged mass-based cost. Conversely, a lower-value shipment can have a high ratio even when its absolute cost is modest. Changes in the denominator therefore need to be reported alongside changes in the conditional charge.

B. Historical counterfactual exposure

At the common EUR 75 price and 2026-rule parameters, exposure for the 2019 basket is EUR 112.1-114.9 million. For 2025 it is EUR 323.0-328.6 million. The change describes the recorded baskets evaluated under the same regulatory parameters. It does not represent a sequence of paid CBAM charges.

The interval for the 2022 basket is wider, at EUR 254.3-316.6 million. Historical urea classifications are an important source of that width. This makes a single-point comparison between 2022 and 2025 sensitive to an unobserved composition assumption. The paper retains the interval instead of assigning every historical urea tonne to a preferred current product.

The annual table in Appendix C provides value, mass and scenario endpoints at consistent precision. A fixed-factor trend can be used to inspect the portfolio's changing composition; an actual-emissions trend would require matched installation-year evidence.

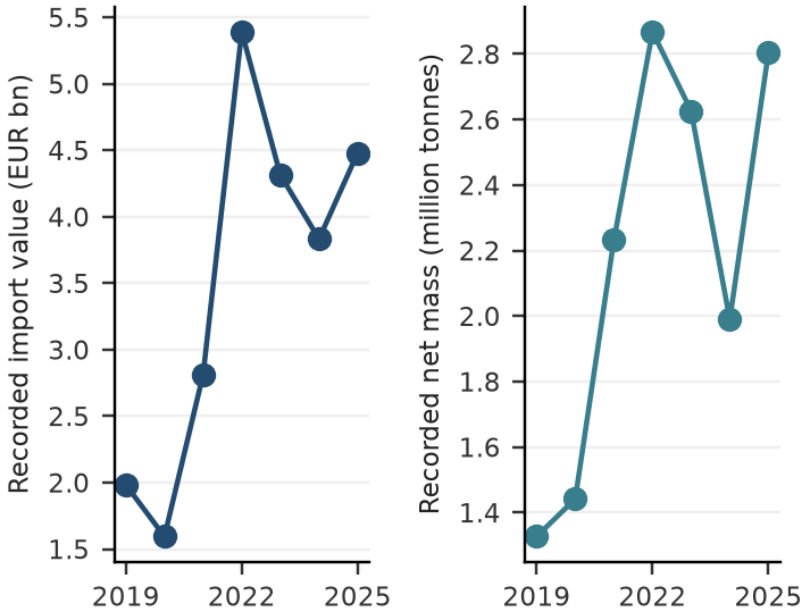


Fig. 1. Recorded EU27 imports from GCC origins in the matched four-sector basket, 2019–2025. Value is in current euros. Mass is net tonnes. Source: calculations from Eurostat DS-045409 [1].

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6.1. Geographic concentration

C. Country composition in 2025

The United Arab Emirates accounts for EUR 1.825 billion of the 2025 basket and Bahrain for EUR 1.479 billion. Saudi Arabia contributes EUR 522.2 million, Oman EUR 448.9 million and Qatar EUR 204.0 million. Kuwait's recorded covered value is EUR 0.391 million. These totals refer to EU-recorded imports from each origin within the selected scope.

The corresponding 2026-rule estimates are EUR 130.4-132.4 million for the UAE, EUR 32.3 million for Bahrain, EUR 98.8-102.4 million for Saudi Arabia, EUR 52.3 million for Oman and EUR 9.15 million for Qatar. Kuwait's estimate is approximately EUR 9,799. Identical displayed endpoints indicate no material classification interval under the retained parameter alternatives; they do not establish certainty about actual emissions or payments.

The UAE has the largest absolute estimate in the calculation. Saudi Arabia has the highest aggregate cost-to-value ratio among the six recorded baskets, at approximately 18.9-19.6%. Bahrain's ratio is approximately 2.18%. Figure 2 shows why the value ranking requires a sector breakdown: Bahrain's basket is heavily concentrated in aluminium, whereas several other origins have meaningful steel, fertiliser or cement quantities.

D. Interpreting small country totals

Kuwait's small recorded EU-facing basket does not measure the size of its domestic industrial sector or its worldwide exports. The same limitation applies to the small observed fertiliser flows for some origins. The analysis makes no claim that these countries have little production capacity. It measures only the products and destination relationship represented in the retained data.

[Inference] A country-level monitoring programme could use the absolute estimates to identify where product and supplier outreach might have the greatest immediate information value. However, the aggregate ratio should not be used to rank national technological performance. Product composition, unit values and fallback assignments all influence the result.

The country-sector matrix in Appendix E separates these influences at the level supported by the data. It also allows the reader to distinguish a large exposure concentrated in a narrow sector from a broader set of smaller product-level estimates.

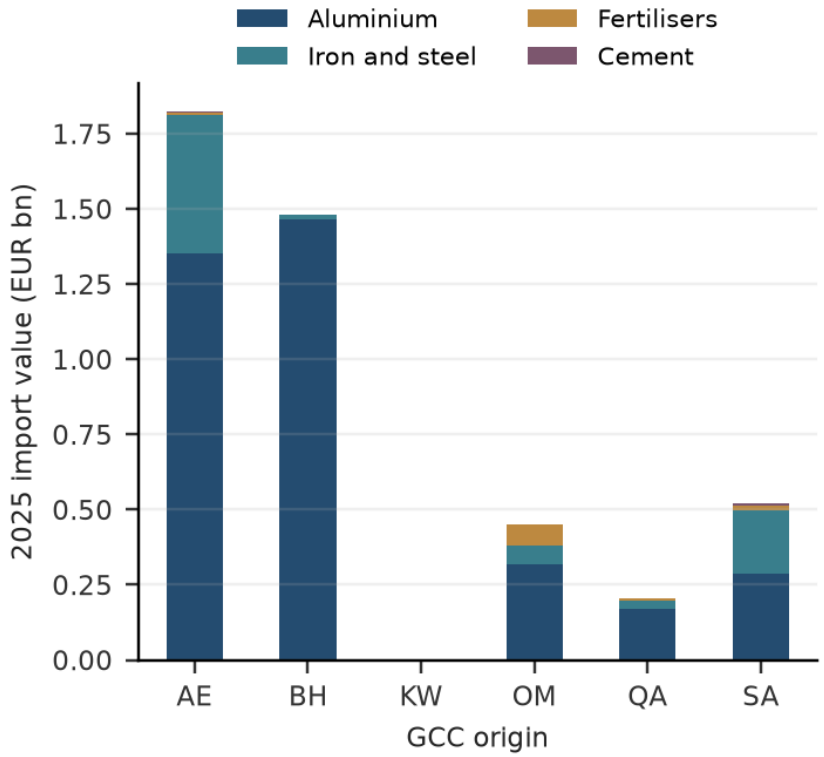


Fig. 2. Composition of the 2025 recorded import basket by GCC origin and sector. AE: UAE; BH: Bahrain; KW: Kuwait; OM: Oman; QA: Qatar; SA: Saudi Arabia. Source: Eurostat calculations [1].

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6.2. Sector composition and conditional cost

E. Value shares and cost shares

Aluminium contributes EUR 3.594 billion, or 80.2%, of recorded 2025 covered import value. Iron and steel contribute EUR 773.8 million, fertilisers EUR 96.6 million and cement EUR 16.1 million. The 2026-rule lower-end cost shares differ substantially: iron and steel contribute EUR 215.0 million, aluminium EUR 68.3 million, fertilisers EUR 27.8 million and cement EUR 11.8 million.

The iron-and-steel share of lower-end exposure is 66.6%. Aluminium's share is 21.1%. Fertilisers contribute 8.6% and cement 3.7%. These are calculations using the official default assignments and recorded masses. They do not measure payments made by companies or the distribution of actual plant emissions.

The sector comparison is affected by both the emissions default and the benchmark deduction. A tonne of high-value metal can have a relatively small net cost after deduction, whereas another covered tonne can have a much larger default-to-benchmark gap. The value denominator further changes the apparent burden when expressed as a ratio.

F. Sector boundaries

The iron-and-steel sector includes covered ores, semi-finished products and selected articles. The fertiliser group includes ammonia and specified nitrogen-containing products. These legal groupings differ from an industrial census classification. A sector total should therefore be compared with another study only after reconciling the product lists.

[Inference] The result supports a product-first approach to commercial analysis. A sector label alone provides insufficient information to identify an exposure ratio. The next four subsections examine the products and default assignments behind the broad comparison, while the appendices preserve the underlying country-CN8 records.

The estimates also show why disclosure of assumptions is material to a ranking. An installation-specific actual-emissions calculation could change the relative sector totals. The present ranking describes a specified default-based scenario and remains useful within that boundary.

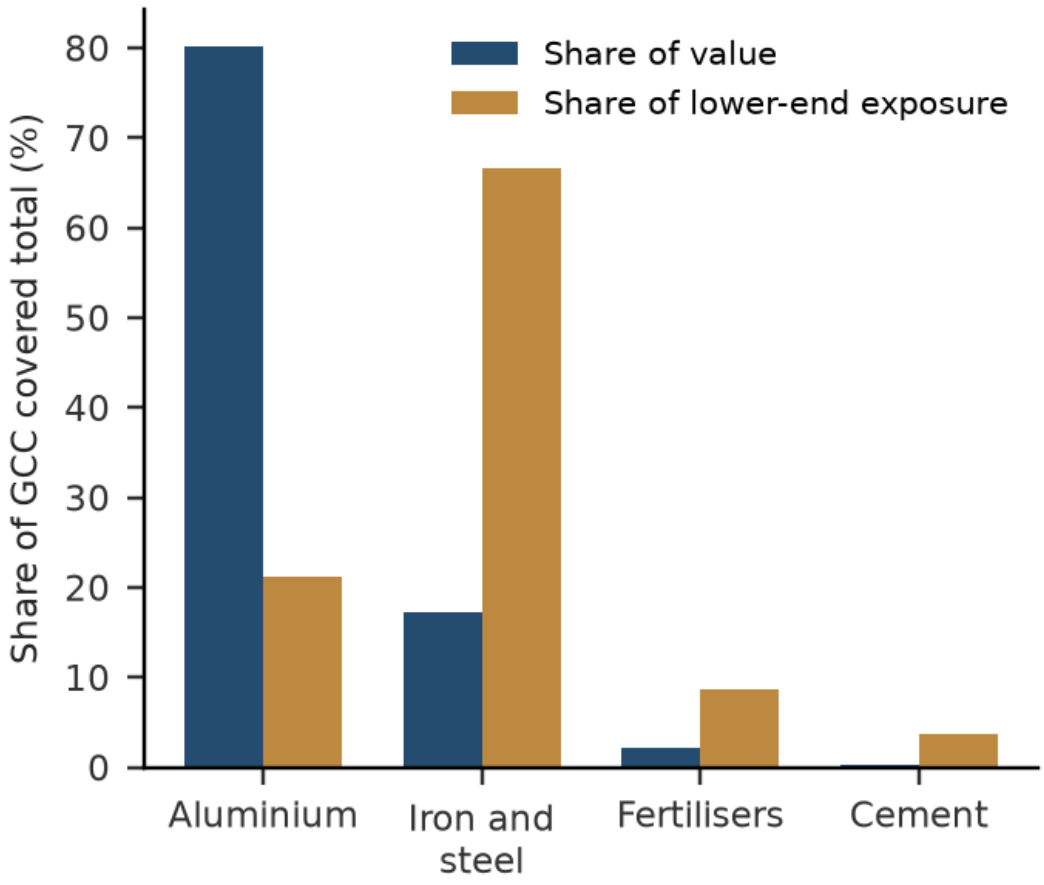


Fig. 3. Sector shares of recorded value and conditional 2026-rule exposure for the 2025 basket. Exposure uses the lower endpoint and EUR 75/tCO2e. Sources: [1], [4], [5]; calculations in Section 5.

6.3. Aluminium results

G. Unwrought products dominate the largest cells

Several of the largest country-product trade cells are unwrought aluminium. Bahrain's aluminium-alloy billets, CN 76012040, have a recorded value of EUR 413.4 million and mass of 158,794 tonnes in 2025. Bahrain's non-alloy unwrought aluminium excluding slabs, CN 76011090, records EUR 374.0 million. The UAE records EUR 343.1 million in alloy slabs and EUR 313.0 million in alloy billets.

The Bahrain billet example illustrates the base calculation. Its selected default is 1.870 tCO2e per tonne of product and its matched primary-aluminium benchmark is 1.423. The 2026 net intensity is 1.10 × 1.870 - 0.975 × 1.423 = 0.669575 tCO2e/t. At EUR 75, this equals EUR 50.218125 per tonne of product. Multiplication by the recorded mass yields EUR 7.974 million.

This example is reproducible from the trade record and the official factor register. It also shows how much information lies between trade value and a conditional cost. The same value could correspond to a different mass, product composition or emissions parameter.

H. Country-level aluminium estimates

Bahrain's aluminium basket generates a 2026-rule estimate of EUR 29.94 million. The UAE estimate is EUR 25.20 million, Oman's EUR 5.51 million, Saudi Arabia's EUR 5.29 million and Qatar's EUR 2.39 million. The smaller Kuwait basket contributes approximately EUR 1,572. All of these figures use the selected defaults and common price.

The default for unwrought aluminium differs across the country tables. Oman and Saudi Arabia use 1.700 tCO2e/t for the relevant unwrought category in the retained register, while Bahrain and the UAE use 1.870. These are regulatory parameter differences. They do not establish a difference between particular named smelters. A country's exports can originate in installations whose measured values differ from its legal default.

I. Electricity and emissions boundaries

The applicable default-based calculation for aluminium does not use a full corporate electricity-related footprint. The sector guidance discusses the emissions boundary and the relevant production processes [16]. An analysis that inserts a broader electricity-intensive footprint into this particular formula would answer a different question and require an explicit extension of scope.

[Inference] This boundary has implications for how industrial improvements are valued. A project can have a substantial wider climate benefit while producing a different change in the currently modelled certificate obligation. The relevant appraisal needs to track the regulatory boundary, the physical emissions effect and the commercial value separately. The present paper calculates the first of these under a specified set of parameters.

The aluminium findings therefore justify careful product and installation matching before commercial negotiation. The largest recorded value cells are prominent in the portfolio, but their conditional cost share is lower than their trade-value share.

6.4. Iron and steel results

J. Concentrated cost under the default scenario

The iron-and-steel basket generates EUR 215.0 million of 2026-rule exposure at the lower endpoint. The UAE contributes EUR 102.5 million and Saudi Arabia EUR 81.7 million. Oman contributes EUR 22.3 million, Qatar EUR 6.16 million and Bahrain EUR 2.35 million. The remaining recorded Kuwait contribution is approximately EUR 8,227.

The UAE's zinc-coated flat-rolled product CN 72104900 is an important individual cell. Recorded imports are EUR 124.53 million and 173,646.815 tonnes. The lower-end conditional cost is EUR 39.82 million. This country-product cell alone accounts for approximately 12.3% of the GCC lower-end total. The calculation uses the official fallback assignment applicable in the retained register.

K. Default-route interpretation

The use of a fallback default must be interpreted carefully. A default route is a regulatory parameter used to determine the applicable benchmark. It does not identify the actual route used by every producer whose goods appear in an origin-code aggregate. The results therefore cannot establish that a particular GCC steel producer uses blast-furnace technology or has the emissions intensity implied by that fallback.

The IEA steel technology roadmap explains the importance of production pathways and material efficiency for emissions reduction [17]. This supports the need for route-specific analysis. It does not provide shipment-

specific evidence for this paper. Plant actuals would require a compatible product boundary, precursor information and verification.

L. Commercial interpretation

[Inference] The steel results identify a high-priority verification problem. Where the default scenario produces a large cost-to-value ratio, obtaining properly bounded actual emissions could materially change a commercial discussion. The direction and size of that change must be established with evidence. It cannot be assumed that actual values are lower in every case.

The public trade data also do not show whether the GCC supplier, an intermediary or the EU buyer would bear the economic cost. Contracts can allocate costs differently, and market conditions can influence renegotiation. The paper therefore reports exposure attached to a trade basket without allocating it to exporter profit.

This limitation is particularly relevant to downstream steel articles. Their recorded value incorporates fabrication and other commercial components, while the emissions calculation follows the covered production chain. Comparing the ratio across a basic metal and a fabricated article requires attention to that difference. The ranking table reports the CN code so that the reader can inspect the product actually involved.

The sector estimate provides a clear conditional result: under the retained defaults, steel contributes a substantially larger cost share than its value share. Establishing the corresponding actual-emissions result is an empirical task for installation-level research.

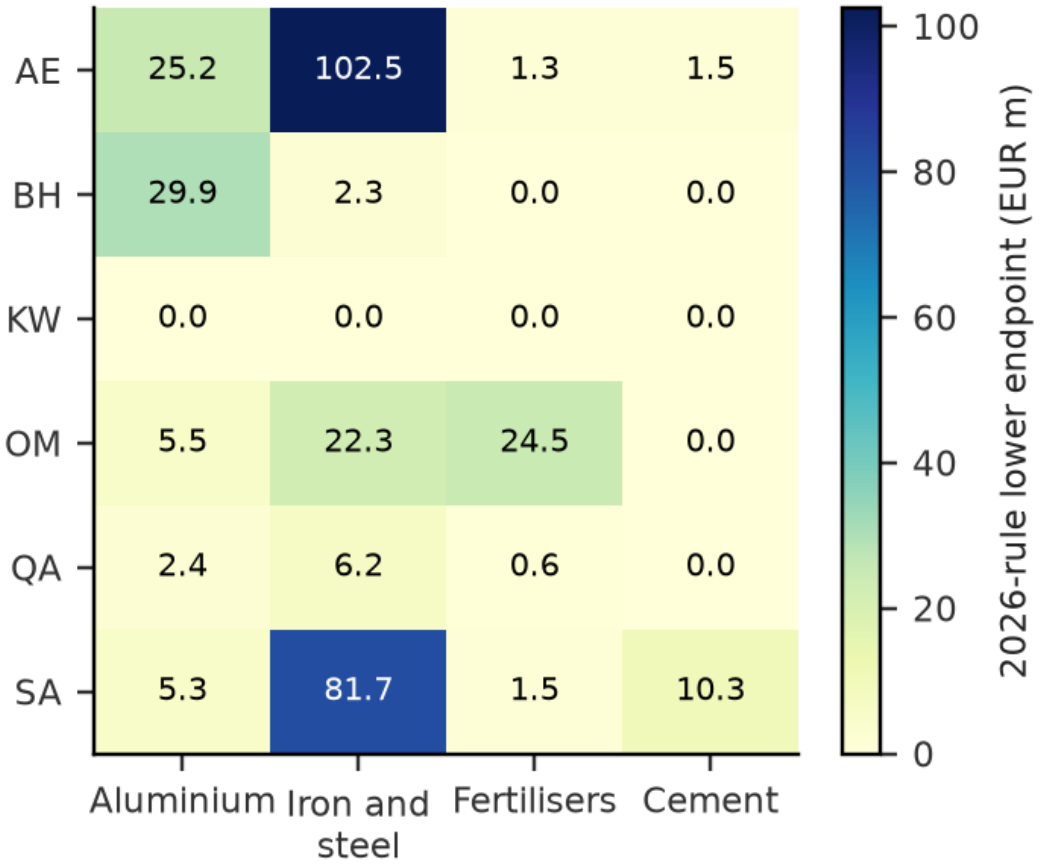


Fig. 4. Country–sector conditional 2026-rule exposure, EUR million, lower endpoint. The 2025 basket, official defaults and EUR 75/tCO2e are held fixed. Zero-looking cells may contain small positive values.

6.5. Fertiliser results and historical classification

M. Concentration in the Oman basket

The recorded fertiliser-group value is EUR 96.59 million in 2025. Oman accounts for EUR 68.98 million and approximately 176,218 tonnes. Its 2026-rule estimate is EUR 24.50 million. Saudi Arabia contributes EUR 15.25 million in trade value and EUR 1.48 million in conditional cost; the UAE contributes EUR 5.52 million and EUR 1.27 million, respectively. Qatar contributes EUR 6.83 million in value and EUR 0.60 million in cost.

The Oman urea record CN 31021019 contains EUR 62.15 million and 162,990.121 tonnes. It is a major contributor to the sector result. The selected emissions factor, benchmark and fallback status are reported in the factor appendix. The monthly-to-annual check reproduces both its annual value and mass.

N. Why the historical interval is wider

Older urea CN 31021010 observations do not supply the product detail required to distinguish all current greater-than-45%-nitrogen categories. The current entries differentiate particular solution concentrations and other urea. Applying one current factor to all historical mass would impose an unobserved composition assumption. The paper instead carries compatible alternatives into the endpoint calculation.

This issue is material to the earlier-year totals. The 2022 aggregate exposure interval is approximately EUR 62.3 million wide, compared with EUR 5.57 million in 2025. The width reflects the set of permitted classifications in the model. It is not a statistical standard error and does not measure variation between actual plants.

O. Technology context

The IEA ammonia roadmap describes the relationship between ammonia production, nitrogen fertilisers, feedstocks and potential emissions-reduction pathways [18]. That context is relevant to the interpretation of a fertiliser portfolio. The present model uses the product-level default table rather than a common ammonia-sector intensity. A tonne of a formulated or dissolved product must be evaluated under its own applicable category.

[Inference] The historical-code result suggests that product-composition records can be as important as a broad sector emissions claim. For an exporter or importer, a precise goods description and its relationship to the declared code can narrow a calculation before any technology decision is considered. The model shows the numerical consequence of that precision without assuming a particular missing concentration.

P. Policy and cost boundaries

The fertiliser scenario uses the 1% default mark-up specified in the retained corrected annex. It does not apply the 10% 2026 mark-up used for the other three sectors. The sector therefore follows a distinct parameter path in the full-phase-in comparison. Applying a common mark-up across all four sectors would change the result incorrectly.

The estimate excludes changes in fertiliser demand, food prices and downstream agricultural output. Those effects require additional data and a behavioural framework. The empirical finding here is the conditional exposure of the observed EU-facing product basket.

6.6. Cement results and commodity value

Q. Low value and substantial physical quantities

The recorded cement basket is EUR 16.10 million in 2025. Saudi Arabia contributes EUR 10.22 million and approximately 205,766 tonnes. The UAE contributes EUR 5.88 million and approximately 63,627 tonnes. Oman records a very small additional flow. The 2026-rule estimate is EUR 11.83-17.40 million for the sector.

This interval is large relative to recorded trade value. The calculation can exceed the value of particular observations because a mass-based emissions cost is compared with a low unit-value commodity. The arithmetic does not establish that the transaction would proceed at that burden. It describes the fixed-basket scenario before changes in sourcing, contracts or quantities.

R. White and grey product alternatives

The eight-digit clinker code contains alternative product definitions in the regulatory defaults. Saudi Arabia's 2025 clinker observation records 205,765.785 tonnes and EUR 10.221 million. The paired emissions-default and benchmark alternatives generate a conditional exposure of approximately EUR 10.33-13.91 million. The endpoints preserve the relation between the product-specific intensity and its corresponding benchmark.

The UAE clinker and other hydraulic-cement observations also contribute to the sector interval. The model does not assume that all cement is grey, or that the product with the lowest emissions factor necessarily creates the lowest net cost. Benchmark differences can change the ordering of the net calculation. Taking the minimum and maximum after calculating each compatible pair handles this issue explicitly.

S. Partial clay scope

The ex-code for calcined kaolinic clay is treated separately. Its 2025 observed value is EUR 7,554 and its recorded mass is 0.078 tonnes. Under the retained default-and-benchmark parameters, the conditional 2026-

rule cost is zero even at the full-mass inclusion endpoint. This is a result for the observed sensitivity record; it does not generalise to all clay imports or future prices and rules.

[Inference] Cement illustrates the limits of treating an exposure ratio as a commercial forecast. A large ratio can indicate that the fixed-basket assumption would be economically important to test. The present dataset cannot establish which response would follow. A model of delivered cost, customer substitution and plant-specific emissions would be needed to examine whether trade adjusts.

The finding also reinforces the need to show both tonnes and euros. A small share of total trade value can still generate a visible share of a carbon-cost scenario. An assessment that screens only by sales value could omit products that deserve detailed regulatory and emissions review.

For this sector, the most immediate research extension is to identify the white/grey composition of the recorded codes. That information would narrow the interval directly and improve the comparison with installation evidence. The paper reports the current envelope transparently pending that evidence.

6.7. Product concentration and portfolio priorities

T. A small number of cells account for much of the estimate

The five largest country-product cells account for 36.3% of the 2026-rule lower-end estimate. The ten largest account for 51.1%. The ten largest value cells account for 59.8% of recorded value, but the membership and ordering differ from the exposure ranking. Figure 5 displays the leading exposure cells, retaining origin and commodity code.

These concentration measures are descriptive statistics of the retained cross-section. A country-product cell may contain multiple exporters, importers or installations. The results cannot be interpreted as a customer or firm concentration measure. A commercial application would need to disaggregate the cell to the relevant counterparties.

U. Ranking uncertainty

The main ranking uses the lower endpoint consistently. For a cell with several compatible alternatives, its upper endpoint can alter its position relative to another cell. The appendices provide both endpoints so that the reader can examine those overlaps. The paper does not present an exact ordering as stable when the underlying intervals overlap.

[Inference] A practical evidence-collection strategy can begin with cells that combine substantial conditional exposure, a high fallback dependence and a feasible route to installation information. This is a proposed use of the findings. It has not been tested as an operational intervention and no collection-cost saving is claimed.

V. Value of additional information

Additional information can affect the calculation in several ways. A clarified product composition reduces classification ambiguity. A verified installation factor can replace a default when the legal requirements are met. Importer identity can establish the relevant threshold treatment. Evidence of an eligible carbon payment can support a credit. Contract terms can help identify who bears the economic cost.

These information improvements address different parts of the problem. A precise tariff code alone does not verify emissions. A measured corporate footprint alone does not establish a product-specific factor. An agreed commercial cost-sharing clause alone does not change the regulatory calculation. The factor register and source lineage make those distinctions visible.

The concentration finding is useful because it turns a broad sector discussion into a bounded set of data questions. The largest cells supply a starting point for research, while the complete machine-readable panel preserves the smaller observations for aggregation and subsequent review.

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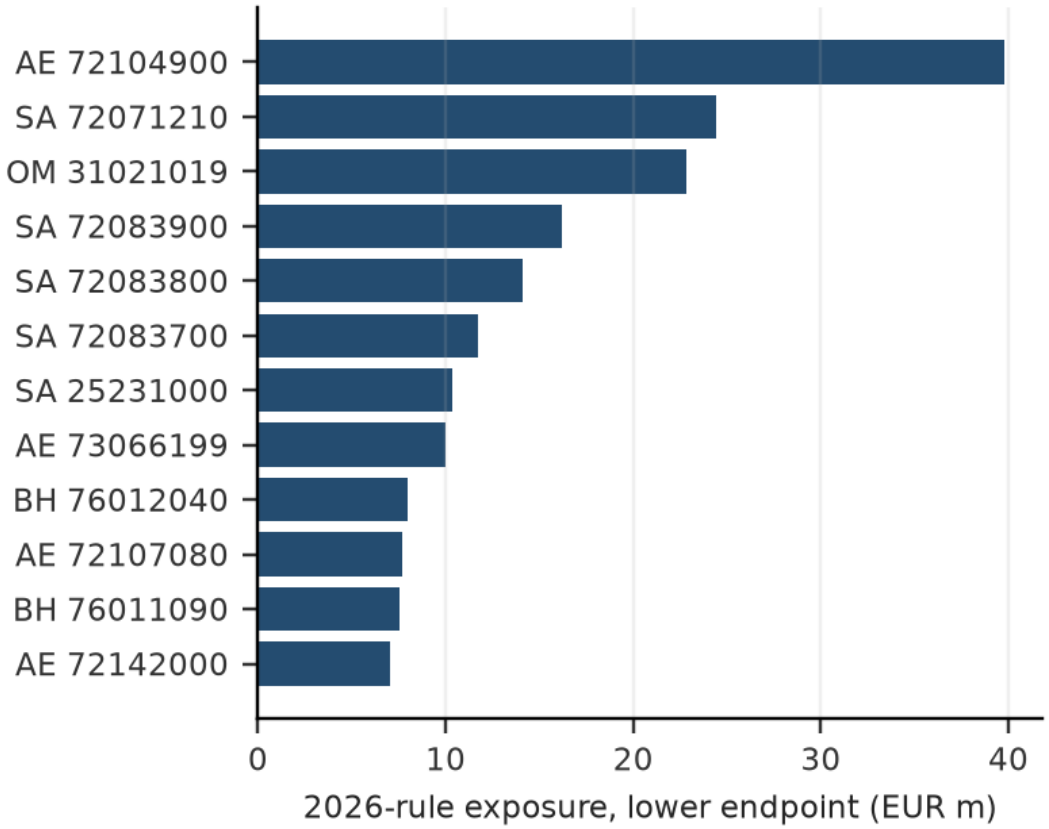


Fig. 5. Leading country–CN8 cells by conditional 2026-rule exposure for the 2025 basket, lower endpoint. Estimates use EUR 75/tCO2e. Both endpoints appear in Appendix F; leading product descriptions appear in Appendix G.

7. Regulatory scenario comparison

A. Three separate monetary measures

For the 2025 basket, the unmarked gross-carbon-price diagnostic is EUR 540.4-543.4 million at EUR 75/tCO2e. The 2026-rule calculation produces EUR 323.0-328.6 million after the prescribed mark-ups and benchmark adjustment. The full-phase-in scenario produces EUR 689.4-693.3 million after retaining the 2028-onward default mark-ups and removing the benchmark deduction.

The gross diagnostic is useful for checking the multiplication of mass, factor and price. It is not a statutory charge. The 2026-rule scenario follows the specified first-year parameter set. The full-phase-in endpoint shows the same basket under a different regulatory adjustment. These measures should be named explicitly whenever their values are reproduced.

The full-phase-in estimate corresponds to 15.39-15.48% of the 2025 recorded import value. Its comparison with the 2026 ratio of 7.21-7.33% isolates changes in the model's regulatory parameters. The calculation holds the trade basket, price and underlying default factors fixed, including their country and product assignments.

B. Temporal interpretation

Figure 6 applies both scenario definitions to each historical basket. The horizontal axis identifies the observed trade year. It does not identify the year when the displayed amount was due or paid. This presentation is intended to show how the same rules interact with changing quantities and product composition.

The earlier-year interval is especially wide around the historical urea categories. The difference between endpoints is generated by the stated admissible classifications. The plot therefore retains an uncertainty band rather than a single line for each scenario. It also avoids drawing a smooth time-series narrative from an unresolved classification change.

[Inference] The increasing gap between the first-year and full-phase-in scenarios for some baskets indicates that long-term commercial planning should examine the adjustment schedule alongside current exposure. This is a conditional planning implication. It is not a forecast of realised cash outflows, future trade or regulatory stability.

No future production growth is built into the endpoint. The analysis also excludes changes in electricity supply, abatement technology and verified actual-emissions use. Those changes could be introduced as separately documented scenarios once their inputs are specified. Keeping the present comparison fixed makes the effect of the selected regulatory parameters transparent.

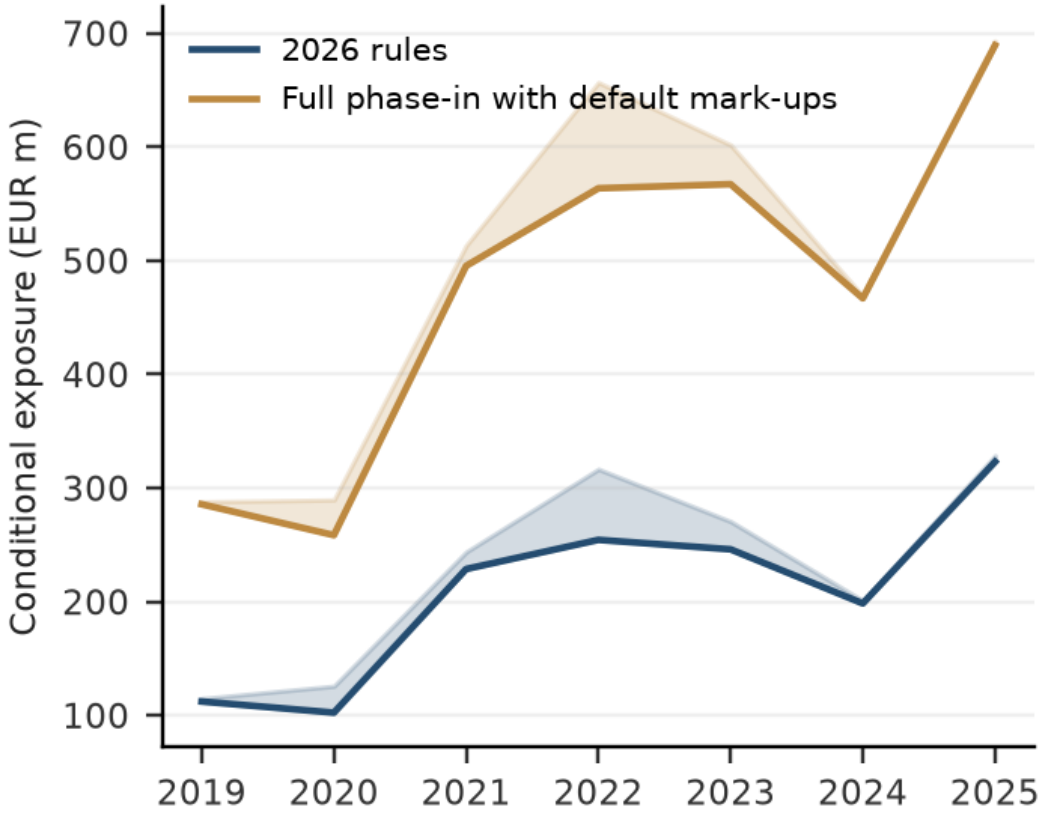


Fig. 6. Conditional cost by observed trade year under 2026 rules and a full-phase-in parameter scenario. All years use the same corrected defaults and EUR 75/tCO2e. Shading shows classification endpoints, not confidence intervals.

7.1. Carbon-price and intensity sensitivities

C. Carbon-price sensitivity

At EUR 50/tCO2e, the conditional 2026-rule estimate for the 2025 basket is EUR 215.4-219.1 million. At EUR 75, it is EUR 323.0-328.6 million. At EUR 100, it is EUR 430.7-438.1 million. The proportional change follows from the accounting equation with quantities and all other parameters held fixed.

Figure 7 displays a wider price range to make that relationship visible. The line does not estimate a market response to the carbon price. Demand, trade quantities and product prices remain fixed. The slope is therefore a sensitivity coefficient of the specified portfolio calculation.

D. Intensity-parameter sensitivity

Reducing every assigned base intensity by 10%, with the same benchmark, mark-up, price and trade mass, lowers the 2026-rule estimate to EUR 264.0-269.2 million. A 20% reduction gives EUR 205.0-209.9 million. A 30% reduction gives EUR 147.4-151.9 million. These reductions are hypothetical parameter changes. They are not measured improvements at GCC installations.

The percentage reduction in cost can exceed the percentage change in the intensity parameter because the benchmark deduction is held fixed. The non-negative floor eventually changes the slope for product alternatives that cross the zero-cost threshold. This accounts for the nonlinearity visible when larger intensity reductions are considered.

The exercise deliberately holds the mark-up in place. A legal switch from defaults to verified actual emissions can require a different calculation and supporting evidence. The sensitivity table therefore should not be described as the savings from verification or a promised return on an industrial technology investment.

[Inference] The sensitivity is useful for screening the scale of a potential emissions issue. An investment appraisal would additionally need the actual baseline, eligible emissions reduction, capital and operating costs,

production effects, verification costs and the share of any commercial benefit captured by the investor. The present data do not supply those quantities.

The paper reports deterministic sensitivity points because the inputs lack verified probability distributions. This preserves the distinction between a transparent what-if calculation and a probabilistic risk estimate. Appendix I presents the price and intensity scenarios in tabular form with the retained assumptions.

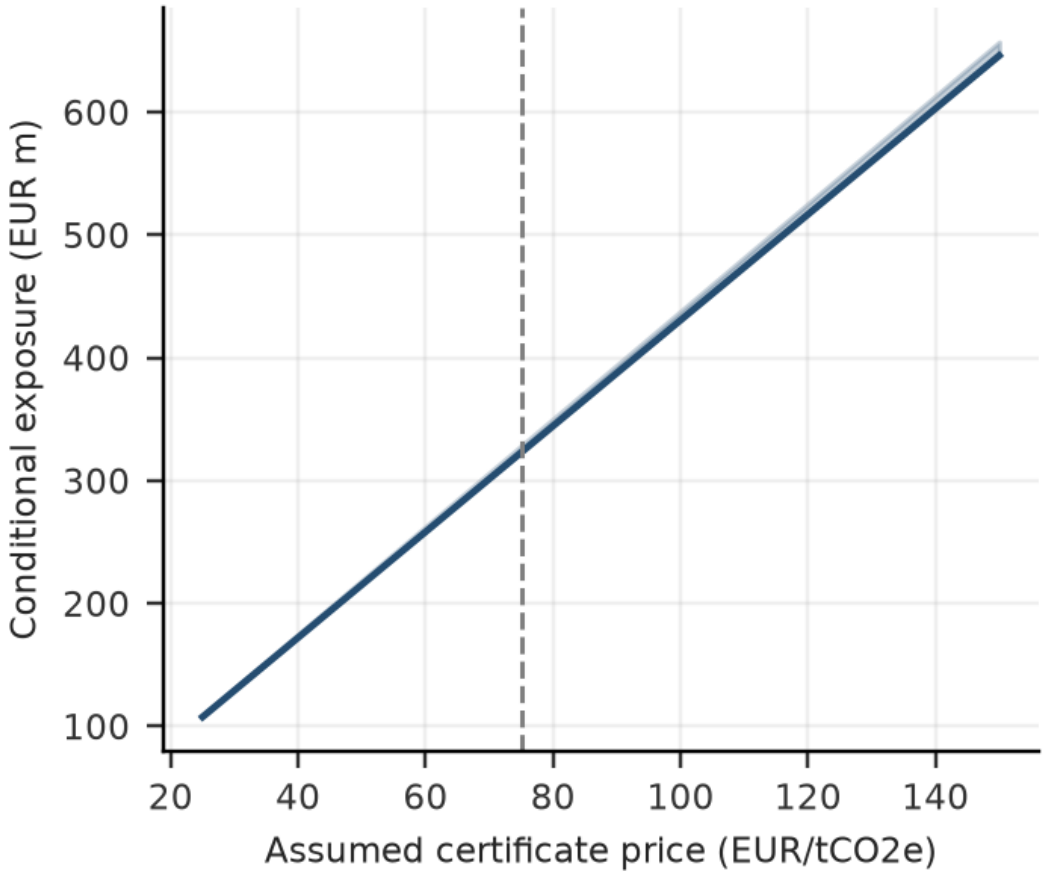


Fig. 7. Price sensitivity of conditional 2026-rule exposure for the fixed 2025 basket. The EUR 75 reference is an analyst-selected scenario. Classification alternatives define the shaded range.

7.2. The benchmark subtraction matters

E. A worked algebraic comparison

For the primary-aluminium illustration, the benchmark is 1.423 tCO2e per tonne. With a default intensity of 1.870, a 10% mark-up and a retained free-allocation factor of 0.975, the net intensity is 0.669575. Multiplying that quantity by EUR 75 gives EUR 50.218 per tonne of product.

A calculation that applies 2.5% to the unmarked intensity would instead give 1.870 × 75 × 0.025 = EUR 3.506 per tonne. The difference between these two calculations is EUR 46.712 per tonne. The second expression omits the benchmark-based structure and the default mark-up. It is included solely to demonstrate the arithmetic difference.

Figure 8 varies the default intensity while holding the benchmark and price fixed. The correct conditional expression is piecewise linear because it includes a non-negative floor. The simple percentage comparison has a different slope and intercept. The two expressions therefore cannot be substituted for one another.

F. Implications for portfolio calculations

The benchmark adjustment varies by product and compatible production route. A blanket sector percentage applied to gross emissions can obscure these differences. It can also change the ordering of products by estimated exposure. The factor register records the selected benchmark so that each cell can be reviewed.

[Inference] This finding is relevant to managerial estimates that rely on broad phase-in percentages. A preliminary business case should identify whether its calculation subtracts the appropriate benchmark and whether its emissions input includes a default mark-up. Those two choices can materially alter the estimate even before questions about actual installation performance are considered.

The calculation also explains why classification alternatives need to remain paired. A lower emissions factor does not necessarily yield the lowest net expression if its matching benchmark is lower by a larger amount. The endpoint algorithm evaluates each compatible pair first, then selects the minimum and maximum. It does not independently combine the minimum factor with the maximum benchmark.

This arithmetic validation is separate from the accuracy of the underlying emissions assignment. A perfectly implemented formula can still describe a scenario far from a plant's actual emissions. Both parameter provenance and formula implementation must therefore be visible in a research paper intended for commercial interpretation.

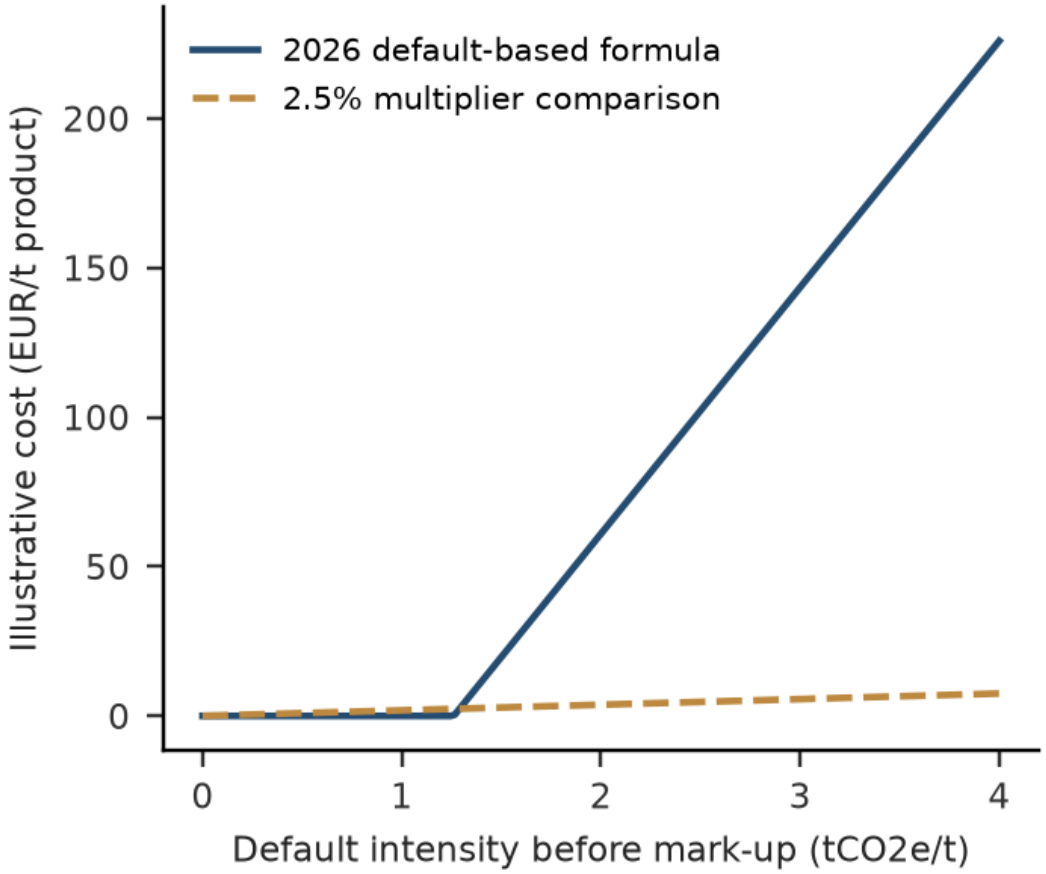


Fig. 8. Illustrative effect of benchmark subtraction for primary aluminium. The solid curve uses the 2026 default-based formula; the dashed curve is a 2.5% multiplication diagnostic. P = EUR 75/tCO2e and b = 1.423 tCO2e/t.

8. Robustness and data quality

A. Fallback dependence

In 2025, EUR 850.75 million of recorded trade value uses at least one fallback emissions default in the model, representing approximately 19.0% of the matched basket. Retaining only country-specific-default observations leaves EUR 3.629 billion of value and a 2026-rule estimate of EUR 72.5-74.5 million. The difference reflects the removal of an economically distinct sample, especially within steel and selected fertilisers.

This reduced-sample estimate is not a verified-actual-emissions scenario. It does not show that the removed exposure could be avoided. The fallback flag identifies where the official country table lacks a numeric assignment for the matched good. It says nothing about whether the underlying exporter possesses a verified emissions report.

Figure 9 reports the value share using fallback defaults across the historical period. Changes can arise from shifts in trade composition and classification. The fixed default-table vintage means the chart does not measure improvements in actual disclosure over time.

B. Classification robustness

All 805 records in the 2025 core have a current benchmark code. Excluding legacy codes therefore leaves the headline 2025 estimate unchanged. Earlier years contain historical nomenclature mappings and should be read

with their reported intervals. The unambiguous-match 2025 variant retains 802 observations and EUR 4.465 billion in value, with a conditional cost of EUR 311.54 million. The omitted ambiguous cells are concentrated in cement.

C. Verification outcomes

The calculations pass uniqueness checks for country-product-year keys, country/year coverage checks, complete benchmark-matching checks and endpoint-order checks. The selected four-digit hierarchy reconciliation uses 336 comparisons across four headings, two measures and 42 batches. The maximum numerical difference is approximately 9.3 × 10^-10 in the underlying reported units.

Six monthly-to-annual checks are documented separately. They cover Bahrain aluminium billets, UAE coated steel, Saudi clinker, Oman urea, Qatar unwrought aluminium and a small Kuwait aluminium-article flow. All mass totals agree at the recorded precision. The UAE steel value differs by EUR 1 between the retained annual and monthly aggregations.

[Inference] These checks support the integrity of extraction, aggregation and formula implementation for the tested operations. They do not verify plant emissions, the completeness of confidential trade or the applicability of an importer exemption. Those limits remain distinct from arithmetic validation.

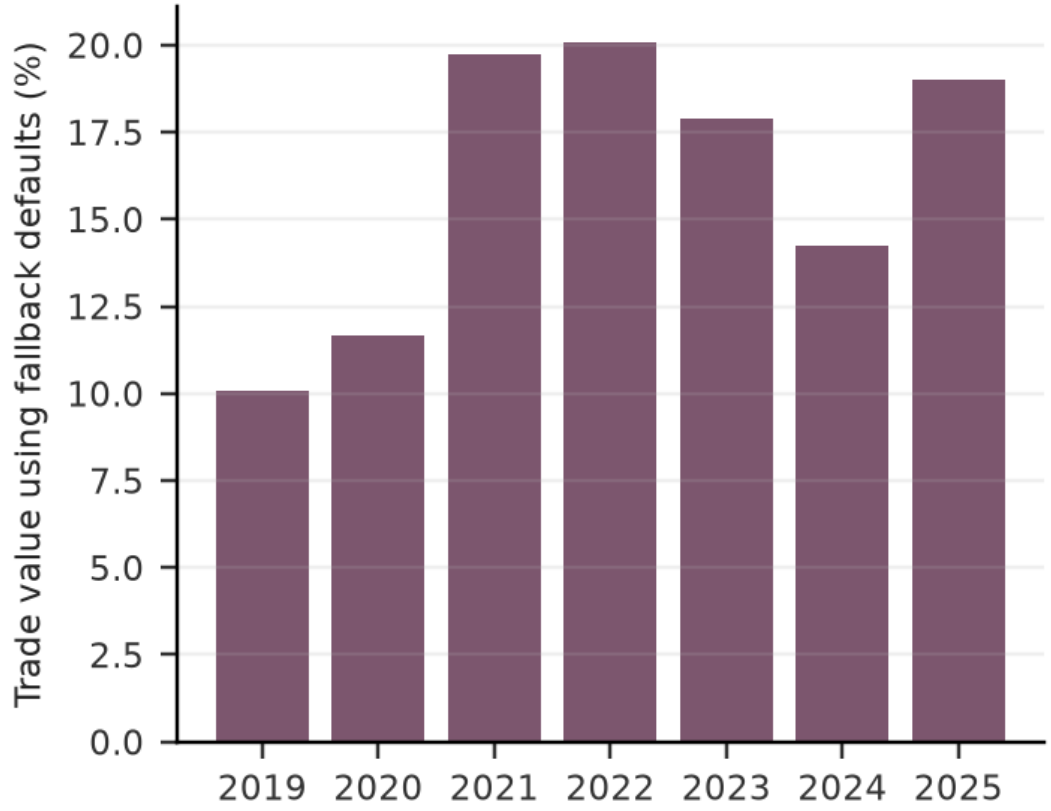


Fig. 9. Share of recorded covered value assigned an other-country fallback default in the model. This is a property of the matched regulatory dataset, not a measure of exporter disclosure behaviour.

8.1. Decomposing quantity and composition effects

D. Symmetric decomposition

The gross diagnostic can be written as P × Q × e-bar for a sector, where e-bar is the mass-weighted default intensity of its recorded product mix. With a fixed price, the change between two years can be decomposed exactly into a quantity term and a composition term. The quantity term is P × (Q1 - Q0) × (e-bar1 + e-bar0)/2. The composition term is P × (e-bar1 - e-bar0) × (Q1 + Q0)/2. Their sum equals the change in the gross diagnostic.

This is a symmetric accounting decomposition. It avoids assigning the interaction term entirely to the initial or final year. It is applied to the lower-end unmarked gross scenario between 2019 and 2025. The results do not decompose actual plant emissions because the regulatory factors are frozen.

E. Results

The iron-and-steel gross diagnostic increases by EUR 205.9 million. The quantity component is approximately EUR 210.2 million and the composition component is negative EUR 4.34 million. Aluminium increases by EUR 56.49 million, comprising EUR 54.43 million from quantity and EUR 2.06 million from composition. Fertilisers increase by EUR 44.27 million, with approximately EUR 27.12 million from quantity and EUR 17.15 million from composition.

Cement increases by EUR 13.78 million, combining a EUR 15.67 million quantity term and a negative EUR 1.89 million composition term. Across sectors, the interpretation is mechanical: a change in total tonnes and a change in the weighted factor associated with the observed product mix explain the diagnostic's change under the chosen endpoint convention.

F. Limits of the decomposition

The composition term can reflect a shift between products, country-specific defaults and fallback assignments. It can also be affected by historical-code ambiguity. A negative term must therefore not be labelled decarbonisation. Installation-level improvements would require time-varying verified intensities for a comparable production boundary.

The lower-end historical urea assignment influences the fertiliser result. Appendix J provides the inputs and algebra so that an alternative endpoint can be evaluated. The paper does not select the lower endpoint because it is more likely; it uses a consistent endpoint convention for a transparent decomposition.

[Inference] The decomposition suggests that rising physical quantities are an important component of the change in this fixed-factor exposure measure. It also shows where composition deserves closer examination. The appropriate follow-up is a more detailed review of product and installation data, rather than attributing the composition term to an unobserved technology change.

This analysis complements the value and mass charts. It provides a reproducible explanation for the change in one modelled measure, while preserving the distinction between an accounting identity and an estimated economic mechanism. The same decomposition can be applied to revised source snapshots or a later verified-emissions panel.

9. Discussion and industrial implications

A. Translating research into evidence collection

[Inference] The most immediate use of the analysis is to prioritise evidence collection at the product and installation level. The default-based steel estimate, the concentration in a small number of cells and the historical urea ambiguity identify specific information gaps. An operational programme could begin with the largest relevant products and request compatible emissions reports, product descriptions and precursor information.

The sequencing matters. A usable record needs a declared product, its quantity, its producing installation and an emissions report whose boundary matches the applicable calculation. A corporate sustainability report may supply useful context, but it does not automatically resolve each of those requirements. The research package preserves the product keys needed for a subsequent installation-level join.

B. Commercial contracts and profitability

[Inference] Buyers and sellers can use a common calculation to clarify what a quoted carbon-cost allowance represents. The assumption set should identify price, factor vintage, emissions method, product code, benchmark, exemption treatment and credits. Differences in estimates can then be traced to a parameter or evidence choice instead of remaining embedded in an unexplained surcharge.

The paper cannot allocate the modelled cost between parties. That allocation depends on contracts and market responses. It also cannot estimate profit effects because firm costs, margins and substitution possibilities are unavailable. An exposure-to-import-value ratio is a useful portfolio descriptor within these limits. It is not a margin forecast.

C. Industrial technology and reliability

[Inference] Energy efficiency, process reliability, material yield and production-route changes may be relevant to an installation's emissions strategy. Their contribution to this particular regulatory exposure must be measured within the applicable boundary. The present analysis does not estimate an effect of predictive

maintenance or industrial AI on emissions, production or cost. Such a claim would require intervention evidence and a documented baseline.

For an investment appraisal, the required inputs include the actual intensity, expected eligible reduction, verification expenditure, capital cost, operating cost, production consequences and commercial incidence. A technology proposal should connect those inputs to a plant-specific calculation. The parameter sensitivity in Section 7 provides a scale illustration without asserting that a technology delivers the assumed reduction.

D. Public policy and research infrastructure

[Inference] A useful public-data extension would connect product-level trade, installation characteristics and compatible verified emissions while preserving confidentiality. Better historical classification correspondence would also narrow uncertainty in long-period comparisons. These improvements would strengthen the evidence base for evaluating actual competitive effects and potential policy responses.

The findings complement aggregate exposure studies by making the calculation traceable at a finer product level. A broader welfare assessment would still require a behavioural model. A firm-level competitiveness assessment would require operational and contractual data. The current evidence supports a clear intermediate result: conditional portfolio exposure under a specified and reproducible regulatory parameter set.

10. Limitations and conclusions

A. Principal limitations

First, the emissions inputs are regulatory defaults. The study does not observe actual installation emissions, technology routes or shipment-level precursor composition. Second, the public data do not identify the importer-level information needed to apply exemptions. Third, the model assumes no origin-carbon-price credit because payment evidence is unavailable. Fourth, it holds quantities and commercial prices fixed when calculating scenarios. Fifth, historical product codes can require a classification envelope.

The classification endpoints address the fifth issue and compatible benchmark alternatives. They do not cover every source of uncertainty listed above. Results should therefore be quoted with both their numerical interval and the underlying scenario definition. The uncertainty language is integral to the estimand.

The trade source is also subject to revisions and confidentiality practices. The retained source snapshot makes the calculation reproducible, but later releases may change particular observations. The hierarchy and monthly checks test internal consistency; they do not establish complete coverage of every unreported transaction. Mirror-data reconciliation and installation-level verification remain future extensions.

B. Answers to the research questions

The recorded four-sector basket increases from EUR 1.983 billion in 2019 to EUR 4.480 billion in 2025, with a value peak in 2022. Aluminium dominates the 2025 value measure. Under the specified default-based 2026-rule scenario, iron and steel dominate the conditional cost measure. The ten largest country-product cells account for 51.1% of the lower-end estimate.

At EUR 75/tCO2e, the 2025 basket produces EUR 323.0-328.6 million of conditional exposure. The full-phase-in parameter scenario produces EUR 689.4-693.3 million. Historical classification ambiguity is more material in some earlier years, particularly for urea. Removing legacy mappings leaves the 2025 headline result unchanged.

The sensitivity exercises establish the scale of the model's response to price and intensity assumptions. They also show that subtracting the benchmark is essential to the stated calculation. None of these findings identifies realised payments, exporter profit losses or a causal effect of CBAM on trade.

C. Research contribution and next evidence

[Inference] The paper's principal value is a transparent bridge between public trade records and a dated regulatory calculation. It supplies a product-level basis for identifying where further evidence could most improve an exposure assessment. The next empirical step is to replace applicable defaults with compatible verified installation information and connect the resulting estimates to importer and contractual records.

The conclusions remain specific to the observed basket and stated assumptions. The accompanying data, factor register, scripts and validation record permit another researcher to change those assumptions, update the source snapshot and reproduce the tables and figures.

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APPENDIX A. Data dictionary and source hierarchy

Table A1 defines the fields needed to reproduce the core calculation. Monetary values are in current euros. The full machine-readable dataset retains additional flags and scenario outputs.

Field	Definition and interpretation
country / country_name	GCC origin code and label in the Eurostat query.
year	Observed annual trade year, 2019 to 2025.
cn8	Eight-digit product code; stored as text.
description	Eurostat commodity label for the retrieved code.
sector	One of the four regulatory sectors selected for this study.
value_eur	Recorded EU import value. No currency conversion or inflation adjustment.
tonnes	QUANTITY_IN_100KG divided by 10.
partial_scope	True for 25070080; excluded from the core calculation.
default_codes	Applicable legal default rows, including TARIC alternatives.
routes	Default-route indicators used to select compatible benchmarks.
fallback	At least one matched default comes from the other-country table.
n_alternatives	Count of compatible factor/benchmark combinations.
e_low / e_high	Minimum and maximum base default intensity among alternatives.
bm_low / bm_high	Range of matched Column B benchmarks; pairing retained in the factor register.
bm_complete	All compatible alternatives have a benchmark.
gross_*_eur	Unmarked intensity multiplied by tonnes and EUR 75.
y2026_*_eur	2026 mark-ups, f = 0.975, k = 1, P = EUR 75.
full_*_eur	Full phase-in with 30% non-fertiliser and 1% fertiliser mark-ups.
low / high	Scenario endpoints over compatible alternatives; not probability intervals.

Source hierarchy: legislation defines scope and calculation; Commission workbooks supply machine-readable parameters; Eurostat supplies trade observations.

APPENDIX B. Coverage and quality audit

Table B1. Every retained core record has a mass field and a matched benchmark. Zero-mass columns identify positive-value observations. Fallback and ambiguous columns report affected trade value in EUR million.

Origin	Year	Records	Zero mass	Fallback EUR m	Ambiguous EUR m
AE	2019	309	5	118.038	0.690
AE	2020	292	3	97.741	0.103
AE	2021	312	2	271.096	0.503
AE	2022	325	5	388.860	5.897
AE	2023	346	1	456.866	24.239
AE	2024	329	2	339.678	2.581
AE	2025	346	2	465.686	4.646
BH	2019	69	8	9.004	0.000
BH	2020	64	5	1.769	0.001
BH	2021	64	3	1.898	0.001
BH	2022	82	2	19.393	16.778
BH	2023	88	1	9.543	5.561
BH	2024	71	2	8.439	0.000
BH	2025	58	1	15.052	0.000
KW	2019	34	0	1.798	0.032
KW	2020	26	3	0.642	0.000
KW	2021	32	4	0.212	0.000
KW	2022	40	2	0.989	0.000
KW	2023	52	3	1.599	0.000
KW	2024	38	2	0.576	0.090
KW	2025	37	4	0.274	0.000
OM	2019	83	6	40.416	2.284
OM	2020	68	0	57.380	40.955
OM	2021	69	2	91.447	31.323
OM	2022	79	4	492.649	379.666
OM	2023	97	2	160.252	71.002
OM	2024	86	1	42.836	0.224
OM	2025	95	2	124.253	0.000
QA	2019	87	5	5.408	0.044
QA	2020	73	5	2.523	0.008
QA	2021	81	5	20.882	0.000
QA	2022	91	6	6.127	0.000
QA	2023	99	6	9.736	12.683
QA	2024	78	3	1.557	0.000
QA	2025	86	5	26.382	0.000
SA	2019	130	2	25.423	5.940
SA	2020	121	6	25.766	8.337
SA	2021	147	2	168.961	12.785
SA	2022	160	10	175.275	29.788
SA	2023	177	3	133.162	10.017
SA	2024	191	3	152.627	5.980
SA	2025	183	3	219.099	10.221

Checks: 5,295 unique country-CN8-year keys; six origins; seven years; 519 distinct codes. Core zero-mass value totals EUR 16,574, including EUR 704 in 2025. Classification intervals do not capture actual-emissions uncertainty. Source: retained dataset and quality.csv.

APPENDIX C. Country-year results

Table C1. Observed trade and conditional 2026-rule exposure at EUR 75/tCO2e. Values and costs are EUR million; mass is thousand tonnes. All historical years use the same corrected regulatory factors.

Origin	Year	Value	Mass kt	Cost low	Cost high
AE	2019	1334.486	779.519	64.363	64.381
AE	2020	891.207	550.332	47.421	47.425
AE	2021	1481.861	909.927	103.631	103.635
AE	2022	2549.883	995.396	109.598	110.848
AE	2023	2224.770	1116.099	120.945	127.286
AE	2024	1752.678	828.146	87.383	88.348
AE	2025	1825.473	985.893	130.441	132.423
BH	2019	409.114	219.287	13.172	13.172
BH	2020	459.198	278.895	14.944	14.944
BH	2021	740.696	338.953	19.008	19.008
BH	2022	1206.790	389.204	21.724	23.860
BH	2023	1021.430	408.218	22.977	23.740
BH	2024	1132.688	454.724	25.650	25.650
BH	2025	1479.169	571.542	32.286	32.286
KW	2019	2.039	1.504	0.312	0.316
KW	2020	0.940	0.611	0.153	0.153
KW	2021	0.336	0.248	0.057	0.057
KW	2022	1.317	0.959	0.210	0.210
KW	2023	2.081	1.509	0.354	0.354
KW	2024	0.727	0.391	0.101	0.101
KW	2025	0.391	0.056	0.010	0.010
OM	2019	86.808	119.773	19.847	20.948
OM	2020	120.684	340.478	22.617	43.226
OM	2021	169.974	290.132	27.706	39.016
OM	2022	752.034	916.368	65.699	123.299
OM	2023	363.460	366.119	37.879	51.909
OM	2024	404.104	205.514	20.380	20.458
OM	2025	448.921	397.085	52.326	52.326
QA	2019	30.359	16.883	1.626	1.629
QA	2020	42.554	29.942	1.540	1.540
QA	2021	44.589	154.048	12.378	12.378
QA	2022	184.458	106.053	5.574	5.574
QA	2023	214.653	235.488	9.733	10.689
QA	2024	115.743	45.253	1.808	1.808
QA	2025	203.986	152.060	9.146	9.146
SA	2019	120.573	190.136	12.816	14.487
SA	2020	80.097	241.592	15.655	18.524
SA	2021	374.418	538.488	65.881	69.747
SA	2022	697.897	460.485	51.524	52.815
SA	2023	487.689	498.943	54.114	56.640
SA	2024	427.242	455.427	63.085	64.676
SA	2025	522.180	698.145	98.818	102.401

Results are before importer exemptions and origin-carbon-price credits. Country totals sum product endpoints. Source: Eurostat [1], regulatory parameters [4], [5], [7], and country_year.csv.

APPENDIX D. Sector-year results

Table D1. The sector grouping follows the covered legal product list. The iron-and-steel group includes specified precursors and downstream articles. Values and conditional costs are EUR million; mass is thousand tonnes.

Sector	Year	Value	Mass kt	Cost low	Cost high
Aluminium	2019	1778.230	940.888	47.004	47.004
Aluminium	2020	1404.495	820.187	41.240	41.240
Aluminium	2021	2247.784	1011.378	51.786	51.786
Aluminium	2022	4068.477	1245.962	64.451	64.451
Aluminium	2023	3397.036	1316.443	68.163	68.163
Aluminium	2024	3259.108	1269.519	65.006	65.006
Aluminium	2025	3593.653	1326.877	68.321	68.321
Cement	2019	6.932	111.090	6.082	7.570
Cement	2020	9.694	191.013	10.299	13.001
Cement	2021	13.726	266.298	12.833	16.353
Cement	2022	8.778	114.486	2.667	5.514
Cement	2023	12.384	181.206	7.893	11.062
Cement	2024	9.890	135.690	5.559	7.974
Cement	2025	16.099	269.392	11.833	17.398
Fertilisers	2019	4.832	19.153	0.695	1.987
Fertilisers	2020	42.938	226.057	10.219	30.999
Fertilisers	2021	36.346	133.751	5.791	17.448
Fertilisers	2022	644.197	880.483	39.836	99.267
Fertilisers	2023	269.563	553.142	27.989	49.436
Fertilisers	2024	21.505	55.019	3.124	3.343
Fertilisers	2025	96.586	231.031	27.844	27.844
Iron and steel	2019	193.384	255.972	58.355	58.373
Iron and steel	2020	137.552	204.593	40.572	40.573
Iron and steel	2021	514.019	820.369	158.252	158.254
Iron and steel	2022	670.927	627.535	147.374	147.374
Iron and steel	2023	635.099	575.584	141.957	141.957
Iron and steel	2024	542.680	529.227	124.719	124.719
Iron and steel	2025	773.782	977.479	215.029	215.029

Historical urea classifications create an admissible composition envelope. Sector totals are fixed-factor portfolio comparisons. They do not measure installation decarbonisation. Detailed factors and quantities remain available in the companion panel.

APPENDIX E. Country-sector results for 2025

Table E1 reports the observed combinations. An omitted country-sector combination has no retained public observation; it is not assigned an invented positive or zero transaction. Value and cost are EUR million; mass is thousand tonnes.

Origin	Sector	Value	Mass kt	Cost low	Cost high
AE	Aluminium	1353.765	484.126	25.200	25.200
AE	Cement	5.878	63.627	1.502	3.484
AE	Fertilisers	5.523	10.228	1.267	1.267
AE	Iron and steel	460.307	427.912	102.473	102.473
BH	Aluminium	1464.117	547.716	29.940	29.940
BH	Fertilisers	0.000	0.000	0.000	0.000
BH	Iron and steel	15.052	23.826	2.347	2.347

Origin	Sector	Value	Mass kt	Cost low	Cost high
KW	Aluminium	0.117	0.026	0.002	0.002
KW	Iron and steel	0.274	0.030	0.008	0.008
OM	Aluminium	317.049	121.114	5.506	5.506
OM	Cement	0.000	0.000	0.000	0.000
OM	Fertilisers	68.982	176.218	24.496	24.496
OM	Iron and steel	62.889	99.753	22.324	22.324
QA	Aluminium	170.771	65.176	2.388	2.388
QA	Fertilisers	6.833	13.228	0.602	0.602
QA	Iron and steel	26.382	73.657	6.156	6.156
SA	Aluminium	287.833	108.720	5.285	5.285
SA	Cement	10.221	205.766	10.332	13.915
SA	Fertilisers	15.248	31.357	1.479	1.479
SA	Iron and steel	208.877	352.302	81.722	81.722

The conditional ratio uses aggregated cost divided by aggregated import value. It does not average individual product ratios. Figure 10 shows those origin-level ratios, including classification ranges.

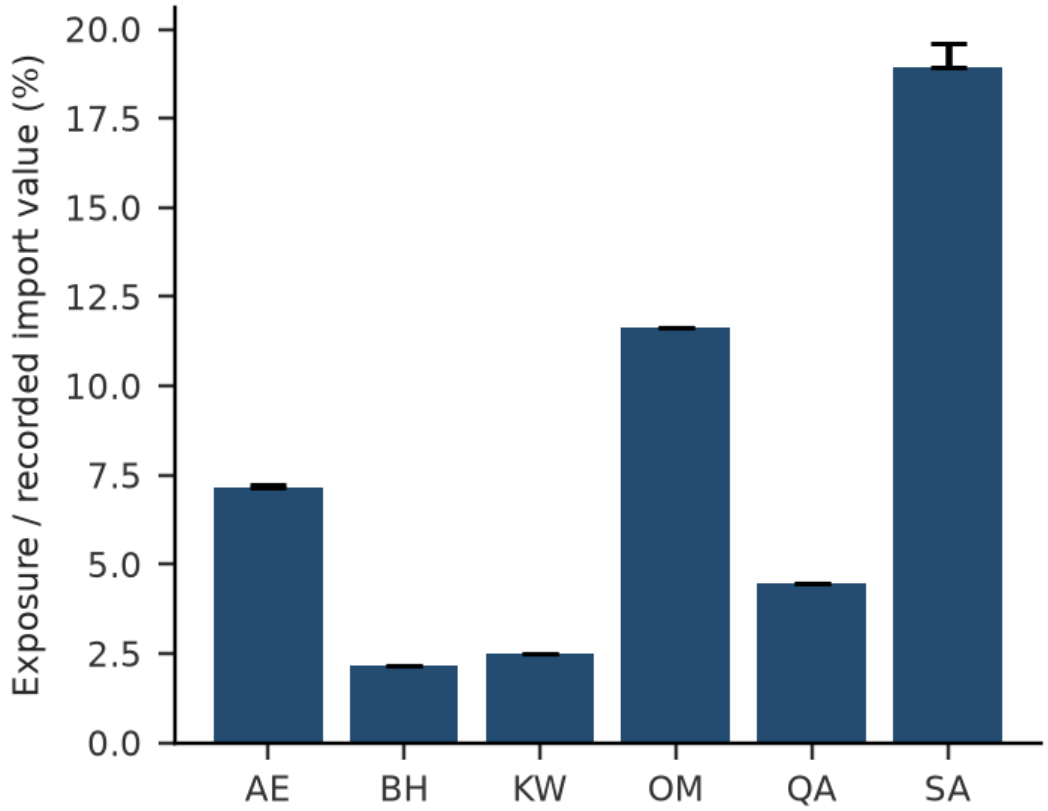


Fig. 10. Conditional 2026-rule cost as a percentage of recorded 2025 import value by origin. Error bars span classification alternatives.

APPENDIX F. Leading 2025 product exposures (1/5)

Table F1. Ranked country-product records 1 to 40 by lower-end conditional exposure. These 200 records account for 99.69% of the 2025 lower-end estimate. The companion dataset contains all 805 records. Values and costs are EUR thousand; mass is tonnes.

Origin	CN8	Sector	Tonnes	Value EUR k	Low EUR k	High EUR k
AE	72104900	Fe	173,646.815	124,531.552	39,817.757	39,817.757
SA	72071210	Fe	106,123.315	54,174.334	24,400.669	24,400.669
OM	31021019	Fert	162,990.121	62,149.596	22,831.860	22,831.860
SA	72083900	Fe	69,242.305	38,410.582	16,193.092	16,193.092

Origin	CN8	Sector	Tonnes	Value EUR k	Low EUR k	High EUR k
SA	72083800	Fe	60,342.470	34,003.142	14,111.765	14,111.765
SA	72083700	Fe	50,223.234	28,578.270	11,745.268	11,745.268
SA	25231000	Cem	205,765.785	10,221.468	10,331.629	13,914.654
AE	73066199	Fe	42,842.274	30,596.911	9,965.247	9,965.247
BH	76012040	Al	158,794.446	413,355.949	7,974.359	7,974.359
AE	72107080	Fe	33,468.587	31,110.516	7,674.452	7,674.452
BH	76011090	Al	149,558.850	374,021.269	7,510.565	7,510.565
AE	72142000	Fe	30,723.255	16,604.979	7,064.121	7,064.121
OM	72071912	Fe	29,222.182	17,680.667	6,718.983	6,718.983
AE	76012030	Al	123,810.753	343,116.022	6,217.544	6,217.544
AE	76012040	Al	119,175.481	313,046.858	5,984.769	5,984.769
QA	72031000	Fe	72,354.946	23,094.635	5,808.791	5,808.791
BH	76012080	Al	108,298.729	287,829.936	5,438.559	5,438.559
AE	73089098	Fe	17,598.909	88,519.485	5,433.674	5,433.674
OM	72071116	Fe	21,799.420	10,141.198	5,012.286	5,012.286
OM	72142000	Fe	19,937.430	10,460.890	4,584.163	4,584.163
AE	76012080	Al	91,075.055	253,887.936	4,573.618	4,573.618
AE	76011090	Al	80,278.032	209,812.505	4,031.412	4,031.412
AE	73084000	Fe	10,912.204	12,709.645	3,369.150	3,369.150
OM	76011090	Al	92,193.798	236,019.814	3,336.782	3,336.782
SA	72107080	Fe	14,364.543	14,280.129	3,293.835	3,293.835
SA	72083600	Fe	13,014.320	7,238.113	3,043.545	3,043.545
AE	73011000	Fe	13,097.712	9,977.060	2,993.891	2,993.891
SA	72104900	Fe	12,914.664	10,551.546	2,961.373	2,961.373
AE	73069000	Fe	10,646.075	7,499.827	2,476.310	2,476.310
AE	72139149	Fe	10,731.771	5,721.166	2,467.529	2,467.529
BH	76012030	Al	45,640.409	121,255.433	2,291.976	2,291.976
BH	76051100	Al	29,769.219	81,403.435	2,170.455	2,170.455
OM	72132000	Fe	8,749.780	4,643.234	2,011.815	2,011.815
AE	76011010	Al	39,974.311	108,128.797	2,007.435	2,007.435
AE	72279095	Fe	5,614.777	3,698.896	1,839.117	1,839.117
BH	76061292	Al	16,224.696	50,871.793	1,798.660	1,798.660
SA	73053100	Fe	7,810.007	4,576.703	1,783.288	1,783.288
SA	76011090	Al	48,728.023	120,045.292	1,763.619	1,763.619
BH	72031000	Fe	21,763.895	9,027.999	1,747.246	1,747.246
OM	28141000	Fert	13,227.979	6,832.679	1,664.096	1,664.096

Conditional 2026-rule calculation at EUR 75/tCO2e. Al: aluminium; Fe: iron and steel; Fert: fertilisers; Cem: cement. Source: retained Eurostat observations and paired regulatory factors.

APPENDIX F. Leading 2025 product exposures (2/5)

Table F2. Ranked country-product records 41 to 80 by lower-end conditional exposure. These 200 records account for 99.69% of the 2025 lower-end estimate. The companion dataset contains all 805 records. Values and costs are EUR thousand; mass is tonnes.

Origin	CN8	Sector	Tonnes	Value EUR k	Low EUR k	High EUR k
AE	73063077	Fe	6,952.502	5,484.772	1,617.174	1,617.174
OM	73063041	Fe	6,846.082	5,153.757	1,592.420	1,592.420
SA	72011090	Fe	7,250.000	2,870.343	1,439.986	1,439.986
AE	72163390	Fe	6,244.938	4,150.224	1,435.883	1,435.883

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Origin	CN8	Sector	Tonnes	Value EUR k	Low EUR k	High EUR k
AE	73061900	Fe	6,101.106	10,129.091	1,433.859	1,433.859
AE	76051100	Al	18,635.342	51,941.763	1,358.691	1,358.691
AE	73063041	Fe	5,777.432	4,838.958	1,343.849	1,343.849
AE	72172030	Fe	5,622.417	4,156.624	1,279.181	1,279.181
AE	28141000	Fert	9,950.156	4,885.739	1,251.742	1,251.742
SA	28141000	Fert	25,273.339	12,445.010	1,207.529	1,207.529
AE	73030010	Fe	4,995.586	4,923.531	1,168.255	1,168.255
AE	25239000	Cem	50,096.590	4,645.469	1,155.916	3,137.956
QA	76011090	Al	29,637.971	73,976.032	1,072.691	1,072.691
SA	76061211	Al	11,039.131	33,576.425	1,068.967	1,068.967
AE	73042300	Fe	4,665.350	5,399.822	1,060.437	1,060.437
SA	73063077	Fe	4,268.352	2,472.787	992.832	992.832
OM	76051100	Al	13,902.823	40,301.336	818.659	818.659
BH	76141000	Al	10,446.822	43,788.642	761.671	761.671
SA	76061292	Al	7,445.845	23,616.250	721.014	721.014
AE	73063072	Fe	3,011.792	2,599.059	700.552	700.552
BH	76011010	Al	13,820.156	37,215.153	694.022	694.022
OM	76061292	Al	7,078.472	18,053.171	685.439	685.439
SA	73089098	Fe	2,207.631	4,209.500	681.607	681.607
QA	76012080	Al	17,880.957	46,410.448	647.168	647.168
AE	73066192	Fe	2,734.191	2,227.764	635.981	635.981
OM	73066199	Fe	2,717.893	1,755.030	632.190	632.190
AE	73102990	Fe	2,578.373	11,475.224	618.244	618.244
QA	28141000	Fert	13,227.979	6,832.679	601.956	601.956
QA	76012040	Al	16,427.372	44,961.749	594.558	594.558
SA	76012040	Al	16,334.667	40,675.757	591.203	591.203
AE	72230019	Fe	1,773.284	4,226.331	546.299	546.299
BH	73084000	Fe	1,539.918	4,061.115	475.451	475.451
SA	76012080	Al	12,391.720	31,165.495	448.495	448.495
SA	72082600	Fe	1,826.870	1,057.869	427.234	427.234
OM	72024190	Fe	3,752.752	5,497.815	414.177	414.177
AE	73269098	Fe	1,602.170	8,274.762	373.992	373.992
AE	72193490	Fe	1,085.165	1,726.059	348.643	348.643
AE	25232900	Cem	13,528.409	1,230.856	345.634	345.634
AE	72149910	Fe	1,473.507	927.168	338.800	338.800
AE	72193310	Fe	1,041.115	2,391.745	334.491	334.491

Conditional 2026-rule calculation at EUR 75/tCO2e. Al: aluminium; Fe: iron and steel; Fert: fertilisers; Cem: cement. Source: retained Eurostat observations and paired regulatory factors.

APPENDIX F. Leading 2025 product exposures (3/5)

Table F3. Ranked country-product records 81 to 120 by lower-end conditional exposure. These 200 records account for 99.69% of the 2025 lower-end estimate. The companion dataset contains all 805 records. Values and costs are EUR thousand; mass is tonnes.

Origin	CN8	Sector	Tonnes	Value EUR k	Low EUR k	High EUR k
AE	72193410	Fe	935.981	2,264.309	300.713	300.713
AE	73181558	Fe	987.280	2,142.633	292.571	292.571
AE	73053100	Fe	1,242.500	1,288.966	283.705	283.705
BH	76149000	Al	3,728.139	16,099.062	271.816	271.816

Origin	CN8	Sector	Tonnes	Value EUR k	Low EUR k	High EUR k
BH	76061293	Al	2,352.225	7,777.000	260.766	260.766
OM	76071111	Al	2,933.490	7,711.740	259.608	259.608
AE	73101000	Fe	1,063.258	2,666.946	254.949	254.949
SA	76011010	Al	7,024.202	15,881.774	254.228	254.228
SA	31021090	Fert	5,670.020	2,613.519	252.791	252.791
AE	72199080	Fe	753.082	1,578.110	241.951	241.951
SA	73051100	Fe	994.017	545.399	226.968	226.968
AE	72123000	Fe	973.001	771.884	223.112	223.112
AE	73110030	Fe	609.378	1,202.542	209.943	209.943
AE	73063080	Fe	901.627	757.941	209.721	209.721
OM	73063072	Fe	900.816	710.593	209.533	209.533
BH	76061230	Al	1,889.401	5,817.754	209.458	209.458
AE	73066110	Fe	577.561	798.107	202.189	202.189
AE	73181499	Fe	880.780	2,025.108	200.045	200.045
OM	72024110	Fe	1,805.118	2,121.215	199.224	199.224
SA	72124080	Fe	858.635	1,015.337	196.888	196.888
AE	73072980	Fe	687.341	5,953.682	196.105	196.105
OM	72072052	Fe	847.480	470.619	194.859	194.859
AE	72172050	Fe	841.743	833.533	191.509	191.509
AE	76061299	Al	1,702.953	15,677.663	188.788	188.788
AE	73063049	Fe	808.144	571.464	187.977	187.977
SA	76061293	Al	1,919.654	6,121.081	185.888	185.888
SA	76051100	Al	2,992.204	8,259.513	178.663	178.663
BH	76031000	Al	3,144.010	9,981.829	167.336	167.336
OM	73066192	Fe	716.486	524.018	166.657	166.657
AE	76042910	Al	2,248.192	14,779.271	163.914	163.914
OM	76061293	Al	1,624.710	4,230.660	157.328	157.328
AE	72259900	Fe	466.488	475.850	156.861	156.861
QA	73089098	Fe	482.748	1,278.564	149.049	149.049
AE	72223097	Fe	467.542	1,032.855	144.578	144.578
AE	73042910	Fe	625.946	345.956	142.278	142.278
AE	73043982	Fe	606.239	368.753	137.799	137.799
AE	72222031	Fe	427.441	1,545.840	131.683	131.683
BH	76061250	Al	1,156.267	4,739.758	128.183	128.183
AE	73181595	Fe	419.159	2,807.140	124.214	124.214
AE	76069200	Al	1,004.918	6,888.253	111.405	111.405

Conditional 2026-rule calculation at EUR 75/tCO2e. Al: aluminium; Fe: iron and steel; Fert: fertilisers; Cem: cement. Source: retained Eurostat observations and paired regulatory factors.

APPENDIX F. Leading 2025 product exposures (4/5)

Table F4. Ranked country-product records 121 to 160 by lower-end conditional exposure. These 200 records account for 99.69% of the 2025 lower-end estimate. The companion dataset contains all 805 records. Values and costs are EUR thousand; mass is tonnes.

Origin	CN8	Sector	Tonnes	Value EUR k	Low EUR k	High EUR k
AE	73181542	Fe	372.365	528.680	110.347	110.347
AE	73110013	Fe	301.865	626.774	103.999	103.999
AE	72107010	Fe	446.878	603.810	102.471	102.471
AE	72193210	Fe	291.594	670.069	93.684	93.684

Origin	CN8	Sector	Tonnes	Value EUR k	Low EUR k	High EUR k
BH	73102990	Fe	385.318	1,584.287	92.392	92.392
AE	72193390	Fe	284.526	433.829	91.413	91.413
BH	76061299	Al	762.368	2,653.942	84.516	84.516
AE	76061293	Al	738.664	7,935.441	81.888	81.888
AE	73110091	Fe	228.448	586.415	78.705	78.705
AE	73030090	Fe	335.733	302.485	78.514	78.514
OM	76061250	Al	804.133	3,243.002	77.868	77.868
AE	72230099	Fe	249.138	540.429	76.752	76.752
QA	72172030	Fe	325.076	302.760	73.959	73.959
OM	73063049	Fe	314.445	194.021	73.141	73.141
AE	73090059	Fe	211.200	2,087.623	72.247	72.247
AE	73181290	Fe	312.499	452.110	70.976	70.976
OM	72139110	Fe	304.516	257.565	70.017	70.017
SA	76129080	Al	774.672	6,008.452	68.840	68.840
AE	73079100	Fe	287.853	768.223	67.590	67.590
AE	76129080	Al	652.614	5,125.372	67.147	67.147
AE	73090030	Fe	194.374	2,573.256	66.492	66.492
AE	76042990	Al	867.354	4,319.084	64.162	64.162
OM	72162100	Fe	265.407	207.789	61.024	61.024
BH	76052100	Al	826.342	2,597.083	60.248	60.248
OM	73043180	Fe	264.090	206.608	60.028	60.028
AE	72179020	Fe	257.769	281.318	58.646	58.646
OM	73063077	Fe	245.652	179.695	57.139	57.139
AE	76109090	Al	770.653	5,139.789	57.009	57.009
QA	73101000	Fe	236.056	538.793	56.602	56.602
AE	76101000	Al	725.608	1,630.637	53.676	53.676
OM	73090030	Fe	153.140	1,217.064	52.386	52.386
AE	72069000	Fe	239.138	171.317	51.460	51.460
AE	76061292	Al	460.328	3,834.377	51.032	51.032
AE	72106100	Fe	216.895	189.384	49.735	49.735
AE	73072100	Fe	163.116	910.141	46.539	46.539
OM	76071190	Al	492.726	1,508.221	43.605	43.605
AE	73049000	Fe	190.531	1,056.611	43.308	43.308
AE	73059000	Fe	179.451	278.423	40.975	40.975
SA	73269040	Fe	170.620	481.045	40.004	40.004
AE	73064080	Fe	113.524	379.778	39.730	39.730

Conditional 2026-rule calculation at EUR 75/tCO2e. Al: aluminium; Fe: iron and steel; Fert: fertilisers; Cem: cement. Source: retained Eurostat observations and paired regulatory factors.

APPENDIX F. Leading 2025 product exposures (5/5)

Table F5. Ranked country-product records 161 to 200 by lower-end conditional exposure. These 200 records account for 99.69% of the 2025 lower-end estimate. The companion dataset contains all 805 records. Values and costs are EUR thousand; mass is tonnes.

Origin	CN8	Sector	Tonnes	Value EUR k	Low EUR k	High EUR k
AE	73181548	Fe	133.286	747.323	39.498	39.498
AE	72124080	Fe	171.795	274.586	39.393	39.393
AE	73063018	Fe	154.271	107.329	36.600	36.600
AE	73181582	Fe	117.935	126.700	34.949	34.949

Origin	CN8	Sector	Tonnes	Value EUR k	Low EUR k	High EUR k
AE	76061230	Al	308.341	628.310	34.182	34.182
AE	72141000	Fe	158.042	132.181	34.019	34.019
OM	76071119	Al	378.775	1,063.889	33.521	33.521
AE	76041090	Al	407.369	1,674.669	30.135	30.135
AE	73181535	Fe	95.324	1,025.903	29.712	29.712
AE	73089059	Fe	93.955	234.223	29.009	29.009
SA	72224090	Fe	93.601	77.779	28.836	28.836
AE	73269040	Fe	122.406	411.713	28.700	28.700
BH	76042910	Al	387.819	1,434.629	28.276	28.276
AE	73045983	Fe	131.880	87.630	27.139	27.139
AE	73110019	Fe	76.983	176.470	26.522	26.522
SA	73084000	Fe	84.783	151.914	26.177	26.177
AE	72161000	Fe	112.190	259.327	25.796	25.796
AE	73041930	Fe	112.447	1,113.301	25.559	25.559
AE	76061250	Al	230.309	962.135	25.532	25.532
QA	76101000	Al	413.900	1,882.762	24.813	24.813
SA	73041910	Fe	104.630	84.263	23.782	23.782
OM	76061191	Al	245.559	663.516	23.779	23.779
AE	73181900	Fe	103.324	287.393	23.467	23.467
OM	72172030	Fe	102.772	75.198	23.382	23.382
AE	73064020	Fe	64.858	158.654	22.705	22.705
AE	73041910	Fe	97.418	1,013.641	22.143	22.143
OM	73045983	Fe	106.650	93.457	21.947	21.947
BH	76069200	Al	194.904	587.430	21.607	21.607
AE	73053900	Fe	93.294	130.488	21.302	21.302
AE	73181588	Fe	71.159	341.481	21.087	21.087
AE	73051200	Fe	89.954	118.445	20.540	20.540
OM	73102990	Fe	82.190	278.920	19.708	19.708
AE	73071990	Fe	90.412	393.837	19.461	19.461
AE	73079311	Fe	82.440	365.826	19.358	19.358
AE	73181491	Fe	84.313	188.299	19.149	19.149
AE	76042100	Al	255.528	1,167.527	18.903	18.903
SA	31021019	Fert	414.000	188.061	18.793	18.793
AE	72149995	Fe	80.800	57.996	18.578	18.578
OM	72165099	Fe	79.828	47.216	18.355	18.355
OM	76011010	Al	492.982	1,407.296	17.843	17.843

Conditional 2026-rule calculation at EUR 75/tCO2e. Al: aluminium; Fe: iron and steel; Fert: fertilisers; Cem: cement. Source: retained Eurostat observations and paired regulatory factors.

APPENDIX G. Factors for leading exposure cells (1/3)

Table G1. The 75 largest lower-end 2026-rule exposure cells. Intensities and benchmarks are tCO2e per tonne of product. A range indicates compatible alternatives; paired combinations remain in the electronic factor register.

Origin and CN8	Product description, abbreviated	Default e	Benchmark b	Assignment
AE 72104900	Flat-rolled products of iron or non-alloy steel, of a width of >= 600 mm, hot-rolled or cold...	4.101	1.491	Fallback

Origin and CN8	Product description, abbreviated	Default e	Benchmark b	Assignment
SA 72071210	Semi-finished products of iron or non-alloy steel, containing by weight < 0,25 of carbon, of...	3.996	1.364	Fallback
OM 31021019	Urea, whether or not in aqueous solution, containing >45% nitrogen in relation to the weight...	2.720	0.902	Fallback
SA 72083900	Flat-rolled products of iron or non-alloy steel, of a width of >= 600 mm, in coils, simply h...	4.049	1.370	Fallback
SA 72083800	Flat-rolled products of iron or non-alloy steel, of a width of >= 600 mm, in coils, simply h...	4.049	1.370	Fallback
SA 72083700	Flat-rolled products of iron or non-alloy steel, of a width of >= 600 mm, in coils, simply h...	4.049	1.370	Fallback
SA 25231000	Cement clinkers	1.370-1.410	0.666-0.859	Fallback
AE 73066199	Tubes and pipes and hollow profiles, welded, of square or rectangular cross-section, of iron...	4.141	1.491	Fallback
BH 76012040	Unwrought aluminium alloys in the form of billets	1.870	1.423	Country
AE 72107080	Flat-rolled products of iron or non-alloy steel, of a width of >= 600 mm, hot-rolled or cold...	4.101	1.491	Fallback
BH 76011090	Aluminium, not alloyed, unwrought (excl. slabs)	1.870	1.423	Country
AE 72142000	Bars and rods, of iron or non-alloy steel, with indentations, ribs, groves or other deformat...	3.996	1.364	Fallback
OM 72071912	Semi-finished products, of iron or non-alloy steel, containing by weight < 0,25% carbon, of ...	3.996	1.364	Fallback
AE 76012030	Unwrought aluminium alloys in the form of slabs	1.870	1.423	Country
AE 76012040	Unwrought aluminium alloys in the form of billets	1.870	1.423	Country
QA 72031000	Ferrous products obtained by direct reduction of iron ore, in lumps, pellets or similar forms	1.325	0.397	Fallback
BH 76012080	Unwrought aluminium alloys (excl. slabs and billets)	1.870	1.423	Country
AE 73089098	Structures and parts of structures of iron or steel, n.e.s. (excl. bridges and bridge-sectio...	5.064	1.491	Fallback
OM 72071116	Semi-finished products, of iron or non-alloy steel, containing by weight < 0,25% carbon, of ...	3.996	1.364	Fallback
OM 72142000	Bars and rods, of iron or non-alloy steel, with indentations, ribs, groves or other deformat...	3.996	1.364	Fallback
AE 76012080	Unwrought aluminium alloys (excl. slabs and billets)	1.870	1.423	Country
AE 76011090	Aluminium, not alloyed, unwrought (excl. slabs)	1.870	1.423	Country
AE 73084000	Equipment for scaffolding, shuttering, propping or pit-propping (excl. composite sheetpiling...	5.064	1.491	Fallback
OM 76011090	Aluminium, not alloyed, unwrought (excl. slabs)	1.700	1.423	Country

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Origin and CN8	Product description, abbreviated	Default e	Benchmark b	Assignment
SA 72107080	Flat-rolled products of iron or non-alloy steel, of a width of >= 600 mm, hot-rolled or cold...	4.101	1.491	Fallback

Column B benchmarks are used. The source workbook and legal annex contain full descriptions. A fallback assignment is a regulatory-table selection; it does not establish an actual plant route. Both endpoints are calculated from compatible factor/benchmark pairs.

APPENDIX G. Factors for leading exposure cells (2/3)

Table G2. The 75 largest lower-end 2026-rule exposure cells. Intensities and benchmarks are tCO2e per tonne of product. A range indicates compatible alternatives; paired combinations remain in the electronic factor register.

Origin and CN8	Product description, abbreviated	Default e	Benchmark b	Assignment
SA 72083600	Flat-rolled products of iron or non-alloy steel, of a width of >= 600 mm, in coils, simply h...	4.049	1.370	Fallback
AE 73011000	Sheet piling of iron or steel, whether or not drilled, punched or made from assembled elements	4.063	1.458	Fallback
SA 72104900	Flat-rolled products of iron or non-alloy steel, of a width of >= 600 mm, hot-rolled or cold...	4.101	1.491	Fallback
AE 73069000	Tubes, pipes and hollow profiles "e.g., open seam, riveted or similarly closed", of iron or ...	4.141	1.491	Fallback
AE 72139149	Bars and rods, hot-rolled, of iron or non-alloy steel, in irregularly wound coils, containin...	3.996	1.364	Fallback
BH 76012030	Unwrought aluminium alloys in the form of slabs	1.870	1.423	Country
BH 76051100	Wire of non-alloy aluminium, with a maximum cross-sectional dimension of > 7 mm (excl. stran...	2.200	1.485	Country
OM 72132000	Bars and rods, hot-rolled, in irregularly wound coils, of non-alloy free-cutting steel (excl...	3.996	1.364	Fallback
AE 76011010	Aluminium slabs, not alloyed, unwrought	1.870	1.423	Country
AE 72279095	Bars and rods, hot-rolled, in irregularly wound coils of alloy steel other than stainless (e...	5.400	1.613	Fallback
BH 76061292	Plates, sheets and strip, of aluminium alloys, of a thickness of > 0,2 mm but < 3 mm, square...	2.660	1.485	Country
SA 73053100	Tubes and pipes having circular cross-sections and an external diameter of > 406,4 mm, of ir...	4.060	1.458	Fallback
SA 76011090	Aluminium, not alloyed, unwrought (excl. slabs)	1.700	1.423	Country
BH 72031000	Ferrous products obtained by direct reduction of iron ore, in lumps, pellets or similar forms	1.325	0.397	Fallback
OM 28141000	Anhydrous ammonia	3.130	1.522	Fallback
AE 73063077	Other tubes, pipes and hollow profiles, welded, of circular cross-section, of iron or non-al...	4.141	1.491	Fallback
OM 73063041	Threaded or threadable tubes "gas pipe", welded, of circular cross-section, of iron or non-a...	4.141	1.491	Fallback

Origin and CN8	Product description, abbreviated	Default e	Benchmark b	Assignment
SA 72011090	Non-alloy pig iron in pigs, blocks or other primary forms, containing by weight <= 0,5% phos...	3.480	1.210	Fallback
AE 72163390	H sections of iron or non-alloy steel, simply hot-rolled, hot-drawn or extruded, of a height...	3.996	1.364	Fallback
AE 73061900	Line pipe of a kind used for oil or gas pipelines, welded, of flat-rolled products of iron o...	4.141	1.458	Fallback
AE 76051100	Wire of non-alloy aluminium, with a maximum cross-sectional dimension of > 7 mm (excl. stran...	2.200	1.485	Country
AE 73063041	Threaded or threadable tubes "gas pipe", welded, of circular cross-section, of iron or non-a...	4.141	1.491	Fallback
AE 72172030	Wire of iron or non-alloy steel, in coils, containing by weight < 0,25% carbon, plated or co...	3.996	1.397	Fallback
AE 28141000	Anhydrous ammonia	3.130	1.522	Fallback
SA 28141000	Anhydrous ammonia	2.100	1.522	Country

Column B benchmarks are used. The source workbook and legal annex contain full descriptions. A fallback assignment is a regulatory-table selection; it does not establish an actual plant route. Both endpoints are calculated from compatible factor/benchmark pairs.

APPENDIX G. Factors for leading exposure cells (3/3)

Table G3. The 75 largest lower-end 2026-rule exposure cells. Intensities and benchmarks are tCO2e per tonne of product. A range indicates compatible alternatives; paired combinations remain in the electronic factor register.

Origin and CN8	Product description, abbreviated	Default e	Benchmark b	Assignment
AE 73030010	Tubes and pipes of a kind used in pressure systems, of cast iron	4.150	1.484	Fallback
AE 25239000	Cement, whether or not coloured (excl. portland cement and aluminous cement)	0.870-1.510	0.666-0.847	Country
QA 76011090	Aluminium, not alloyed, unwrought (excl. slabs)	1.700	1.423	Country
SA 76061211	Beverage can body stock, of aluminium alloys, of a thickness of > 0,2 mm	2.490	1.485	Country
AE 73042300	Drill pipe, seamless, of a kind used in drilling for oil or gas, of iron or steel (excl. pro...	3.981	1.383	Fallback
SA 73063077	Other tubes, pipes and hollow profiles, welded, of circular cross-section, of iron or non-al...	4.141	1.491	Fallback
OM 76051100	Wire of non-alloy aluminium, with a maximum cross-sectional dimension of > 7 mm (excl. stran...	2.030	1.485	Country
BH 76141000	Stranded wire, cables, plaited bands and the like, of aluminium, with steel core (excl. such...	2.200	1.485	Country
SA 76061292	Plates, sheets and strip, of aluminium alloys, of a thickness of > 0,2 mm but < 3 mm, square...	2.490	1.485	Country
AE 73063072	Other tubes, pipes and hollow profiles, welded, of circular cross-section, of iron or non-al...	4.141	1.491	Fallback

Origin and CN8	Product description, abbreviated	Default e	Benchmark b	Assignment
BH 76011010	Aluminium slabs, not alloyed, unwrought	1.870	1.423	Country
OM 76061292	Plates, sheets and strip, of aluminium alloys, of a thickness of > 0,2 mm but < 3 mm, square...	2.490	1.485	Country
SA 73089098	Structures and parts of structures of iron or steel, n.e.s. (excl. bridges and bridge-sectio...	5.064	1.491	Fallback
QA 76012080	Unwrought aluminium alloys (excl. slabs and billets)	1.700	1.423	Country
AE 73066192	Tubes and pipes and hollow profiles, welded, of square or rectangular cross-section, of iron...	4.141	1.491	Fallback
OM 73066199	Tubes and pipes and hollow profiles, welded, of square or rectangular cross-section, of iron...	4.141	1.491	Fallback
AE 73102990	Tanks, casks, drums, cans, boxes and similar containers, of iron or steel, for any material,...	4.228	1.491	Fallback
QA 28141000	Anhydrous ammonia	2.070	1.522	Country
QA 76012040	Unwrought aluminium alloys in the form of billets	1.700	1.423	Country
SA 76012040	Unwrought aluminium alloys in the form of billets	1.700	1.423	Country
AE 72230019	Wire of stainless steel, in coils, containing by weight >= 2,5% nickel (excl. such products ...	4.820	1.225	Fallback
BH 73084000	Equipment for scaffolding, shuttering, propping or pit-propping (excl. composite sheetpiling...	5.064	1.491	Fallback
SA 76012080	Unwrought aluminium alloys (excl. slabs and billets)	1.700	1.423	Country
SA 72082600	Flat-rolled products of iron or non-alloy steel, of a width of >= 600 mm, in coils, simply h...	4.049	1.370	Fallback
OM 72024190	Ferro-chromium, containing by weight > 6% carbon(2004-2500);Ferro-chromium, containing by we...	2.350	1.142	Country

Column B benchmarks are used. The source workbook and legal annex contain full descriptions. A fallback assignment is a regulatory-table selection; it does not establish an actual plant route. Both endpoints are calculated from compatible factor/benchmark pairs.

APPENDIX H. Worked calculations and independent checks

Table H1. Each line is a compatible parameter alternative. Formula: tonnes × 75 × max[(1 + mark-up) × e - 0.975 × b, 0]. Mark-up is 1% for fertilisers and 10% otherwise. Multiple clinker rows define endpoints.

Origin and CN8	Tonnes	e	b	Net intensity	Cost EUR m
BH 76012040	158,794.446	1.870	1.423	0.669575	7.974359
AE 72104900	173,646.815	4.101	1.491	3.057375	39.817757
OM 31021019	162,990.121	2.720	0.902	1.867750	22.831860
SA 25231000	205,765.785	1.370	0.859	0.669475	10.331629
SA 25231000	205,765.785	1.410	0.666	0.901650	13.914654

Table H2 compares selected annual observations with independently aggregated monthly observations from the same official data source. This is an internal-source consistency check, not an independent measurement of the original transactions.

Origin	CN8	Annual EUR m	Monthly EUR m	Annual kt	Monthly kt
BH	76012040	413.355949	413.355949	158.794446	158.794446

Origin	CN8	Annual EUR m	Monthly EUR m	Annual kt	Monthly kt
AE	72104900	124.531552	124.531551	173.646815	173.646815
SA	25231000	10.221468	10.221468	205.765785	205.765785
OM	31021019	62.149596	62.149596	162.990121	162.990121
QA	76011090	73.976032	73.976032	29.637971	29.637971
KW	76169990	0.005158	0.005158	0.000009	0.000009

APPENDIX I. Scenario and reduced-sample comparisons

Table I1. Conditional costs for the 2025 basket, EUR million. Intensity reductions are hypothetical parameter changes. They are not measured abatement or the statutory result of switching to actual emissions.

Scenario	Low	High	Retained assumptions
Price EUR 50	215.351	219.061	All other parameters fixed
Price EUR 75	323.027	328.592	All other parameters fixed
Price EUR 100	430.703	438.123	All other parameters fixed
Price EUR 125	538.379	547.654	All other parameters fixed
Intensity -0%	323.027	328.592	Price 75; benchmarks and mark-ups fixed
Intensity -10%	263.990	269.223	Price 75; benchmarks and mark-ups fixed
Intensity -20%	204.953	209.853	Price 75; benchmarks and mark-ups fixed
Intensity -30%	147.357	151.925	Price 75; benchmarks and mark-ups fixed

Reduced-sample checks below change which observations are retained. The country-specific-only variant removes fallback observations; its difference from the baseline is not an estimate of verification savings.

Variant	Year	Value EUR m	Low EUR m	High EUR m	Records
All core	2019	1983.379	112.136	114.934	712
All core	2020	1594.680	102.329	125.813	644
All core	2021	2811.874	228.661	243.840	705
All core	2022	5392.379	254.328	316.605	777
All core	2023	4314.082	246.002	270.618	859
All core	2024	3833.183	198.407	201.041	793
All core	2025	4480.120	323.027	328.592	805
Current benchmark codes only	2019	731.555	78.823	80.312	669
Current benchmark codes only	2020	511.459	62.084	64.786	600
Current benchmark codes only	2021	1042.156	184.551	188.072	663
Current benchmark codes only	2022	1979.442	180.726	183.573	763
Current benchmark codes only	2023	4200.008	235.523	238.692	854
Current benchmark codes only	2024	3831.690	198.301	200.715	790

Variant	Year	Value EUR m	Low EUR m	High EUR m	Records
Current benchmark codes only	2025	4480.120	323.027	328.592	805
Country-specific defaults only	2019	1783.292	47.501	47.690	156
Country-specific defaults only	2020	1408.860	41.721	41.889	151
Country-specific defaults only	2021	2257.377	53.265	53.610	163
Country-specific defaults only	2022	4309.086	75.318	77.463	188
Country-specific defaults only	2023	3542.924	81.761	83.732	205
Country-specific defaults only	2024	3287.471	69.517	70.488	198
Country-specific defaults only	2025	3629.375	72.528	74.510	201
Unambiguous matches only	2019	1974.390	106.910	106.910	694
Unambiguous matches only	2020	1545.276	84.371	84.371	627
Unambiguous matches only	2021	2767.261	212.726	212.726	692
Unambiguous matches only	2022	4960.250	223.237	223.237	766
Unambiguous matches only	2023	4190.579	228.290	228.290	850
Unambiguous matches only	2024	3824.307	193.403	193.403	783
Unambiguous matches only	2025	4465.253	311.540	311.540	802

APPENDIX J. Quantity and composition decomposition

Table J1. Change in the lower-end unmarked gross diagnostic between the 2019 and 2025 baskets, EUR million, at the same EUR 75 price. The decomposition uses sector tonnes and the mass-weighted default intensity.

Sector	Quantity effect	Composition effect	Total change
Cement	15.6668	-1.8875	13.7793
Fertilisers	27.1169	17.1503	44.2673
Iron and steel	210.2257	-4.3352	205.8905
Aluminium	54.4287	2.0649	56.4936

Identity: Delta(PQe) = P(Q1-Q0)(e1+e0)/2 + P(e1-e0)(Q1+Q0)/2. The two components sum to the total change before rounding. The composition term includes product/origin mix and classification effects under fixed regulatory defaults. It is not a measured technology effect. Figure 11 provides the recorded sector-value context.

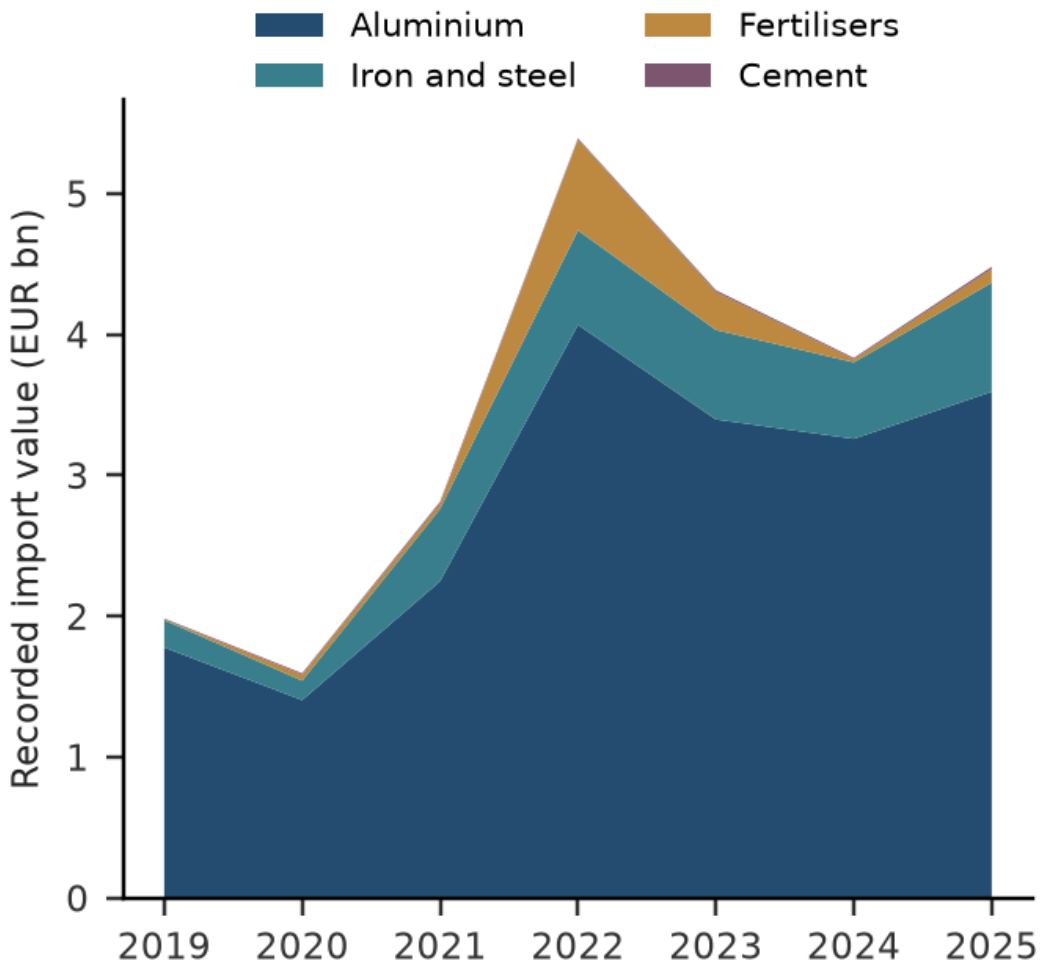


Fig. 11. Recorded import value by covered sector from 2019 to 2025 in current EUR billion. Source: Eurostat DS-045409.

APPENDIX K. Source provenance and reproducibility

Table K1. SHA-256 fingerprints of principal retained sources. The companion archive includes the complete source manifest, all 42 trade snapshots, parameter workbooks, the cleaned panel and analysis scripts. Retrieval date: 26 September 2026.

Source file	Bytes	SHA-256
benchmark_law.html	1,214,211	e0daae6477f96cd7e2662dc479719397bed9759a644e9ad6d7ab8033d18c9cf3

Source file	Bytes	SHA-256
benchmarks.xlsx	95,624	b79108b025e697822f0f59de477fa68066c1c05c228fae2270cd230af84e8a7b
cscf_law.html	276,928	eb1ad5d5b54f8112cfbd48c4c97f9a5af87b2d0297cf7fab02d1d074f691bc3d
defaults.xlsx	642,541	900583811c7e1194799eb9bdbad2d6d7e1100f5a7d80a664c1584a8fce6f9f35
defaults_law.html	16,665,012	d97a169e4105bcb14d47b4d4b108efd82652f637df63e66610b4fc7bfe1f769a
free_allocation_guidance.pdf	1,021,425	6854641617e77c18f7c752283e56871b180cb8790806cfde9cbd6ef6f62f8698
imf2025.pdf	835,769	9dc3b296e9c9957998722f80b7c65d357e073d6b02f94686ce99f535abc533bb
oecd2025.pdf	3,491,281	d00e0028a6151754b7c58240cf02d85d5e7ba9daba03fc0e10f4d62259ecb3b3
regulation.html	754,838	35d15035d2bda12dfc8aa3f76aab20769e4d0b749bdb69a3db51df73f4257294
wb2025.pdf	2,064,336	3c7615db0009808b213e21d1f872d852554822c71294711dd0d7125a84b01625

Trade query specification: dataset DS-045409; freq=A; reporter=EU27_2020; flow=1; partner in AE, BH, KW, OM, QA, SA; time=2019 through 2025; indicators VALUE_IN_EUROS and QUANTITY_IN_100KG. Raw responses retain the product labels, dimension indices, values and source update timestamp. Query URLs are saved alongside snapshots.

Reproduction order: analyse.py; validate_data.py; make_assets.py; sensitivity.py. The analysis uses Python with pandas, NumPy, openpyxl, requests, matplotlib and pypdf. Local source snapshots permit the core analysis to run without new data retrieval. Fetch scripts are supplied separately for an explicit refresh. Font paths and output-directory settings may need adaptation on another system.

Validation checks cover unique keys, country/year coverage, complete benchmark matching, endpoint ordering, four product-hierarchy reconciliations per country-year and six monthly checks. Reproduction is conditional on the retained snapshot; a later download can legitimately revise results.