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What Do European CBAMs Leave Unpriced? Value-Chain Coverage Gaps in Global and Chinese Imports

Hanzhe Xing and Michael G. Pollitt

Energy Policy
Research Group

Abstract :

European carbon border adjustment mechanisms (CBAMs) leave most of the quantified emissions embodied in imports outside their present boundaries. Applying EU and UK statutory schedules to fixed 2025 trade, we estimate coverage of 31.0% and 26.9% of the respective Global product accounts, with still lower shares for imports from China. Adding electricity within goods already listed closes only a minority of the gap. The larger additions come from wider product coverage. In an illustrative passenger car, covered materials and production electricity account for 49.8% of quantified production emissions, although the finished vehicle falls outside the current schedules. Across trade, vehicles, machinery and photovoltaic products are major downstream carriers, while chemicals, petroleum products and textiles dominate the residual. These findings identify two distinct policy tasks. Effective origin carbon prices can pass through domestic materials and electricity into downstream exports, creating a basis for selective climate-club recognition. Residual industries outside carbon pricing require broader emissions trading system coverage. We suggest that EU and UK authorities should signal a longer-term direction for possible CBAM expansion across products and sectors, alongside principles for recognizing carbon costs paid in origin countries. This would not commit either authority to immediate expansion. But it could encourage stronger and broader carbon pricing in origin countries while the technical requirements for any future expansion are still being developed.

Keywords : Carbon border adjustment mechanism, EU ETS, CN ETS, UK ETS

JEL Classification : Q51

What Do European CBAMs Leave Unpriced? Value-Chain Coverage Gaps in Global and Chinese Imports

Hanzhe Xing and Michael G. Pollitt¹

Energy Policy Research Group, Judge Business School, University of Cambridge, Cambridge, UK

Correspondence hx279@cam.ac.uk

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1 Introduction

European Carbon Border Adjustment Mechanisms (CBAMs) price selected imported goods (namely cement, iron and steel, aluminium, fertilisers, hydrogen and electricity), but much of the production represented in European imports enters through products outside the current schedules of covered imports. Thus, steel and aluminium imports face a border charge as basic materials and escape that charge when incorporated abroad into an unlisted finished good. Similarly, embodied electricity can also fall outside the emissions boundary even when direct imports of electricity are subject to CBAM (European Parliament and Council of the European Union, 2023a, HM Revenue & Customs, 2025). These gaps raise three distinct questions about broader CBAM coverage: 1) how much is added by including electricity-related emissions in goods already covered, 2) how much more is captured by tracing covered materials and production electricity into additional traded products, 3) and how much remains in products and industries outside those two extensions. We quantify each component and examine what its industrial composition implies for strengthening carbon prices and extending sectoral coverage in exporting countries.

The effects of border adjustments on leakage and competitiveness depend on CBAM design and production and trade responses (Fischer and Fox, 2012, Branger and Quirion, 2014), while legal and practical constraints limit what can be implemented (Böhringer et al., 2022). Exposure varies across trading partners and sectors (Magacho et al., 2024). Within China, projected burdens differ across provinces (Ren et al., 2025), while steel-export costs depend on production routes and carbon prices (Lu et al., 2026). A wider product boundary needs a practicable method for attributing emissions to traded goods (Cosbey et al., 2019, Mehling and Ritz, 2023) and criteria for selecting downstream products to be included (Montrone et al., 2025). CBAM can also encourage carbon pricing among European trading

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partners ([Mehling et al., 2024](#)). Our account separates the emissions added through wider product scope from those added within existing goods. Locating each addition by industry identifies where expansion can build on the pricing of existing inputs and where it requires broader origin-country sector coverage.

CBAM coverage depends not only on the material being traded, but also on whether it is imported as a listed material or incorporated into an unlisted finished product. Our steel and aluminium calculations establish the price adjustment on listed materials. Consideration of a typical passenger car then reveals both how much of its production could be reached through CBAM listed materials and electricity, and how much would still require coverage of other industries. Fixed-trade accounts for 2025 place these channels within observed EU and UK imports. Global imports provide the primary account for each destination, with China examined as a nested origin subset. China is particularly informative because it exports many downstream manufactured products and already operates an emissions trading system (ETS) in important upstream sectors. Its export structure and carbon market together expose the scope for domestic input prices to carry a carbon cost into goods that currently receive no border charge.

Current statutory coverage of the EU and UK CBAMs reaches only 31.0% of the EU Global imported emissions and 26.9% of the UK Global imported emissions. These shares fall to 17.6% and 14.1% for China imports. Widening CBAM product scope could significantly raise these percentages. For downstream goods, an effective origin price on domestic materials and electricity can travel through input costs, providing a basis for recognition through a selective climate-club arrangement, reducing the need for product scope extension. For residual industries outside an effective carbon price, the task is to extend CBAM and origin-country ETS coverage. These responses don't need to wait for a comprehensive CBAM on all imports. We argue that a credible CBAM expansion roadmap can place future export treatment on the policy agenda so that governments and firms develop the necessary product information. Announcing which products and sectors will be addressed, and how origin costs will be recognised, gives CBAM expansion an influence before the corresponding border calculations become operational.

The paper proceeds as follows. Section 2 looks at the material impact of both UK and EU CBAMs, with a special focus on steel and aluminum and its impact on Chinese imports. Section 3 considers the extension of UK and EU CBAMs to complex products, specifically cars and batteries. Section 4 reports on our calculations of what percentage of UK and EU imported emissions are covered by their CBAMs and the materiality of the impact of possible extensions in CBAM coverage. Section 5 offers a conclusion.

2 CBAM and material prices

2.1 Payment and production incentives

A CBAM payment depends first on the classification of the imported good. Only goods within the destination schedule require an emissions and price calculation, whose payments align with the domestic manufacturer's costs and involve deducting carbon costs paid in the country of origin. Table 1 compares the EU and UK mechanisms. We apply the EU definitive schedule operating from 2026 and the legislated UK schedule due to begin on 1 January 2027 to the same observed trade in 2025. Throughout the paper, current statutory coverage refers to those schedules and emissions boundaries.

Table 1. EU and UK CBAM payment mechanisms

Step	EU	UK
Product and timing	Specified Annex I goods, definitive regime from 2026	Specified goods, commencement scheduled for 2027
Emissions base	Product-specific direct and indirect emissions rules	Direct emissions at commencement
Destination price	CBAM certificate price linked to EU ETS auctions, with the applicable allocation adjustment	Sectoral CBAM rate incorporating the UK allocation adjustment
Origin carbon price	Reduction under the applicable Article 9 route	Carbon Price Relief under UK calculation rules
Settlement	Included emissions and destination price, adjusted for qualifying origin carbon costs	Included emissions and sectoral rate, adjusted for qualifying relief

Some CBAM covered sectors currently receive a free allocation of carbon permits on home production, which must be adjusted for in calculating the CBAM applied to imports. This enters the EU and UK calculations differently. The EU deducts a benchmark-based allowance quantity from the required CBAM certificates, incorporating the free allocation proportion. ([European Commission, 2025](#)). The UK treats CBAM as a tax and reduces the headline carbon rate by a sectoral free-allocation percentage and applies that adjusted rate to imported emissions ([HM Treasury and HM Revenue & Customs, 2026](#), [HM Revenue & Customs, 2026b](#)). Both systems also recognise qualifying carbon costs paid at origin under their respective rules ([European Parliament and Council of the European Union, 2023a](#), [HM Revenue & Customs, 2026c](#)). Free allocation in the country of origin can reduce the carbon cost actually paid in the exporting country (HM Revenue & Customs, 2026c), leaving less to deduct from CBAM. The border charge therefore depends on the destination's charge after its own free-allocation adjustment, minus the eligible carbon cost paid at origin.

The design mechanism of CBAM aims to deduct the same amount from domestic and imported products, which leaves the difference in their carbon costs unchanged, if neither cost falls to zero. This incentive changes when the import payment reaches zero, as the carbon cost cannot fall below zero after the deduction ([European](#)

[Commission, 2025](#)). Further abatement cannot generate a negative CBAM payment. A domestic manufacturer in ETS with unchanged free allocation, by contrast, can retain or sell allowances released by further reductions in emissions. Cleaner production can therefore continue to earn an ETS reward after the border reward has stopped. The UK sectoral-rate discount also affects only the positive CBAM payment. Another factor weakening the abatement incentive is the employment of default values. In either system, using verified actual emissions rewards abatement while a fixed default cannot reflect manufacturer's improvement in emission performance. ([Mehling and Ritz, 2023](#)).

For products listed in CBAM, exemptions of scope 2 emissions lead to worries in exempting unfair amount of importers' emissions because of a significant difference in aluminum production between EU/UK domestic manufacturers and importers. Primary production (most importers' route) uses the Hall–Héroult process, in which alumina is reduced electrolytically to molten aluminum. Secondary production (most UK/EU domestic route) recycles and remelts existing aluminum scrap, thereby avoiding the highly energy-intensive electrolytic reduction stage and requiring only around 5% (International Aluminum Institute, 2019) of the energy used for primary production. (Zore, 2024) Yet the EU CBAM excludes indirect emissions for listed aluminum and steel ([European Parliament and Council of the European Union, 2023a](#)), and the UK CBAM excludes them across all of its covered goods ([HM Revenue & Customs, 2025](#)) because of subsidy on domestic manufacturer's energy bill. This means that the electricity emissions associated with imported aluminium is ignored by both the EU and UK CBAM.

These observations on aluminum suggest lessons on how to coordinate subsidy on electricity bill with CBAM. Extending CBAM to electricity-related emissions should take account of electricity bill compensation paid to domestic producers. If domestic firms are reimbursed for part of the carbon cost in their electricity bills, charging imports for these costs in full would impose unequal costs, but exempting all of carbon cost from electricity is also unfair and environmentally inefficient. Any extension should therefore align the import charge with the electricity-related carbon cost that domestic producers actually bear, whether in the form of a deduction in CBAM or by cancelling the current subsidy on domestic producer's energy bill.

2.2 Steel and aluminum

To further illustrate how CBAM works on products from importers with their own ETS and to work out if the current CBAMs change the product competitiveness, Table 2 gives how allocation and origin-price recognition alter the initial price advantage of China-origin steel and aluminium. The assumed direct intensity of steel is 2.10 t CO_{2e} per tonne for imports and 1.40 for domestic production. Aluminium has an assumed intensity of 1.50t CO_{2e} per tonne in both cases. We apply a UK headline price of £40 per t CO_{2e}, and an EU price of €65. The calculations follow each material from adding freight and other landing costs to the ex-works price to its post-

CBAM landed price. For the EU illustration, we convert the assumed UK product prices and delivery costs into euros at £1 = €1.15, rather than using separate EU market prices.

Table 2. Illustrative Chinese steel and aluminium (per tonne) competitiveness under EU and UK CBAM calculations

Input or result	UK steel £	UK aluminium £	EU steel €	EU aluminium €
(1)Direct intensity, domestic / import (t CO ₂ e per tonne)	1.40 / 2.10	1.50 / 1.50	1.40 / 2.10	1.50 / 1.50
(2)Carbon price (per t CO ₂ e)	40.00	40.00	65.00	65.00
(3)Free-allocation	72.2% of rate	68.89% of rate	0.705550 t CO ₂ e	0.732845 t CO ₂ e
(4)Gross import carbon cost (1)*(2)	84.00	60.00	136.50	97.50
(5)Free-allocation adjustment UK: (3)*(4); EU: (3)*(2)	60.70	41.33	45.86	47.63
(6)Cost after allocation adjustment (4)-(5)	23.30	18.67	90.64	49.87
(7)Origin carbon cost (see Notes below)	1.00	0.00	1.15	0.00
(8)Net border charge (6)-(7)	22.30	18.67	89.49	49.87
(9)China-origin ex-works price	440.0 0	1,900.00	506.00	2,185.00
(10)Freight and other landing costs	50.00	85.00	57.50	97.75
(11)Landed price before CBAM (9)+(10)	490.0 0	1,985.00	563.50	2,282.75
(12)Domestic reference price	580.0 0	2,150.00	667.00	2,472.50
(13)Landed price after CBAM (11)+(8)	512.3 0	2,003.67	652.99	2,332.62
(14)Pre-CBAM landed-price advantage (12)-(11)	90.00	165.00	103.50	189.75
(15)Post-CBAM landed-price advantage (12)-(13)	67.70	146.33	14.01	139.88

Notes The EU free-allocation assumptions for 2030 are based on the published CBAM benchmarks for BF/BOF steel and primary aluminium and the 2030 CBAM factor (European Commission, 2025; European Parliament and Council of the European Union, 2023c). The UK assumptions are informed by published sectoral free allocation and emissions data for 2021–2023, adjusted using the UK’s 2030 reduction factor (Department for Energy Security and Net Zero, 2025, 2026).

The current CBAM does not eliminate the cost advantage of Chinese importers. The UK steel importers’ payment of £22.30 absorbs almost a quarter of the initial £90 landed-price advantage, and aluminum retains negligible CBAM charges compared to price advantages. The EU scenario produces charges of €89.49 for steel and €49.87 for aluminum, taking a much larger share of the steel price advantage. The difference comes from emissions intensity, allocation and the carbon price. For aluminium, the failure of aligning with the free allocation in scope 2 emissions lead to failure of deducting original carbon cost, and the high free allocation share in EU and UK now makes the CBAM payments low. In both industries, a qualifying origin cost reduces the amount collected at the border but does incentivize the imposition of a higher carbon price and lower free allocation rate in China’s national ETS. The exporting country (China) consequently has a fiscal reason to price covered production itself, since part of the payment otherwise collected abroad can be retained at origin.

More worries about CBAM's leakage lie in downstream products of CBAM listed materials. A short chemical supply chain shows how quickly the product boundary can interrupt this treatment. Hydrogen is an input to ammonia and methanol. Hydrogen and ammonia appear on CBAM, whereas methanol is outside the lists. The EU includes indirect emissions for ammonia, while the UK launch covers direct emissions only ([European Parliament and Council of the European Union, 2023a](#), [HM Revenue & Customs, 2025, 2026b](#)). If hydrogen is incorporated into methanol abroad, importing the finished methanol does not bring that input under the same charge merely because hydrogen is listed. Worse still, methanol produced from coal is not identified under CBAM, giving less incentive to ex-European methanol producers to abate their production.

3 Embodied emissions in passenger cars

3.1 Materials and production electricity

The current CBAM product boundary excludes the carbon cost embodied in a tonne of imported steel incorporated into an imported car. The listed-steel calculation does not automatically follow the material into an unlisted finished product though its carbon costs paid in origin ETS is included in its final price. A downstream extension would have to recover the relevant material quantities and production emissions within that new product boundary. Cars make the scale of this task visible because they combine substantial metal inputs with electricity, batteries and components from industries beyond the initial CBAM list.

Our illustrative passenger-car account follows steel, cast iron and aluminium into the finished vehicle and separately identifies electricity used in material, battery and vehicle production. Generic vehicle inputs and life-cycle boundaries provide the basis for this comparison ([Japan Automobile Manufacturers Association, 2024](#), [Jungmeier et al., 2024](#), [Tang et al., 2022](#)). Battery-material production is also included ([Engels et al., 2022](#), [Peng et al., 2026](#)), alongside electronics and other components, so that the account retains the emissions left outside the covered-material and electricity channels.

Our generic electric car contains 588.90 kg of steel, 71.01 kg of cast iron and 290.20 kg of aluminium, with total quantified production emissions of 14.05 t CO_{2e}. Table 3 assigns this account to three layers. Layer 1 covers the current listed-product boundary, including any extension to electricity within those same goods. Layer 2 follows covered materials and production electricity into downstream goods outside Layer 1. Layer 3 contains the quantified remainder. The battery remainder is reported separately within that residual because battery-specific environmental requirements already apply to this component. Table B1 retains the full input quantities and the separation of material electricity from other material emissions.

Table 3. Material quantities and emissions in the passenger car

Component or account	Relevant quantity	Emissions t CO ₂ e per car	Allocation
(1)Finished car under the current product schedule	One car	0.000	Layer 1
(2)Steel	588.90 kg	1.228	Layer 2 material
(3)Cast iron	71.01 kg	0.053	Layer 2 material
(4)Aluminium	290.20 kg	1.899	Layer 2 material
(5)Identified production electricity	Materials, battery and vehicle manufacture	3.812	Layer 2 electricity
(6)Layer 2 subtotal (2)+(3)+(4)+(5)	49.8% of the car account	6.992	Layer 2
(7)Battery residual	Remaining battery emissions	1.92	Layer 3
(8)Other residual	Other supported car emissions	5.140	Layer 3
(9)Layer 3 subtotal	50.2% of the car account	7.061	Layer 3
(10)Total (6)+(9)	100% of the quantified car account	14.052	Layers 1 to 3

The embodied emissions of the example passenger car falls outside both statutory product schedules, so its Layer 1 contribution is zero ([European Parliament and Council of the European Union, 2023a](#), [HM Revenue & Customs, 2025](#)). Steel and aluminium now enter the destination inside a vehicle, where the current border treatment no longer applies the standalone material charge illustrated in Table 2. Among all its embodied emissions of 14.05 t CO₂e., covered materials contribute 3.18 t CO₂e from steel, cast iron and aluminium after their electricity emissions have been separated (2)+(3)+(4). Production electricity adds 3.812 t CO₂e across the supply chain, including metal production, the battery and vehicle manufacture. Together they bring Layer 2 to 6.99 t CO₂e, or 49.8% of the car account.

At the illustrative rate of £40 per t CO₂e used in Table 2, the carbon cost of this example vehicle is £562.0 and the 3.18 t CO₂e from CBAM listed material contribution corresponds to a gross carbon cost of £127.2 per vehicle. The finished car faces no CBAM charge under the scope examined here, and its embodied emissions receives no CBAM liability because of three reasons: 1) The boundary of complex products, 2) The exemption of scope 2 emissions in materials, though electricity is also a CBAM listed products, 3) The materials not included in CBAM and their products.

The non-CBAM materials account for 7.06 t CO₂e, or 50.2% of the car. It comprises a battery residual of 1.92 t CO₂e and 5.14 t CO₂e from other materials and production activities. Extending the treatment of steel, aluminium and electricity into complex products won't cover these emissions. Further progress requires the relevant producing industries to enter carbon pricing. The embodied emissions in complex products thus expose two different tasks within a single product, following covered inputs downstream and pricing the remaining production.

A vehicle can carry an original carbon cost to price embodied emissions of its materials including its original ETS. When its assembler buys domestic steel, aluminium and electricity subject to effective carbon pricing, the carbon pricing passes into the exported car. The downstream assembly sector doesn't need to have a separate allowance obligation. A climate-club agreement could allow carbon costs (if effective) paid on materials to be credited without extending CBAM to complex products and save the efforts of building Bill of Materials (BOM) and Lifecycle Assessment (LCA) for complex products. But this would not address embodied emissions in non-CBAM materials that remain outside carbon pricing. However it is the case that European produced cars do not fully embody carbon pricing depending on both the extent of European carbon pricing and the imported components that go into European assembled cars. Battery standards and product passports could help by setting environmental requirements and providing emissions information for those activities.

3.2 Batteries and product information

The battery already faces environmental regulations beyond the vehicle's current CBAM treatment. The EU Batteries Regulation provides carbon-footprint declarations and performance classes. It also provides for an electronic passport for electric-vehicle batteries from 18 February 2027 ([European Parliament and Council of the European Union, 2023b](#)). The battery's 1.92 t CO_{2e} residual therefore sits within a separate environmental regime. CBAM can work with the EU Batteries Regulation to effectively price these embodied emissions by determining the carbon cost when footprint information and performance requirements address that component's production. Coordinating these functions would connect the information collected for environmental regulation with the emissions and origin costs needed for wider pricing.

The difficulty of using the EU Battery Regulation lies in how to follow the configuration actually produced. A manufacturer can retain a vehicle model name while changing its steel supplier, battery chemistry and assembly location altering embodied emissions, the country in which production occurs, and the carbon cost already paid. A static bill of materials may then fail to describe the vehicle being exported. Digital product records should link material quantities, supplier identities, production countries and carbon intensities to the relevant configuration and trace that link when production changes. This is the practical information problem behind downstream attribution. The passport must keep a product's changing physical composition connected to the carbon pricing requirements.

The EU Ecodesign for Sustainable Products Regulation establishes a framework for product-specific passport requirements through delegated measures ([European Parliament and Council of the European Union, 2024](#)). EU battery rules also apply in Northern Ireland, whereas Great Britain's wider digital-product-record policy was at the call-for-evidence stage in July 2026 ([Office for Product Safety and Standards,](#)

2026, [Department for Business and Trade, 2026](#)). The lessons from earlier installed mechanisms may bring insights into its design. Different policies serve different purposes but can draw on the same supply-chain records. Information collected for battery and product rules could also help calculate carbon pricing, which could reduce repeated data collection. Table 4 summarizes the role of each policy and their roles in more efficient carbon pricing.

Table 4. Policy schemes and their roles in more efficient carbon pricing

Policy	Summary	Contributions to more efficient carbon pricing
Origin ETS	Carbon pricing in covered domestic sectors	Prices carbon on covered domestic inputs, but fails to price imported emissions
CBAM	Add carbon cost on importers to align with domestic manufacturers	Adds costs to imported emissions, but hard to trace the precise embodied emissions in complex products
Climate club	Align carbon pricing schemes among different economies to reduce fraction	Encourages carbon pricing in the exporting economies
Battery law	Sets component-specific information and environmental requirements on key products	Regulates emissions from products made with non-CBAM materials
Digital product records	Track composition, origin and production changes	Supports bill of materials (BOM) attribution, verification and consistent accounting

An effective carbon pricing mechanism calls for good coordination among different schemes to cover embodied emissions from different sources into a consistent policy scheme. To visualize where the EU imported emissions come from and how effective CBAM prices them, we use observed trade to identify the scale and sector composition of these contributions, first for Global imports and then for the China subset within each destination.

4 Coverage of European imports

4.1 Current coverage and the wider product account

Wider product scope accounts for most of the increase in covered emissions. We calculate emissions by matching product mass in 2025 EU and UK imports ([Eurostat, 2026](#), [HM Revenue & Customs, 2026a](#)) to CBAM coverage rules, material content, production electricity and emissions factors (Appendix A.1). The low, central and high scenarios apply different material, electricity and residual emissions coefficients to the same trade data (Appendix A.2). A separate EE-MRIO calculation compares the product account with broader supply chains for 2021 (Appendix A.3).

Table 5 reports current statutory coverage and three successive additions under our central scenario. The first includes electricity omitted within goods already listed. Layer 2 then adds covered-material and production-electricity emissions in downstream products, and Layer 3 adds the quantified residual product contribution.

Table 5. Emissions coverage of 2025 imports under central scenario (Mt CO₂e)

Measure	EU Global	EU China	UK Global	UK China
(1)Current CBAM statutory coverage	315.309	44.218	58.863	4.430
(2)CBAM-goods electricity increment	85.312	12.332	16.656	2.221
(3)Cumulative after same-goods electricity (1)+(2)	400.622	56.550	75.519	6.651
(4)Layer 2 increment	180.596	116.776	43.337	12.233
(5)Cumulative after Layer 2 (3)+(4)	581.217	173.325	118.856	18.884
(6)Layer 3 increment	436.240	78.621	100.269	12.433
(7)Final quantified product account (5)+(6)	1,017.457	251.947	219.124	31.317
(8)CBAM priced emissions share (1)/(7)	31.0%	17.6%	26.9%	14.1%
(9)Unpriced emissions share 100%-(8)	69.0%	82.4%	73.1%	85.9%

Current statutory coverage reaches 315.309 Mt CO₂e in EU Global imports, compared with a final quantified product account of 1,017.457 Mt CO₂e under our central coefficient scenario. UK Global rises from 58.863 to 219.124 Mt CO₂e. The current shares are consequently 31.0% for the EU and 26.9% for the UK. Most of the quantified emissions lie beyond the current boundary in both schemes, and the gap is larger for China. Table 5 shows the necessity of CBAM expansion, but a principal expansion question arises. Apart from scope 2 emissions exempted from current CBAM covered materials, which products and producing industries account for this uncovered majority in Layer 2 and Layer 3?

4.2 Downstream products

Figure 1 separates the material and electricity contributions within these and the other downstream product families.

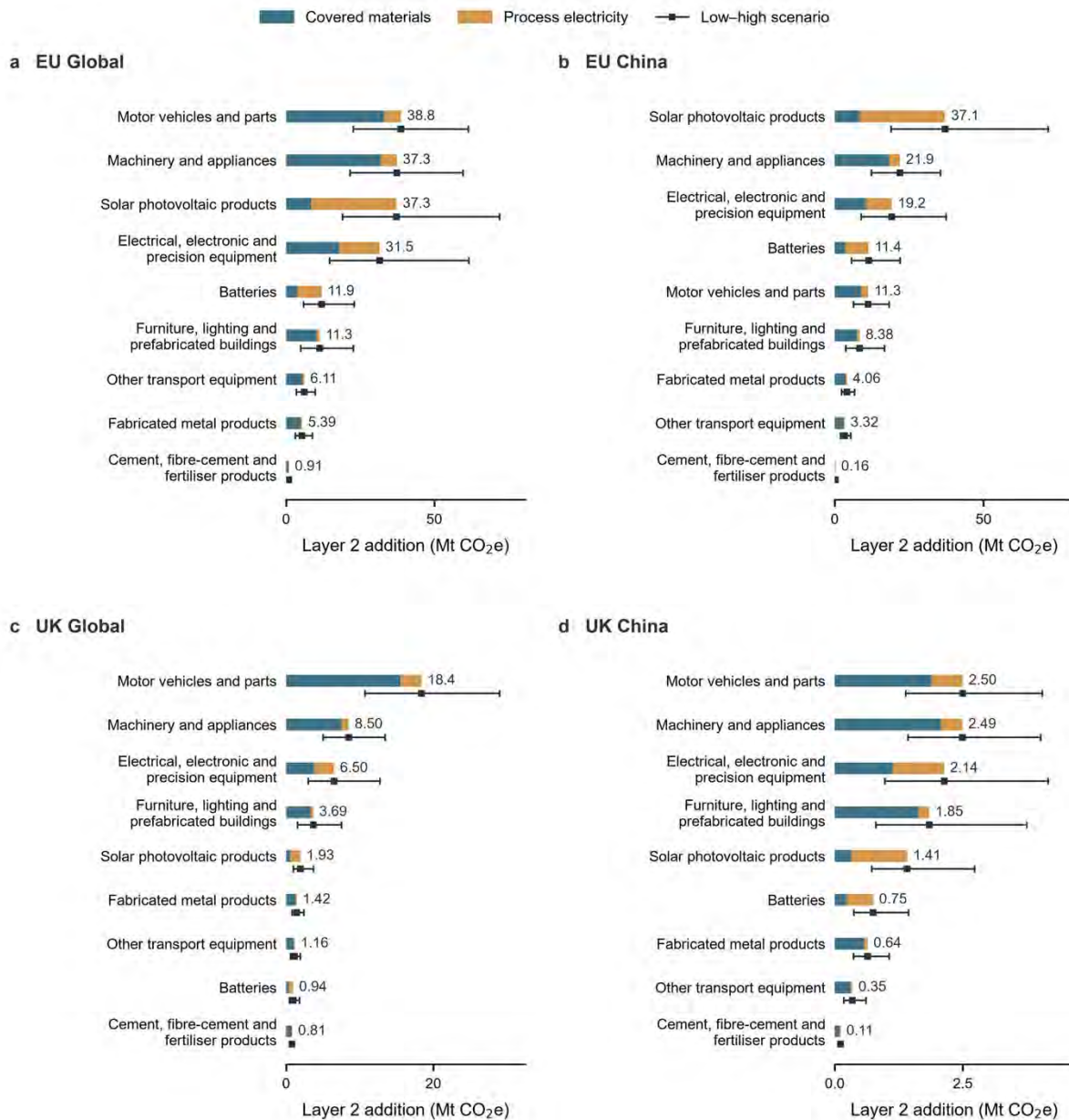


Figure 1. Downstream emissions by product family. Covered materials and production electricity are shown separately for EU and UK Global imports and their China subsets. Bars show central values. Lines below the bars show low to high coefficient scenarios, with squares marking central values (Appendix A.2).

Among downstream leakage from CBAM products, motor vehicles and parts, machinery and appliances, electrical, electronic and precision equipment, and solar photovoltaic products make large contributions to the EU Global Layer 2, accounting for 144.9 Mt CO₂e. The UK pattern is strongly led by motor vehicles and parts but machinery and appliances and electrical, electronic and precision equipment also account for a significant amount. The car illustration thus represents a major trade channel.

The results also signify the large emissions embodied in photovoltaic and electrical components, which are key to electrification of economy. Such products are

important to decarbonization of economy and mostly come from China, making it even more important in an emissions accounting sense comparing with the battery, which has been regulated by a separate regulation. China accounts for 116.776 Mt CO₂e of the EU Layer 2 increment, or 64.7% of its Global downstream, this signifies the substantial relevance between downstream leakage in EU and upstream carbon pricing in China. The decarbonization of China's power system is also of great importance, as EU+UK bears 71.7Mt CO₂e from embodied emissions of electricity from all China's products including scope 2 exemptions and Layer 2, especially for photovoltaic products. When considering the downstream expansion of CBAM, for more materials dominated products like vehicles and machinery, expansion calls for detailed BOM and LCA while for electricity dominant products, reporting emissions could be easier through using green electricity. However, an effective carbon pricing in the existing ETS sectors (e.g. China's national ETS) will always be much easier than CBAM expansion when implementing but price the externality same.

4.3 Residual industries

From the car example in Table 3 and CBAM coverage analysis in Table 5, it is found that non-CBAM materials have similar levels of emissions of CBAM materials. To illustrate which industries brings this embodied emissions, Figure 2 gives a sectoral analysis of each industry in layer 3 emissions.

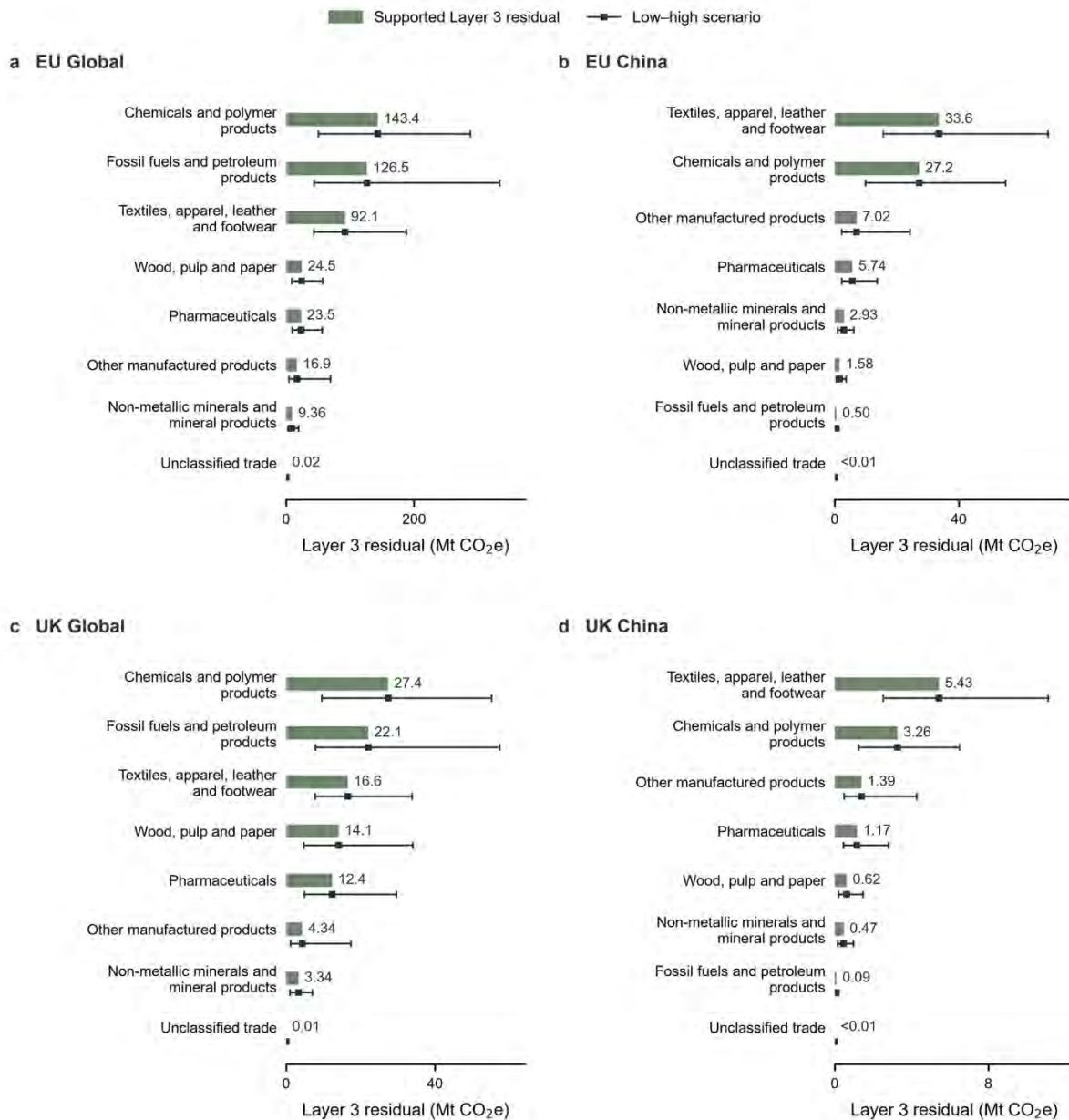


Figure 2. Residual emissions by industry. Bars show central values for 2025 EU and UK Global imports and their China subsets. Lines below the bars show low to high coefficient scenarios, with squares marking central values (Appendix A.2).

The majority of Layer 3 comes from fossil fuel-based products, including chemicals and oil products while textiles play the second important role. They contribute 143.40, 126.53 and 92.08 Mt CO₂e respectively in EU Global, and 27.43, 22.09 and 16.58 Mt CO₂e in UK Global. Wood products and pharmaceuticals also have non-negligible embodied emissions. These emissions come from fossil fuel combustion for heat and the chemical reaction in processing the materials.

The current EU ETS and UK ETS have included emissions from consumption of oil products, including transportation, maritime and aviation, but fail to trace the emissions from processing the oil and making oil products before they are imported.

To properly price the carbon content in such sectors, an expansion for carbon intensive industries with non-CBAM materials is required.

5 Conclusion and Discussion

This research reviews two European CBAMs and calculates their unpriced emissions using both micro and macro level analysis. The unpriced emissions from CBAM is categorized as embodied emissions in complex products from CBAM materials (Layer 2) and non-CBAM products (Layer 3). In the micro analysis of an example car, Layer 2 and Layer 3 each account for approximately half of its quantified emissions. In the total unpriced emissions from 2025 trade records, the priced emissions reach 31.0% of the EU Global emissions and 26.9% of the UK Global account with lower shares for their China subsets. Embodied emissions from CBAM materials in downstream products (Layer 2) are concentrated in vehicles, machinery and photovoltaic products, and residual emissions (Layer 3) are concentrated in chemicals, petroleum products and textiles. Unpriced electricity emissions in EU and UK imports are substantial, accounting for 14.7% of the EU Global quantified product account and 11.9% of the UK Global quantified product account.

Effective carbon pricing in an origin ETS (a climate club) helps price Layer 2 emissions which are used in complex products. But Layer 3 requires broader scope of current carbon pricing mechanisms. Products from fossil fuel (chemicals and oil products) are the two largest Global residual categories, while textiles and related products lead the China subsets. These industries should be considered when designing the expansion of CBAM. At the same time, CBAM expansion should include downstream CBAM materials in complex products (Layer 2), to effectively price their embodied emissions.

China's national ETS expansion shows both an alignment with CBAM covered materials and carbon-intensive Layer 3 industries. Its 2025 work plan extended national carbon market coverage to steel, cement and aluminum smelting ([Ministry of Ecology and Environment of China, 2025](#)). The January 2026 notice addresses allowance management for these industries and power generation, and brings petrochemicals including crude-oil processing, chemicals, flat glass, copper smelting, paper and civil aviation into emissions reporting and verification. ([General Office of the Ministry of Ecology and Environment of China, 2026](#)). For the non-CBAM sectors, monitoring and reporting have started but the carbon content hasn't been priced yet.

When planning CBAM expansion, EU and UK authorities should set out a clear roadmap first with sectors, sequences and how importer's existing carbon costs should be offset. This would give the governments of their trade partners clearer incentives to strengthen the effectiveness of their domestic carbon pricing measures. Measures of effective carbon pricing, the expansion in Layer 3 can start from key sectors, and learning the lessons of properly designing the bill of materials, supplier & production routes, and life-cycle assessment boundaries in those separate policy

schemes like the EU Battery Regulation. Authorities should align the records used for environmental standards, origin ETS verification and CBAM attribution so that the same material quantities, production locations and emissions evidence can serve more than one instrument.

Appendix A. Accounting methods

A.1 Product accounts

To distinguish wider coverage from a change in trade, the calculation uses observed 2025 imports fixed and links product mass to destination-specific coverage rules and physical emissions factors. Product-level mass comes from Eurostat CN8 trade records for the EU and HMRC UK Trade Info for the UK ([Eurostat, 2026](#), [HM Revenue & Customs, 2026a](#)). Global includes all origins. China is selected within the corresponding destination account using the same assignments. Each trade row enters one layer only, and each addition remains separate from the cumulative total it produces. The EE-MRIO comparison uses its own system boundary and does not enter this sequence.

Within each reporting account, Layer 1 separates emissions covered by the applicable statutory schedule from the additional electricity that would be counted if indirect electricity were included for all those listed goods. For destination r , origin o , year t and coefficient scenario s , emissions assigned to the statutory product list are

$$E_{r,o,t}^{(1,s)} = \sum_{i \in C_{r,t}} q_{r,o,i,t} [d_{r,o,i,t} + I_{r,i,t}^{(s)} u_{r,o,i,t}]$$

Here, $C_{r,t}$ is the destination-specific set of listed products, q is imported mass, d and u are the scenario direct- and indirect-emissions factors, and I records whether the relevant indirect component is accountable under scenario s . Evaluating the statutory expression with the statutory indicator gives current statutory coverage.

Evaluating it with indirect electricity included for all goods already in $C_{r,t}$, then subtracting the statutory value, gives the same-goods electricity increment. Adding that increment to current statutory coverage gives the first cumulative extension. The product list remains unchanged at this step.

Layer 2 traces covered-material and production-electricity channels into downstream products outside Layer 1. After current-goods rows have been removed, its addition is

$$\Delta E_{r,o,t}^{(2,s)} = \sum_{j \in D_{r,t}} q_{r,o,j,t} [\sum_{m \in M} b_{j,m}^{(s)} f_{r,o,m,t} + g_j^{(s)} c_{o,t}]$$

The set $D_{r,t}$ contains the selected downstream products, and M contains the covered materials traced into them. The term $b_{j,m}^{(s)}$ is the scenario material share, $f_{r,o,m,t}$ the corresponding material-production factor, $g_j^{(s)}$ the product's process-electricity requirement and $c_{o,t}$ the origin grid factor. The two terms capture the non-electric remainder of covered materials and the electricity used in materials and downstream production. Product selection uses the CN8 concordance and longest applicable product match, with each trade row assigned once. The accompanying technical documentation records the concordance and coefficient provenance.

Layer 3 aggregates the quantified emissions assigned to the eligible product rows remaining after Layers 1 and 2. It reports the addition by industry as

$$\Delta E_{r,o,t}^{(3,s)} = \sum_{g \in R_{r,o,t}^Q} q_{r,o,g,t} a_g^{(s)}$$

where $RQ_{r,o,t}$ is the set of residual rows with adequate factors and $a_g^{(s)}$ is the scenario coefficient applied to industry g . The result is reported by the industries that produce and carry the emissions. Eligible rows for which no adequate factor exists enter a separate set, $RU_{r,o,t}$, and their mass is retained as

$$U_{r,o,t} = \sum_{g \in R_{r,o,t}^U} q_{r,o,g,t}$$

No emissions value is imputed to $U_{r,o,t}$. These products remain unquantifiable under the available evidence, rather than being treated as zero-emissions products. Their separately reported mass is outside the denominator of the final quantified emissions account.

The reported sequence therefore has four cumulative positions and three separately visible additions. Current statutory coverage is the starting position. Adding same-goods indirect electricity gives the first extended cumulative account. Adding $\Delta E_{r,o,t}^{2,s}$ gives the Layer 2 cumulative account. Adding $\Delta E_{r,o,t}^{3,s}$ gives the final quantified product account. We report each increment beside its resulting cumulative value, the current statutory share of the final account and the share of expansion beyond current coverage produced by wider product scope.

A.2 Coefficient scenarios and data coverage

Across the cases, wider product scope contributes 75.3% to 94.0% of expansion beyond current coverage in EU Global, 88.2% to 96.9% in EU China, 78.6% to 94.9% in UK Global and 83.8% to 95.7% in UK China. Chemicals and polymer products lead the central Global residual accounts, while fossil fuels and petroleum products lead their high cases. Textiles, apparel, leather and footwear remain the largest residual category in both China subsets across all three scenarios. The accompanying source tables retain the complete values.

The ranges in Figures 1 and 2 come from applying low, central and high coefficients to the same trade mass and product assignments. Layer 2 varies the material shares and electricity requirements per tonne of product; Layer 3 varies the emissions coefficients for the remaining products. Each case uses its corresponding coefficients throughout the calculation. Table B5 gives examples of these assumptions.

Products without adequate mass, a usable product assignment or a supported coefficient are recorded as unquantifiable. UK record-type-3 confidentiality representatives encode 990 followed by HS2 and SITC3 information without

identifying a unique CN8 product. Table B4 reports their physical mass separately from the emissions layers. Ordinary Chapter 99 trade remains a distinct reporting category. Official UK numerical defaults were unavailable at the calculation snapshot, so the UK estimates use EU factors as an analytical proxy. These rules define the quantified-product denominator in Table 5. Products that cannot be quantified under the available evidence are not assigned zero emissions.

A.3 Comparison with EE-MRIO estimates

A comparison with environmentally extended multi-regional input-output (EE-MRIO) estimates examines how the estimated scale changes under a broader supply-chain boundary. Table A1 compares the archived 2021 product accounts with an independent EE-MRIO calculation for the same year. This calculation follows monetary supply chains, including services and indirect production links beyond the physical customs-product account (Stadler et al., 2018, 2026, Owen and Kilian, 2025). Imported final and intermediate demand enter the calculation as

$$E_{r,o}^{\text{MRIO}} = \varepsilon^T (I - A)^{-1} (y_{r,o}^{\text{imp}} + z_{r,o}^{\text{imp}})$$

where ε is the EXIOBASE emissions-intensity vector, A the technical-coefficient matrix, y^{imp} imported final demand and z^{imp} imported intermediate demand. The monetary EE-MRIO boundary contains sectoral supply chains and services that do not map one-to-one to a CN8 customs row. Its result is consequently kept outside every cumulative value in the three-layer account and outside any customs-charge interpretation.

Table A1. Product-account and EE-MRIO estimates for 2021

Import account	Product account (Mt CO ₂ e)	EE-MRIO (Mt CO ₂ e)	Difference (%)
EU Global	955.62	1,250.41	30.8
EU China	169.31	216.36	27.8
UK Global	206.40	257.50	24.8
UK China	25.12	39.96	59.1

Notes. Both estimates refer to 2021. The product column reports the archived central quantified account. EE-MRIO uses the unadjusted EXIOBASE satellite account. Difference is the percentage excess of EE-MRIO over the product account, calculated before rounding. China is included in Global. The 2025 product accounts are reported separately in Table 5.

EE-MRIO exceeds the product account in all four comparisons, by 24.8% to 59.1%. The relative difference is largest for UK imports from China, while EU Global has the largest absolute difference at 294.78 Mt CO₂e. The estimated scale therefore changes substantially with the accounting framework. System boundary, sector aggregation, source data and coefficients all contribute to the difference. A separate system-level perspective remains useful when interpreting product-based coverage, but the discrepancy cannot be assigned to an additional product layer or read as a measured quantity of omitted emissions.

Appendix B. Supporting tables

The supporting tables report the full passenger-car calculation, the Layer 2 and Layer 3 industry accounts, and the separate physical mass of HMRC confidentiality representatives. Global is the primary account and China its nested subset. Coefficient scenarios and full precision are retained in the accompanying data files.

Table B1. Passenger-car inputs and electricity allocation

Input	Quantity	Gross t CO ₂ e	Electricity t CO ₂ e	Remainder t CO ₂ e	Account assignment
Steel	588.90 kg	1.454583	0.226759	1.227824	Layer 2
Cast iron	71.01 kg	0.063909	0.010685	0.053224	Layer 2
Aluminium	290.20 kg	3.496910	1.597913	1.898997	Layer 2
Glass	31.56 kg	0.035663	0.004232	0.031431	Layer 3 supported residual
Paint	5.26 kg	0.029877	0.004692	0.025185	Layer 3 supported residual
Plastic	157.63 kg	0.569044	0.060805	0.508239	Layer 3 supported residual
Rubber	52.60 kg	0.173580	0.005657	0.167923	Layer 3 supported residual
Oil and fluids	5.26 kg	0.007469	0.004692	0.002777	Layer 3 supported residual
Copper	84.05 kg	0.303420	0.056224	0.247197	Layer 3 supported residual
Other non-ferrous metals	21.04 kg	0.161377	0.018767	0.142610	Layer 3 supported residual
Electronics and BMS	85.25 kg	3.122708	0.076040	3.046667	Layer 3 supported residual
Textiles	53.91 kg	1.307317	0.048086	1.259231	Layer 3 supported residual
LFP active cathode material	80.74 kg	0.851726	0.041749	0.809977	Layer 3 supported residual
Graphite	41.62 kg	0.400218	0.192914	0.207304	Layer 3 supported residual
Carbon black	5.44 kg	0.019638	0.002098	0.017540	Layer 3 supported residual
Binder	6.73 kg	0.024295	0.002596	0.021699	Layer 3 supported residual
Electrolyte	54.87 kg	0.128944	0.048942	0.080002	Layer 3 supported residual
Insulation	1.59 kg	0.005740	0.000613	0.005127	Layer 3 supported residual
Coolant	17.34 kg	0.062597	0.006689	0.055909	Layer 3 supported residual
Vehicle manufacturing, factory electricity	1,060.00 kWh	0.657730	0.657730	0.000000	Layer 2
Vehicle manufacturing, factory heat	590.00 kWh thermal	0.115345	0.000000	0.115345	Layer 3 supported residual
Vehicle manufacturing, natural gas	420.00 kWh	0.082110	0.000000	0.082110	Layer 3 supported residual
Battery manufacturing, electricity	1,198.50 kWh	0.743669	0.743669	0.000000	Layer 2
Battery manufacturing, heat	1,198.50 kWh thermal	0.234307	0.000000	0.234307	Layer 3 supported residual

Table B2. Layer 2 product-family account (Mt CO₂e)

Layer 2 major category	EU Global	EU China	UK Global	UK China
Solar photovoltaic products	37.277	37.102	1.929	1.413
Batteries	11.935	11.409	0.943	0.749
Motor vehicles and parts	38.796	11.252	18.385	2.499
Other transport equipment	6.107	3.325	1.157	0.346
Machinery and appliances	37.320	21.913	8.505	2.491
Electrical, electronic and precision equipment	31.539	19.174	6.502	2.135
Furniture, lighting and prefabricated buildings	11.328	8.377	3.685	1.847
Fabricated metal products	5.386	4.061	1.424	0.640
Cement, fibre-cement and fertiliser products	0.907	0.164	0.807	0.111

Table B3. Layer 3 industry account (Mt CO₂e)

Layer 3 major category	EU Global	EU China	UK Global	UK China
Chemicals and polymer products	143.398	27.243	27.431	3.263
Pharmaceuticals	23.493	5.737	12.352	1.168
Fossil fuels and petroleum products	126.534	0.500	22.091	0.090
Textiles, apparel, leather and footwear	92.081	33.619	16.576	5.429
Wood, pulp and paper	24.463	1.575	14.122	0.624
Non-metallic minerals and mineral products	9.357	2.930	3.340	0.467
Other manufactured products	16.893	7.016	4.344	1.392
Unclassified trade	0.021	0.001	0.012	0.001

Table B4. HMRC confidentiality representatives by decoded HS2 (2025 product mass, Mt)

Decoded HS2	HS2 family	Decoded SITC3 code(s)	UK Global	UK China
25	Mineral products	278, 661	4.140922	0.004372
29	Organic chemicals	512, 513	0.610748	0.106347
28	Inorganic chemicals	522, 525	0.036808	0.005121
87	Vehicles	782, 891	0.025026	0.000178
39	Plastics	575	0.013360	0.003741
05	Animal products	291	0.009842	0.001337
93	Arms	891	0.003950	0.000003
36	Explosives	593	0.003020	0.000284
85	Electrical machinery/electronics	764	0.002737	0.000731
88	Aircraft	792	0.001475	0.000181
90	Optical/medical instruments	871	0.000173	0.000126
89	Ships	793	0.000024	0.000011

Table B5. Examples of coefficients used in the low, central and high scenarios

Product and coefficient	Unit	Low	Central	High
Passenger cars (HS 8703), steel content	t/t	0.45	0.60	0.75
Passenger cars (HS 8703), aluminium content	t/t	0.08	0.15	0.25
Photovoltaic products (HS 854143), production electricity	MWh/t	5	10	20
Fossil fuels (HS 27), emissions	t CO ₂ e/t	0.05	0.15	0.40

Notes. Values are assumptions used in the coefficient scenarios. The fossil fuel coefficients cover extraction and processing before import.

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