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Carbon Border Adjustments: The potential effects of the EU CBAM along the supply chain

Antoine Dechezleprêtre[1], Antton Haramboure[1], Clara Kögel[1], Guy Lalanne[1], Norihiko Yamano[1]

Disparities in carbon pricing and other climate policies across countries can raise the risk of carbon leakage. To address this, the European Union introduced a Carbon Border Adjustment Mechanism (CBAM) which will require importers of certain energy-intensive goods to pay a levy on embedded emissions. This paper combines multiple data sources to measure the coverage of the CBAM in terms of trade flows and emissions and uses an enhanced input-output model to simulate the impact of the CBAM on value added and emissions across sectors and countries, accounting for supply chain linkages. Results show that the CBAM can effectively prevent carbon leakage. However, it only partially mitigates the negative effects of higher carbon prices and free allowances removal on the value added of CBAM-protected industries and negatively affects downstream EU industries.

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Executive summary

In April 2023, the EU adopted the 'Fit for 55' package, which included a major reform of the European Union Emissions Trading System (EU ETS). The policy package includes a faster reduction of the emissions cap and a gradual phasing out of free allowances between 2025 and 2034. These measures have intensified concerns about carbon leakage, whereby the introduction of domestic climate policies partly shifts production and emissions to countries with less stringent policies. To mitigate this risk, the EU introduced the Carbon Border Adjustment Mechanism (CBAM), which will require EU importers of certain emission-intensive trade-exposed goods (iron, steel, cement, fertilisers, aluminium, electricity, and hydrogen) to pay an adjustment on emissions embedded in their imports equal to the price of allowances under the EU ETS (minus any domestic carbon price already paid in the third country).

This paper combines multiple data sources to (1) document the coverage of the CBAM in terms of trade flows and embedded emissions and (2) simulate the impact of implementing the CBAM in its definitive regime across sectors and countries. The simulation compares the CBAM impact with that of the increase in the EU ETS carbon price induced by the reduction in the cap and the full removal of free allowances for CBAM-covered sectors, which will be completely phased out in 2034. The simulation, based on an enhanced input-output model, is designed to capture the first-order effects of the policies in the short run. It simulates short-term input substitution, efficiency gains and price and quantity changes, and provides detailed insights into the effect of the CBAM on trade flows, value added, and emissions. Longer-term changes in production processes, within-country resource reshuffling, backfilling, and the potential endogenous implementation of new climate policies in non-EU countries are not included in the model. The simulation does not model the planned gradual implementation of the policy but instead measures the impact of the CBAM and of the rest of the 'Fit for 55' package as if they were fully implemented on the current economy.

The CBAM regulation covers a minor fraction of global emissions and trade. The targeted products cover 0.37% of the value of global trade in goods and services and 3% of EU imports from non-EU countries in 2022. Emissions embedded in imported products covered by the CBAM represent 0.31% of global greenhouse gas (GHG) emissions in 2022. The most covered trade flows concern basic metals, predominantly originating from the People's Republic of China (hereafter, 'China'), Türkiye, and the Russian Federation (hereafter, 'Russia'). In the European Union, CBAM-covered goods represented 7% of manufacturing production, 2.3% of gross output, 1.1% of value added and 0.6% of employment in 2019. With a carbon price of EUR 80 per tonne of CO2 (its value on 1 January 2024) and no change in trade flows, the CBAM would generate EUR 14.7 billion (USD 15.3 billion) in revenue yearly.

Model based simulations suggest that the removal of free allowances combined with the increase in the price of EU ETS permits would lead to a small reduction in the value added of the CBAM industries in the EU (-1.06%) as some production is shifted to non-EU countries (+0.16% value added in CBAM industries). This would result in carbon leakage: the 175 million tonnes of CO_2 emissions reduction within the EU would be partially offset by an increase of 34 million tonnes in partner countries' emissions, corresponding to a carbon leakage rate of 19.2%. However, the model shows that the CBAM effectively mitigates carbon leakage, leading emissions to also fall in non-EU countries due to a rerouting of EU imports towards less emission-intensive sources. This shift in trade patterns reduces production in high emission economies, leading to a 36% increase in global emissions reductions compared to a scenario without CBAM (and free allowances removed) and to a 29% increase compared to a scenario where free allowances are kept (and CBAM not implemented).

The CBAM also mitigates the economic impact of the EU ETS reform (including the removal of free allowances) on the EU industry, but only partially so: value added losses in CBAM industries are reduced, but still amount to -0.85% (down from -1.06%). This is double the effect of only increasing the EU ETS price but keeping free allowances (-0.40%). This reduced competitiveness despite CBAM is to be expected as CBAM industries also consume CBAM-covered inputs (whose price will rise) and CBAM does not level the playing field on export markets. Moreover, while the CBAM reduces part of the adverse effects on covered sectors, it negatively affects downstream non-covered sectors that face increased input costs, diminishing their competitiveness. Consequently, the macro effect across all EU industries remains identical with or without the CBAM (-0.29%), as losses in downstream sectors almost perfectly balance the gains in covered industries.

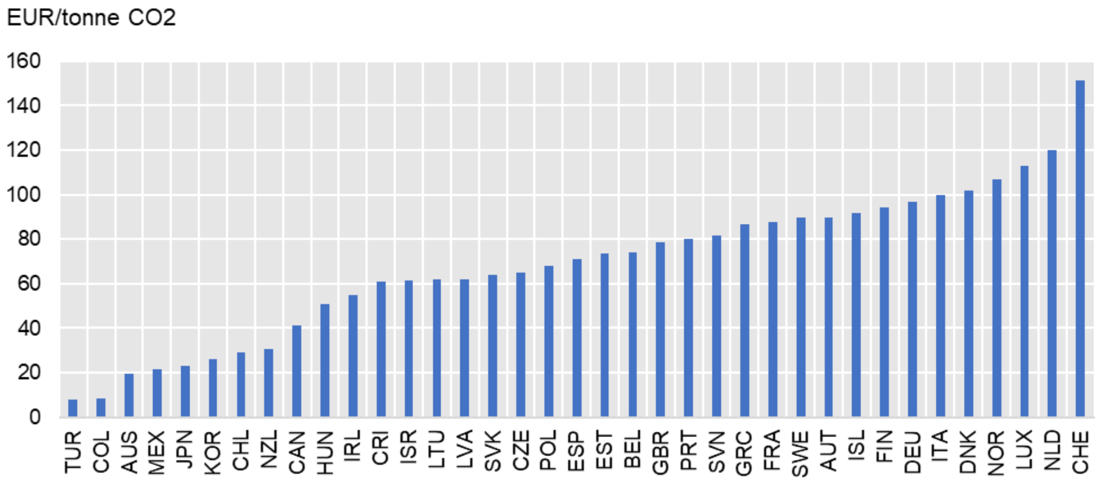
In the simulations, most non-EU economies benefit from the implementation of the EU ETS reform adopted as part of the ‘Fit for 55’ package despite the CBAM implementation, as their relative production costs decrease. However, the CBAM implies that those with higher production emission intensities see smaller gains than relatively “cleaner” economies. This underlines the CBAM's potential to encourage cleaner export-oriented production globally.

1 Introduction

In 2020, the European Union (EU) decided to take a significant leap forward in the fight against climate change by increasing its climate targets to at least 55% net reductions of greenhouse gas (GHG) emissions by 2030 compared to 1990 emissions and committed to reach carbon neutrality by 2050 (European Commission, 2020[1]). At the core of this 'Fit for 55' package lies a comprehensive reform of the current EU Emission Trading System (EU ETS), including more ambitious emission reduction goals, an extension of the ETS to maritime transport, a separate new ETS for buildings, road, transport, and fuels for additional sectors (ETS 2), and increased funding dedicated to the decarbonisation of ETS sectors.

The EU is not alone in this endeavour: over 100 countries around the world have committed to carbon neutrality goals by mid-century. Despite this common goal, the specific climate policy measures adopted to reach these ambitious targets differ considerably across countries (Figure 1). For example, while carbon permits in the EU ETS were traded at almost 100 EUR/tonne in 2023, the price of carbon permits that year amounted to around 14 USD/tonne within the Regional Greenhouse Gas Initiative (RGGI) – which covers 11 Eastern states of the United States – and to 8 USD/tonne within the People's Republic of China's ETS (World Bank, 2023[2]). In addition, the share of emissions these various carbon markets cover varies across countries. While the EU ETS regulates over 10 000 installations, covering approximately 40% of the EU's GHG emissions, the RGGI covers less than 14% of the participating states emissions (ICAP, 2022[3]). China's national ETS currently covers only the power sector, accounting for over 40% of its carbon emissions (ICAP, 2022[3]).

Figure 1. Average effective carbon prices in EUR per tonne of CO_2 equivalent by country, 2023



Source: OECD Effective Carbon Rates (OECD, 2024[4])

In the absence of international coordination on carbon pricing, differences in the stringency of domestic climate policies raise the concern of negative international spillovers: compliance costs for domestic businesses can result in imports from countries with less ambitious regulations gaining a production cost advantage over domestic goods (Condon and Ignaciuk, 2013[5]). This loss of competitiveness for emissions-intensive, trade-exposed domestic firms risks diminishing industry and public support for climate policy. A parallel concern is carbon leakage, whereby foreign emissions increase following the introduction or tightening of domestic climate policies, undermining the global effectiveness of climate mitigation efforts (Fowlie and Reguant, 2018[6]).

In the EU ETS, these concerns have primarily been addressed through the allocation of free allowances. During phase I of the scheme (2005-2007), free allowances were distributed based on firms' historical emissions, a method known as 'grandfathering'. From Phase III onwards (2013-2020), the allocation shifted to product-specific benchmark values, with a gradual reduction in free allowances overall, except for firms in sectors classified "at significant risk of carbon leakage" – specifically, emission-intensive trade-exposed (EITE) industries. The rationale for free allowances is to prevent the displacement of production and emissions to countries with less stringent environmental regulations (Böhringer, Carbone and Rutherford, 2012[7]). Similarly, competitiveness concerns have justified energy tax exemptions across EU countries, particularly for large energy-intensive companies. However, both free allowances and energy tax exemptions weaken abatement incentives and are not compatible with the EU's long-term net zero ambitions (Flues and van Dender, 2017[8]; Dechezleprêtre, Nachtigall and Venmans, 2018[9]).

A border carbon adjustment (BCA) is an alternative policy option to address the risk of carbon leakage. The objective is to level the playing field between firms located in countries implementing the most ambitious carbon pricing policies and firms operating in more lenient jurisdictions. BCAs are essentially levies on imported products based on the carbon price they would have incurred if produced domestically. Research indicates that BCAs can, in theory, effectively reduce carbon leakage and promote more ambitious climate policies in other countries (Clausing and Wolfram, 2023[10]; Jakob and al., 2022[11]). However, BCAs have also faced criticism for potentially acting as a form of protectionism (Horn and Sapir, 2013[12]) and creating tensions with global trade rules (World Trade Organization, hereinafter WTO, compatibility). Additionally, designing an effective and feasible BCA is challenging (OECD, 2020[13]).

In December 2022, the EU Council and the European Parliament announced the introduction of a European Carbon Border Adjustment Mechanism (CBAM), which aims to address the risk of European companies circumventing EU climate policies through outsourcing and to promote cleaner industrial production in non-EU countries. After a transitional period, EU importers of certain energy-intensive goods will be required to pay an adjustment on emissions embedded in their imports at the European border, corresponding to the price of allowances under the EU ETS minus any explicit carbon price already paid in the exporting country. Importantly, some Scope 2 (electricity-related) and Scope 3 (upstream) emissions are covered by the regulation. The EU CBAM will be a first of its kind: the only existing similar mechanism is California's carbon tax applied to certain imports of electricity (Fowlie, Petersen and Reguant, 2021[14]). However, several countries, such as Canada[1] and the United Kingdom[2] are planning to introduce similar border adjustment mechanisms, while Australia[3] and the United States[4] are currently exploring policy options. The United Kingdom authorities have announced the introduction of a BCA in 2027.

Although a BCA can address the risk of carbon leakage, significant questions remain open regarding the EU CBAM design and impact. Will it effectively reduce carbon leakage and contribute to a reduction in global emissions? What will be its impacts on value added in the EU and beyond? How will the competitiveness of downstream domestic industries using CBAM-covered products as inputs be affected? How feasible is the accurate measurement of the emission intensity of production outside of Europe, especially accounting for Scope 2 and 3 emissions? Should CBAM be extended to additional goods?

The objective of this paper is twofold. First, it aims to document the coverage of the CBAM in terms of trade flows and embedded emissions, shedding light on which sectors and countries would have been the most affected had the CBAM been implemented in 2022. Second, it simulates the effect of the CBAM (coupled with the expected increase in the price of carbon of the EU ETS scheme and the gradual removal of free allowances) on value added and emissions, not only for directly targeted sectors but also for their upstream and downstream partners along the value chain.

The first part of the paper aims at accurately measuring the coverage of the CBAM as defined in the May 2023 regulation based on a broad range of data sources. Product-level trade data from Comtrade is used to measure the value of CBAM-covered trade. Data on embedded carbon emissions are derived from the OECD's Greenhouse Gas Footprint Indicators database, which captures energy and process emissions for multiple greenhouse gases across various industries and countries and are complemented with data from the US Environmentally-Extended Input-Output (USEEIO) tables. Installation level data derived from the European Union Transaction Log (EUTL) is used to compute the country- and sector-level coverage of the EU ETS and free allowances. The value added, production, and input-output linkages are based on the OECD Inter-Country Input-Output (ICIO) tables.

This descriptive analysis reveals that the current CBAM regulation covers a minor fraction of total emissions and trade. In terms of trade value, the CBAM currently encompasses USD 132 billion or 0.37% of global trade in goods and services and 3% of such trade from non-EU countries to the EU. Emissions covered by CBAM embedded in imports from non-EU countries to the EU represent 171 million tonnes of CO_2eq, or 0.31% of global emissions. The largest share of CBAM-covered trade flows consists of trade in basic metals, predominantly originating from China, Türkiye, and the Russian Federation. 24% of embedded emissions covered by the CBAM regulation come from Scope 2 and 3 emissions. In Europe, CBAM-covered goods represent 7% of the sold production of manufactured goods in 2019; this corresponds to 2.3% of the total gross output and is associated with 1.1% of the value added and 0.6% of employment in the EU. Assuming a carbon price of EUR 80 per tonne of CO_2 (its value on 1 January 2024) and no change in trade flows, the CBAM would generate EUR 14.7 billion (USD 15.3 billion) in revenue yearly.

The second part of the analysis is based on a simple model exploiting the ICIO framework to measure not only the direct effect of the CBAM on covered industries but also its indirect value chain effect on downstream customers and upstream suppliers. Accurately measuring these indirect value chain effects is crucial for understanding the full impact of the policies, especially for the CBAM, which targets narrowly defined sectors located upstream in the value chain, thus affecting a wide array of firms indirectly. To track how costs disseminate throughout the production network, the simulation relies on a Leontief price model (Leontief, 1936[15]) (also known as a cost-push model), while allowing for input substitution, price elasticities and quantity changes. The model is similar to those used by Hebbink et al. (2018[16]) and Schotten et al. (2021[17]) and is designed to capture the initial first-order effects of the policies in the short run. It simulates short-term input substitution, efficiency gains, and price and quantity changes, and provides detailed insights into the effect of the different policies on trade flows, value added, and emissions. On the contrary, longer-term adaptation of production, within-country resource reshuffling, backfilling, and the potential endogenous implementation of new environmental policies in non-EU countries are not included in the model.

The impact analysis is based on a comparison of key economic outcomes under several policy scenarios. The first scenario simulates both an EU ETS price increase (due to the reduction in the EU ETS cap, or total amount of allowances) and the removal of free allowances for non-EITE sectors proposed in the last EU legislation (European Commission, 2023[18]). In this scenario, free allowances for non-EITE sectors are removed, while free allowances continue to be granted to EITE sectors, including those covered by CBAM. The second scenario models removing free allowances for EITE sectors in addition to the first scenario. Last, the “Full Policy Mix” scenario includes the CBAM and is the closest to the one outlined in the ‘Fit for 55’ EU regulation.

Simulation results indicate that the removal of free allowances combined with the increase in the price of EU ETS permits would lead to a small reduction in value added in the EU for CBAM-covered industries (-1.06%) and to an increase in production in non-EU countries (+0.16%). However, the introduction of the

CBAM partially alleviates this impact, with the value added decline in the EU decreasing to -0.85%. This is double the effect of only increasing the EU ETS price but keeping free allowances (-0.40%). This reveals CBAM's partial effectiveness in offsetting the reduction in value added and the potential loss of competitiveness resulting from the removal of free allowances, which is to be expected as CBAM industries also consume CBAM-covered inputs (whose price will rise) and CBAM does not level the playing field on export markets. The decline in value added within EU countries can be reduced to -0.52% by redistributing the revenue generated by ETS auctioned permits and CBAM to support the EU economy, a strategy known as revenue recycling. While the CBAM reduces part of the adverse effects on covered sectors, it negatively affects downstream non-covered sectors that face increased input costs, diminishing their competitiveness. As a consequence, the EU macro effects on all industries remains identical with or without the CBAM in place (-0.29%), with losses on downstream sectors exactly balancing the gains in CBAM industries.

Within CBAM-covered industries, the relocation of production outside the EU and the improvements in emission efficiency of firms operating in the Common Market result in a large decrease of emissions in the EU (-11,7%, -145 Mt CO_2eq) coupled with a small increase for its trade partners (0.11%, 28 Mt CO_2eq). Said differently, in the absence of the CBAM, the EU ETS reform (including the removal of free allowances in EITE sectors) would lead to carbon leakage, with every tonne of CO_2 saved in the EU leading to 0.19 tonnes emitted outside. A more detailed analysis shows that the removal of free allowances is responsible for more than two third of the carbon leakage and has a negative impact on global emissions. The introduction of the CBAM, however, reverses this effect, leading to a reduction in emissions outside the EU and to “negative leakage” within CBAM industries—approximately 0.15 tonnes of CO_2 are saved in non-EU countries for every tonne saved within the EU due to a rerouting of EU imports towards less emission-intensive sources. This increases global emission reductions by 36% compared to the scenario without CBAM and to a 29% increase compared to a scenario where free allowances are kept (and CBAM not implemented), with the Full Policy Mix Scenario reducing global emissions by 0.5% (-192 Mt CO_2eq).

The removal of free allowances and the implementation of the CBAM have uneven impacts on EU sectors in terms of prices and value added. Sectors that previously received free allowances covering more than 85% of their emissions, such as Basic metals and Non-metal minerals, face larger price increases than other sectors and value added losses of up to 2.8%. The CBAM helps mitigate most of this loss for the Basic metals sector but offers less protection to the Non-metal minerals sector due to its lower product coverage under the policy. Indirect effects are also felt in sectors not directly targeted by these policies (e.g. Construction and Electrical Equipment sectors), as their reliance on covered sectors drives an increase in prices and modest reductions in their value added. These non-targeted sectors, which make up most of the EU economy, account for 83% of the total value added loss in Europe, underscoring the importance of considering indirect value chain effects in the policy impact analysis.

A country-level analysis reveals significant variation in the impact of the CBAM across nations, driven by their emission intensity in production and the presence of domestic carbon pricing mechanisms. With the CBAM in place, European importers favour countries with lower emission intensities and existing carbon pricing, as this results in a lower levy compared to imports from more emission-intensive alternatives. As a result, while almost all non-EU countries experience modest gains following the implementation of the three policies, low emission countries like Chile benefit the most. Conversely, countries with high emission intensity in production, such as South Africa, India, and Tunisia, see a slight reduction in value added, though the impact remains limited (around -0.25%). Overall, this result highlights how the CBAM can address carbon leakage by shifting European input sourcing towards cleaner production origins.

As the current CBAM regulation mentions the possibility of extending the CBAM to other products in the future, the paper also analyses the effect on value added and emissions of a hypothetical extended CBAM-covered product list including 1 400 additional emission-intensive and trade-exposed goods. The findings indicate that further expanding the CBAM product list results in only a minor loss in value added (0.08%) in the EU and an additional reduction of 0.02% in global emissions, suggesting that the initial list has been well selected to maximise impact while covering relatively few goods. Moreover, the indirect value chain effect significantly impacts downstream non-CBAM industries in the extended product list scenario. Safeguarding these sectors from leakage risks would necessitate a substantial further expansion of the CBAM product coverage, which may pose challenges in terms of technical feasibility.

Finally, a series of sensitivity analyses, encompassing variations in carbon prices, trade elasticities, and lower cost pass-through rates, validate the robustness of the key findings to alterations in these parameters. While the exact magnitude of the effects naturally fluctuates in response to parameter adjustments, the relative ranking of affected sectors and countries remains consistent.

The remainder of this paper is organised as follows. Section 2 provides the details on the institutional background of the CBAM, while Section 3 provides a review of the relevant literature. Section 0 presents the data, the modelling, and the design of the policy scenarios. Section 5 presents the results. A final section concludes.

2 Institutional background

The CBAM is a new EU regulation to address the concern of carbon leakage while creating incentives for non-EU producers to reduce emissions (Bellora and Fontagné, 2023[19]; Baudry and Cameron, 2022[20]). It is a central part of the 'Fit for 55' package, a range of proposals to update existing EU law to ensure EU policies are in line with reaching the ambitious EU climate goals of reducing net GHG emissions by at least 55% by 2030 (European Commission, 2023[18]).

So far, the concern of carbon leakage has been addressed through freely allocating EU ETS allowances. In theory, free allowances can preserve firms' competitiveness while maintaining incentives to reduce emissions at the margin, since firms have an opportunity cost of using the allowances instead of selling them at market price.[5] Thus, the existence of free allowances should not modify the theoretical property of cap-and-trade mechanisms to achieve the equalisation of marginal abatement costs among firms, leading to an equitable distribution of the climate policy burden aligned with societal efficiency goals (Coase, 1960[21]).

In practice, however, emission permits might not be allocated optimally. This might be due to transaction costs (Stavins, 1995[22]), imperfect competition (Hahn, 1984[23]), and behavioural anomalies, such as endowment effects (Kahneman, Knetsch and Thaler, 1990[24]; Venmans, 2016[25]) leading to sub-optimal outcomes (De Vivo and Marin, 2018[26]; Zaklan, 2016[27]). Moreover, overallocation of permits may occur when allocation is based on grandfathering, which relies on firms' historical emissions; when benchmarks are outdated or lack sufficient granularity; or when there is limited responsiveness to macroeconomic or technological shocks, coupled with minimal output-based adjustments. In Phase I (2005-2007) of the EU ETS, the allocation of freely distributed allowances was linked to historical reference measures ("grandfathering") (ICAP, 2024[28]), a practice that exhibits limited responsiveness to external shocks or shifts in technology and productivity. Consequently, this approach led to a significant surplus of complimentary allowances, reducing the intended carbon price signal, and diminishing the impetus for fostering investments in low-carbon production processes (Pellerin-Carlin et al., 2022[29]). Therefore, while emissions within the energy-generating sector decreased by 29,4% between 2012 and 2022, the reduction in emissions for industrial sectors (which benefit from free allowances) amounted to a more modest 13.7% (European Environmental Agency, 2023)[6]. In the same vein, Dechezleprêtre et al. (2023[30]) document that the impact of the EU ETS on carbon emissions is negatively correlated with the generosity of free allowance allocation across regulated installations.

The allocation rules for free allowances have undergone substantial enhancements over the life of the EU ETS. In the context of the fourth trading phase (2021-2030), several modifications were introduced to allocate free allowances based on more updated production levels (Quirion, 2009[31]; Heilmayr and Bradbury, 2011[32]).[7] These include annual allocation adjustments, periodic five-year reviews of the list of eligible facilities for free allowances, and updates of the 54 benchmark values that determine the level of free allowances for each installation.

One alternative to free allowances is the introduction of a BCA, imposing a charge on the carbon content of imports at the EU border, which was suggested by the European Commission in 2019.[8] In December 2022, the EU Council and the European Parliament reached a provisional political agreement and announced the introduction of the CBAM.[9] EU importers of certain EITE goods will be required to pay an adjustment on emissions embedded in their imports corresponding to the difference between the domestic carbon price already paid in the third country and the price of allowances under the EU ETS. The price will be calculated as the average auction price of EU ETS allowances in EUR / tonne of CO_2 for the previous week (European Commission, 2023[18]; European Commission, 2023[33]).

The CBAM entered into application on 1 October 2023, starting with a transition period until 31 December 2025 to ensure a smooth roll-out. This initial period aims at collecting data and only implies reporting obligations. The financial adjustment induced by CBAM will gradually phase in at the same pace that free allowances in CBAM sectors are phased out during the 2026-34 period.

Table 1. Description of CBAM-covered goods

Category	Specific goods covered	ICIO Sectors
Cement	Kaolinic clays; Cement clinkers; Portland cement; Aluminous cement; Hydraulic cements	Mining non-energy, Non-Metal Minerals
Fertiliser	Nitric acid, sulphonitric acids; Ammonia; Nitrates of potassium; Mineral or chemical fertilisers; Mineral or chemical fertilisers	Chemicals
Aluminium	Unwrought aluminium; Aluminium powders, flakes, bars, rods, profiles, wire, plates, sheets, strip, foil, tubes and pipes, tube or pipe fittings, structures, reservoirs, tanks, vats, casks, drums, cans, boxes, and similar containers, cables, plaited bands; Other articles of aluminium	Basic Metals Fabricated Metals
Iron and Steel	Iron and steel; Agglomerated iron ores and concentrates; Articles of iron or steel such as sheet piling, welded angles, shapes and sections, railway or tramway track construction material, tubes, pipes, hollow profiles, seamless, structures, plates, rods, angles, shapes, sections, reservoirs, tanks, vats, casks, drums, cans, boxes, screws, bolts, nuts, coach screws, screw hooks, rivets, cotters, cotter pins, washers; Other articles of iron or steel	Basic Metals And Fabricated Metals
Electricity	Electrical energy	Electricity
Hydrogen	Hydrogen	Chemicals

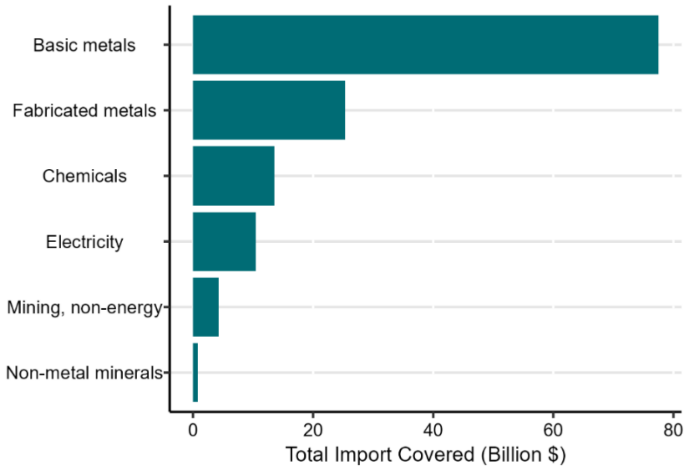
Note: Additional details, corresponding CN codes and sectoral mapping are provided in Table A A.1 in the Appendix.
Source: European Commission (2023[18]).

In this first phase, the CBAM will focus on certain goods only, selected based on their high carbon emissions, high risk of carbon leakage, and technical feasibility. These include iron, steel, cement, fertilisers, aluminium, electricity, and hydrogen (see Table 1 and Table A A.1 for further details). For each of the CBAM-covered goods, the European Commission provides the corresponding Common Nomenclature product codes (CN) at the 8-digit level of product detail. These can be transformed into Harmonised System (HS) product codes (at the 6-digit level) and identified in international bilateral trade statistics – notably in UN Comtrade, and the pre-processed BACI data (Gaulier and Zignago, 2010[34]). A product-industry mapping allows matching the HS codes to the ICIO industry breakdown (Table A A.1). Figure 2 displays the total value of imports from non-EU countries to the EU covered by CBAM. CBAM goods within the Basic metals sector account for the largest value in CBAM-covered imports, with a value of USD 78 billion, followed by fabricated metals, with covered imports of USD 25 billion. Overall, the CBAM covers imports valued at approximately 132 billion USD.

The CBAM will apply to direct (Scope 1) GHG emissions[10] released during the production process for all goods and to indirect emissions arising from the generation of electricity (Scope 2) for a subset of products (cement and fertilisers).[11,12] Embedded emissions from input materials ("upstream" Scope 3) will be included, as long as these input materials are themselves covered by CBAM. For example, CBAM covers not only crude steel but also iron and steel products. Therefore, when importing steel products, embedded emissions from the raw steel used as the input will also be covered. Similarly, when importing cement, embedded emissions stemming from clinker production will be included, as clinker is itself covered by CBAM.

Embedded emissions in goods other than electricity should be determined based on the actual emissions at the producing factory. Where the actual emissions cannot be determined, and for determining indirect emissions, the emissions are defined by default values set at the average emission intensity for the country or region.[13] Throughout the transitional phase, the gathered data will contribute to refining the methodology employed for computing emissions.

Figure 2. Value of imports covered by CBAM by exporting sector, 2022.



Note: The figure plots the total value of CBAM-covered imports from non-EU countries to the EU in 2022 USD billions.
Source: Own computation based on 2022 Comtrade data.

If the importer can prove that a carbon price has already been paid in the country of origin in respect of GHG emissions embedded in the goods, the CBAM declarant can claim a reduction in the number of the CBAM certificates equal to the carbon price already paid in the third country. Due to variations in carbon pricing practices across the world, the EU will have to clarify the approach on how to evaluate effective carbon pricing paid abroad (Delbeke and Vis, 2023[35]). Third countries that participate in the ETS, i.e. members of the European Economic Area[14] and Switzerland, are exempt from the CBAM. Before the end of the transition period, the agreement foresees a review of the CBAM's overall functioning as well as an analysis of the list of products for which indirect emissions are included. Also, the feasibility of including other goods covered by the EU ETS in the product scope will be reviewed.

The latest CBAM regulation (European Commission, 2023[18]) aims at ensuring compatibility with WTO law. A large literature has discussed WTO-compatibility of various BCA designs (OECD, 2020[13]); this is left out of the scope of this analysis.

The CBAM will come along with administrative costs, through compliance costs for businesses and enforcement costs for authorities. For businesses, compliance costs will arise for importers located in the EU that will have to pay the CBAM obligation. These costs will likely depend on whether embodied emissions are calculated based on a default value or on verified data about actual emissions. For authorities, costs will arise related to the interoperability of monitoring, verification, and reporting information provided by economic operators. These administrative costs are not considered in this modelling exercise as their magnitude seems small overall (0.5% of the price of allowances).[15]

3 Literature

The effect of domestic climate policies on carbon leakage and competitiveness

The implementation of ambitious domestic climate policies is associated with concerns over competitiveness losses and carbon leakage, whereby foreign emissions increase because production moves to countries with less ambitious climate policies (Fowlie and Reguant, 2018[6]). The literature distinguishes between a direct and an indirect channel through which carbon leakage can occur.

- Direct leakage occurs through a trade and investment channel. A climate policy-induced loss in competitiveness might result in declining exports and increasing imports. In the long run, this can also result in a change in foreign direct investment patterns implying a reallocation of manufacturing capacity to countries with lower environmental regulation.
- Indirect leakage, on the other hand, occurs through the energy price channel. The implementation of domestic climate policy by large countries should reduce domestic demand for fossil energy, lowering the world price of these fuels. This, in turn, can lead to an increase in foreign consumption, raising GHG emissions in these countries (Daubanes, Henriet and Schubert, 2021[37]; Keen and Kotsogiannis, 2014[38]).

This section provides a brief overview of the carbon leakage literature, distinguishing between *ex-ante* evaluations and *ex-post* empirical studies. Carbon leakage estimates tend to be higher in ex-ante modelling than in ex-post studies. This is largely because ex-ante analyses model price increases beyond historical levels. Furthermore, ex-ante models often overlook various sources of inertia that can dampen responsiveness to climate policies.

Ex-ante modelling

Ex-ante analyses are mainly based on computable general equilibrium (CGE) models, although few studies are also built on sectoral partial equilibrium (PE) models. Branger and Quirion (2014[39]) and Carbone and Rivers (2017[40]) provide extensive reviews of this literature.

Ex-ante analyses generally agree that domestic climate policies are likely to lead to carbon leakage, measured by the carbon leakage rate, which is calculated as the negative ratio of the simulated change in emissions within the region implementing a unilateral climate policy to the simulated change in emissions outside that region (see Table 2 for interpretation). Typically, the estimates of carbon leakage rate range from 5% to 25%[16] of the carbon abated domestically (with a mean of 14%) without border carbon adjustment (BCA). Both sets of reviews referenced above indicate that there is a positive relationship between abatement targets and leakage rates. This suggests that as the target increases, so does the rate of leakage. The *ex-ante* literature also shows that domestic emission abatement has a modest but negative effect on competitiveness, measured as output and exports, of EITE sectors. Results based on CGE models predict output losses ranging from 0% to 4% (mean 2%) without BCAs, while PE models estimates are even larger. In these studies, the mean emission abatement target is 19% (Branger and Quirion, 2014[39]).

Table 2 Interpretation of the carbon leakage rate

Change in emissions in implementing region	Change in emissions outside implementing region	Value of the carbon leakage rate	Interpretation	Impact on global emissions
Decrease	Increase	Above 100%	The increase in emissions outside the policy region more than offsets the decrease in the policy region	Increase
Decrease	Increase	between 0 and 100%	The increase in emissions outside the policy region partially offsets the decrease in the policy region.	Decrease
Decrease	Decrease	Below 0%	Decrease in emissions outside the policy region complements the decrease in the policy region	Decrease

Source: Authors elaboration.

Ex-post empirical studies

Alongside *ex-ante* analyses, a smaller literature is dedicated to *ex-post* empirical studies. To date, the existing empirical evidence on the effect of carbon leakage on industry competitiveness has yielded mixed results.[17] However, recent studies provide evidence of some degree of carbon leakage, particularly in specific trade and pollution-intensive sectors.

Ex-post studies encounter several caveats (Verde, 2020[41]). Much of the existing literature has primarily concentrated on two trading periods of the EU ETS, namely Phase I (2005-07) and Phase II (2008-12). During these periods, carbon prices remained notably low, with values consistently below EUR 10 per tonne of CO_2 equivalent between 2011 and 2018, thereby inadequately representing current prices. Furthermore, the Global Financial Crisis of 2008 precipitated a decline in production and associated emissions, which, in turn, diminished the risk of carbon leakage. The presence of free allowances and a variety of subsidies may also have been effective in mitigating carbon leakage amidst the context of these subdued carbon prices. In a recent paper, Levinson (2023[42]) illustrates a further challenge when assessing whether environmental regulations in developed countries have led to the relocation of polluting industries to pollution havens empirically. The lack of detailed industry-specific emissions intensities across countries makes it difficult to disentangle between clean and polluting industries within the same sector. Baudry and Cameron (2022[20]) offer a comprehensive review of the channels through which carbon leakage has manifested within the EU and anticipate its increase with the EU's augmented climate ambitions, a phenomenon that is yet to be validated by future *ex-post* studies.

Early papers have used changes in relative energy prices as a proxy for changes in relative environmental policy stringency and estimated their effect on trade (Aldy and Pizer, 2015[43]; Sato and Dechezleprêtre, 2015[44]). These papers have found that increases in energy prices can have a statistically significant negative impact on trade, employment, and productivity but that the magnitude is small compared to general trends in production. Aldy and Pizer (2015[43]) estimate how changes in energy prices affect US net imports. They find that if the US unilaterally imposes a price of USD 15 per tonne of CO_2, net imports of energy-intensive industries would increase by 0.1 to 0.8%. According to Sato and Dechezleprêtre (2015[44]), an increase in energy prices has only a limited impact on bilateral trade flows as changes in relative energy prices over time only account for 0.01% of the variation in trade flows. It is worth noting that these papers use the value of trade flows as dependent variables, instead of actual emissions embodied in trade flows. This approach has its drawbacks as it does not consider actual changes in emissions, which depend on the emission intensity of the exporting partner. Exploiting an emissions accounting framework, Misch and Wingender (2021[45]) use policy-induced changes of energy prices and estimate significant leakage rates across European countries. The paper estimates an average carbon leakage rate of 25% over the period of 2005-20 period.

A more recent literature uses the implementation and subsequent reforms of European Union Emissions Trading System (EU ETS) as an exogenous event to test whether domestic environmental policy leads to carbon leakage. The evidence for carbon leakage in these studies is not clear-cut. Branger, Quirion and Chevallier (2016[46]) conclude that there is no evidence of carbon leakage in two energy-intensive sectors, cement and steel. Similarly, Naegele and Zaklan (2019[47]) find no empirical evidence for carbon leakage in the manufacturing sectors. Dechezleprêtre et al. (2022[48]) focus on the effect of the EU ETS on the geographic distribution of carbon emissions by multinational companies. While multinational companies are expected to be most prone to carbon leakage as they already operate internationally, the paper finds no evidence that the EU ETS has led to a displacement of carbon emissions from Europe towards the rest of the world. Results hold for energy-intensive companies and focusing on third countries with particularly lax climate policies.

Studies looking at foreign investment of German and Italian firms reveal a rise in their investments in countries with fewer restrictions after the EU enacted more stringent climate policies (Koch and Mama, 2019[49]; Borghesi, Franco and Marin, 2020[50]). Koch and Mama (2019[49]) study the effect of the EU ETS on foreign investment among German firms. They find that the EU ETS has had no effect on a large majority of firms. However, for a small number of firms, the effect of the EU ETS on their FDI activity outside the EU was statistically significant and increased by 43.9%. These firms were paradoxically not operating within energy-intensive or emission-intensive sectors, but rather had emissions permit shortages and were less capital-intensive and thus also more geographically mobile. Nevertheless, these firms only account for a small share of total EU ETS emissions and thus the effect of carbon leakage is found to be limited. Focusing on the Italian case, Borghesi, Franco and Marin (2020[50]) show that the EU ETS increased production taking place in foreign subsidiaries, especially in trade-intensive sectors, while it had only a weak effect on the number of new subsidiaries abroad.

Some *ex-post* studies have studied at the effect of environmental policies on carbon leakage in the United States. For example, Hanna (2010[51]) demonstrates that US air quality regulations resulted in a 9% uptick in production and a 5% rise in the asset value of US firms operating overseas during the period spanning from 1966 to 1999. In a recent study, Saussay and Zugravu-Soilita (2023[52]) confirm this, finding that environmental policy stringency impacts cross-border M&A decisions.

A recent study conducted by Teusch et al. (2024[53]) examine the aluminium, cement, and steel industries across 140 nations. The study assesses whether increased carbon prices have resulted in reduced emissions at the plant-level and investigates the impact of growing asymmetries in carbon pricing on countries' trade patterns and “imported” carbon. The findings indicate that for every USD increment in carbon pricing, the "imported" emissions associated with cement and steel products rise by 1.3%.

Another recent study by Eskander and Fankhauser (2023[54]) explores the impact of national climate legislation in 111 countries on international carbon emissions from 1996 to 2018. Unlike existing studies focusing on specific products or industries, this paper provides a macro-level perspective, evaluating the aggregate impact across economies. The paper finds that in the long-term (laws older than 3 years) climate legislations lead to significant reductions in both domestic and imported emissions, finding no evidence of trade-related carbon leakage.

A related empirical literature focuses on the effect of environmental policies on firms’ competitiveness, based on different measures of competitiveness such as employment, productivity, and innovation. Dechezleprêtre and Sato (2017[55]) provide a review of this literature. While papers document a statistically significant harmful effect on competitiveness in the short run, the magnitude of the effect is small, and tend to fade away after few years. Venmans, Ellis and Nachtigall (2020[56]) review existing studies on the effect of carbon pricing on competitiveness in G20 and OECD Member countries. Most studies find no statistically significant effect of carbon prices on the different dimensions of competitiveness. If they do so, the effect is small and either positive or negative. This is perhaps not surprising as, up to now, carbon prices have been low and free allowances were granted to EITE sectors.

To date, the available evidence on the impact of domestic climate policies on carbon leakage and competitiveness remains constrained. Only specific industries with energy-intensive production processes seem to have experienced a statistically significant impact from climate policies. However, while *ex-post* studies estimate the effect of past environmental stringency, these may not mirror the implications associated with more stringent environmental policies currently being enacted.

Carbon border adjustment as a tool to reduce carbon leakage and output loss

A substantial body of existing literature has investigated the extent to which CBAMs can effectively mitigate the issue of carbon leakage. Cosbey et al (2019[57]), Böhringer et al. (2022[58]), Zhong and Pei (2023[59]), and Fontagné and Schubert (2023[60]) provide extensive reviews of the *ex-ante* studies modelling the design and impact of CBAMs. The CGE literature suggests that BCA mechanisms reduce leakage, with a reduction in the leakage ratio due to BCAs between 1 and 15 percentage points. With BCAs, carbon leakage estimates range from −5% to 15% (mean 6%), down from 5%-25% without BCA (Branger and Quirion, 2014[39]).[18] A couple of studies including McKibbin et al. (2008[61]) and Mathiesen and Maestad (2004[62]) even estimate a negative carbon leakage rate, implying that emissions are reduced among countries outside the BCA thanks to learning spillovers and technology diffusion.

BCA also reduces output loss in CGE models, but less so in PE models (Branger and Quirion, 2014[39]).[19] Further, domestic emission abatement is found to have a slightly stronger impact on EITE exports than on output. A common important limitation of CGE and PE is that they cannot take into account firm-level heterogeneity in pollution intensity (Carbone and Rivers, 2017[40]). For example, Holladay (2016[63]) shows that increased import competition can induce the exit of the smallest, most pollution-intensive plants, thereby lowering the average carbon intensity of firms operating in the importing market.

The European CBAM

A small number of studies have so far modelled the effect of various versions (sometimes hypothetical) of the European CBAM on competitiveness and emissions.[20] The simulated size of the CBAM impact is highly sensitive to the extent of trade covered by the mechanism and to key modelling choices.

Several studies that simulate a more ambitious scope for the CBAM than the one adopted by the EU (Schotten et al., 2021[17]; Bellora and Fontagné, 2023[19]) tend to find a larger impact of the policies on emissions, trade flows and welfare for Europe and its trade partners. The simulations by Bellora and Fontagné suggest that, following the implementation of the CBAM, the EU GDP could decrease by 2.4% to 6.4% by 2040 depending on the scenario. Other studies, which more closely follow the current EU legislation by simulating a more restricted sectoral coverage (Olijslagers et al., 2024[64]; Korpar, Larch and Stöllinger, 2022[65]; European Commission, 2021[36]) report much smaller impacts. For example, Korpar et al. (2022[65]) find that the CBAM reduces global emissions by 0.08% and increases EU GDP by 0.2%, with effects more in line with the results of this paper (0.05% and 0.001%, respectively). On coverage, this paper goes one step further by adopting a product-based definition of the CBAM scope, acknowledging that only part of the imports from sectors targeted by the CBAM are actually covered by the legislation. Import coverage and the associated levy are computed at the country and sector-level, allowing for a nuanced understanding of how exposure varies across European countries depending on the origin and composition of their imports. Lastly, this paper is the first to incorporate Scope 2 and 3 emissions in computing the CBAM levy for a subset of products in accordance with EU legislation.

Another main methodological difference between the studies is centred around the choice of modelling frameworks. Many studies are based on multi-sector multi-region CGE model Bellora and Fontagné (Bellora and Fontagné, 2023[19]; Center for Climate and Energy Analyses, 2020[66]; European Commission, 2021[36]; Olijslagers et al., 2024[64]) while Magacho et al. (2023[67]), Schotten et al. (2021[17]), and this paper use I-O models and Korpar et al. (2022[65]) a structural gravity equation. CGE models are more versatile in accounting for how price fluctuations impact emissions and the complex feedback loops and adjustment processes in play. The strength of I-O models lies in their easy implementation, the lower computational power requirement that allows for more granularity in the input and output structure and their ability to assess the primary policy impacts in the short-term while offering insights into sectoral and regional interdependencies. Unlike structural gravity models, both CGE and I-O models account for value chain effects, which, as demonstrated in this paper, are significant.

Another important distinction among these studies is the specific policies they model. The EU CBAM is being implemented alongside major reforms to the EU ETS, including the phase-out of free allowances. This paper simulates the joint impact of these policies to assess their interactions. The findings reveal that carbon leakage is highest when the EU ETS price change is implemented without free allowances and is lower when the ETS is coupled with the CBAM, rather than free allowances, confirming previous results (Bellora and Fontagné, 2023[19]; Olijslagers et al., 2024[64]).

Related to this study, the European Commission's original impact assessment (European Commission, 2021[36]) uses the JRC-GEM-E3 general equilibrium model to assess the potential consequences of various scenarios related to the CBAM. It is so far the only detailed analysis of the CBAM fully reflecting the policy as defined by the current EU legislation, including accurate representation of covered sectors in its modelling. The assessment focuses on critical variables such as trade flows between the EU and the rest of the world, production, GDP, unemployment, and GHG emissions. Notably, the findings revealed that the CBAM's impact on European GDP would be minimal, resulting in only a slight 0.001% reduction by 2030 compared to a baseline scenario where free allowances continue to be the main instrument to address carbon leakage.[21] CBAM is estimated to reduce GHG emissions by 1% in the EU, and 0.4% in the rest of the world in 2030, compared to the scenario without the CBAM. Measured impacts on downstream industries are less pronounced than the effects estimated in this study, which might be due to the CGE modelling approach. One methodological drawback of this assessment is that it does not consider any carbon price paid in the country of origin.

Other papers have used I-O models to estimate the impact of the CBAM on competitiveness. Magacho et al. (2023[67]) focus on the potential impact of the European CBAM on exports, output and employment in emerging markets and developing economies. The study examines the earlier CBAM proposal, which had a narrower scope of covered goods. The paper reveals that the most exposed countries are Moldova and Mozambique, where approximately 2% of employment faces potential risk. Similarly, Bosnia-Herzegovina, Serbia, North Macedonia, Ukraine, Montenegro, Bahrain, and Albania could experience a wage bill and employment reduction exceeding 0.5%.

The Swiss government has commissioned two studies (Ecoplan, 2022[68]; Ecoplan, 2023[69]) to evaluate the implications of diverse policy options in response to the introduction of the European CBAM. Using a CGE model, the analysis suggests that the implementation of the CBAM by the EU and Switzerland is effective in mitigating carbon leakage for CBAM sectors. However, the adjustment on CBAM goods raises the cost of imported inputs, resulting in increased input costs and higher production costs for other sectors, thereby negatively affecting their competitiveness. The CBAM leads to 8% more reductions in global greenhouse gas emissions when compared to the policy scenario without CBAM. Other possible scenarios for Switzerland are investigated, including (1) remaining linked to the EU ETS, and transitioning to full auctioning of emission rights for CBAM sectors, and (2) discontinuing the linkage to the EU ETS and introducing a Swiss ETS with a free allowances system. The analysis concludes that if Switzerland does not introduce a CBAM, it would increase carbon leakage and reduce the cost efficiency of global greenhouse gas mitigation.

4 Data and design of policy scenarios

This section begins by detailing the Inter-Country Input-Output (ICIO) tables and the OECD's associated Greenhouse Gas Footprint indicators, which form the foundation of the proposed simulation. It then incorporates micro-level data to assess the coverage of the EU ETS and CBAM, capturing the extensive variation of these policies across sectors and countries. Finally, the section outlines the policy scenarios employed to estimate both the direct and indirect effects of the CBAM.

The ICIO tables and the Greenhouse gas footprint indicators

The OECD ICIO database measures the interrelatedness of economic production for 67 countries and 45 industries for the year 2019[22]. The ICIO infrastructure enables an analysis of the consequences of the EU CBAM on upstream and downstream sectors that are not directly affected by the policy, considering the structure of global value chains. This allows, for example, to capture the effect of the CBAM on domestic car manufacturers who rely on intermediate inputs covered by the policy (e.g. steel). The industry classification of the ICIO database is based on ISIC Rev.4 (NACE Rev.2). Although ICIO data are available up to 2020, the analysis deliberately excludes this year to avoid distortions associated with the COVID-19 pandemic. The data is complemented with the OECD's Trade in Employment (TiM) database, which contains indicators of employment by industry, consistent with output and value added in the ICIO data (Chiapin Pechansky and Lioussis, 2024[70]).

Data on embedded carbon emissions stems from the new OECD's Greenhouse gas footprint indicators[23], which provide yearly estimates of carbon emissions embodied in final demand and international trade for 77 economies and 45 unique industries based on the combination of the OECD's ICIO tables, International Energy Agency (IEA) CO_2 emissions from fuel combustion statistics, OECD Air emission account as well as information from national accounts (Yamano, Lioussis and Cimper, Forthcoming[71]). These data capture both energy and process emissions for several greenhouse gases across different industries and countries.

Measuring the coverage of the EU ETS and free allowances

The core of the scenario based analysis revolves around two pivotal components, capturing the cost to European industries of (a) the increase in the carbon price in the EU ETS and the removal of free allowances and (b) the CBAM. These components are then used to simulate the various policy scenarios.

The EU ETS covers around 10 000 installations across Europe, together representing roughly 40% of the EU's total greenhouse gas emissions. Power stations and industrial plants are classified according to their main GHG-emitting activity: combustion of fuels (irrespective of the installation's sector of activity), production of cement clinker, production of paper, etc. To limit administrative costs, the EU ETS was designed to cover only large installations. Activity-specific capacity thresholds determine which installations are included (European Commission, 2003[72]). For instance, only steel manufacturing plants with a production capacity greater than 2.5 tonnes per hour or glass manufacturing plants with a melting capacity above 20 tonnes per day are covered. This feature implies that the coverage of the EU ETS differs across countries and sectors, depending on the size distribution of installations at the country-sector-level.

The coverage of the EU ETS at the country-sector-level is computed using microdata at the establishment level installation level for 2019, consistently with the simulation base year. Emissions and free allowances at the installation level are recovered from the EU ETS info database, which also maps each installation to a NACE code at the 4-digit level. These data allow computing, for each country-sector pair at the NACE 2-digit level (which is the level of observation in the ICIO tables), the total emission generated by the installations covered by the EU ETS ($covered\ emission_{s,c,2019}$) as well as the total free allowance allocated to them ($free\ allocation_{s,c,2019}$). The coverage of the EU ETS and of the free allowances for each country j and sector s is derived as follows:

$$share_{s,j}^{cov\ ETS} = \frac{covered\ \ emission_{s,j,2019}}{total\ emission_{s,j,2019}} \text{ and } share_{s,j}^{freeA} = \frac{free\ allocation_{s,j,2019}}{total\ emission_{s,j,2019}} \qquad \textbf{Equation 1}$$

Where $total\ emission_{s,j,2019}$ is the total emission recorded in the Greenhouse gas footprint database. Due to measurement errors across datasets[24], $share_{s,j}^{cov\ ETS}$ is greater than 1 for 7% of the country-sector pairs. For these pairs, the ratio is capped at 1.

The EU ETS coverage varies significantly across both sectors and countries (Figure 3). Sectors producing goods subject to CBAM generally exhibit EU ETS emissions coverage that aligns closely with their allocation of free allowances: for example, the Basic metals and Non-metal minerals sectors have high EU ETS coverage (median value >90%) and receive substantial free allowances (>85%, whereas the Fabricated metals sector has coverage below 10% in both respects. A notable exception is the Electricity sector, which combines almost 100% EU ETS coverage with free allowances covering less than 10% of its emissions, as this sector is not trade-exposed and thus not considered at risk of competitiveness loss.[25]

The EU ETS coverage is used to calculate the country-sector cost of carbon in EU ETS countries. As part of the 'Fit for 55' package (European Commission, 2021[73]), the EU announced it will reduce emissions allowances within the EU ETS by over 4% per year (instead of 2.2% per year previously), which will increase their price. Chateau, Miho and Borowiecki (2023[74]) estimate that, besides the introduction of announced EU regulations[26], a carbon price of EUR 178 per tonne of CO_2 would be necessary to reach 'Fit for 55' goals. In reality, EU ETS carbon pricing is only a part of the whole policy package to reach the EU's climate targets, which includes renewable energy targets, energy efficiency targets and various technology support policies. Therefore, the emission cost increase under the revised EU ETS is proxied using a projected carbon price ($price^{CO2}$) of EUR 80 per CO_2 tonne. The price of EUR 80 per CO_2 tonne corresponds to average levels observed in 2023 during the energy price crisis. As a sensitivity check, the analysis also provides estimates based on a higher carbon price of EUR 150 per CO_2 tonne.

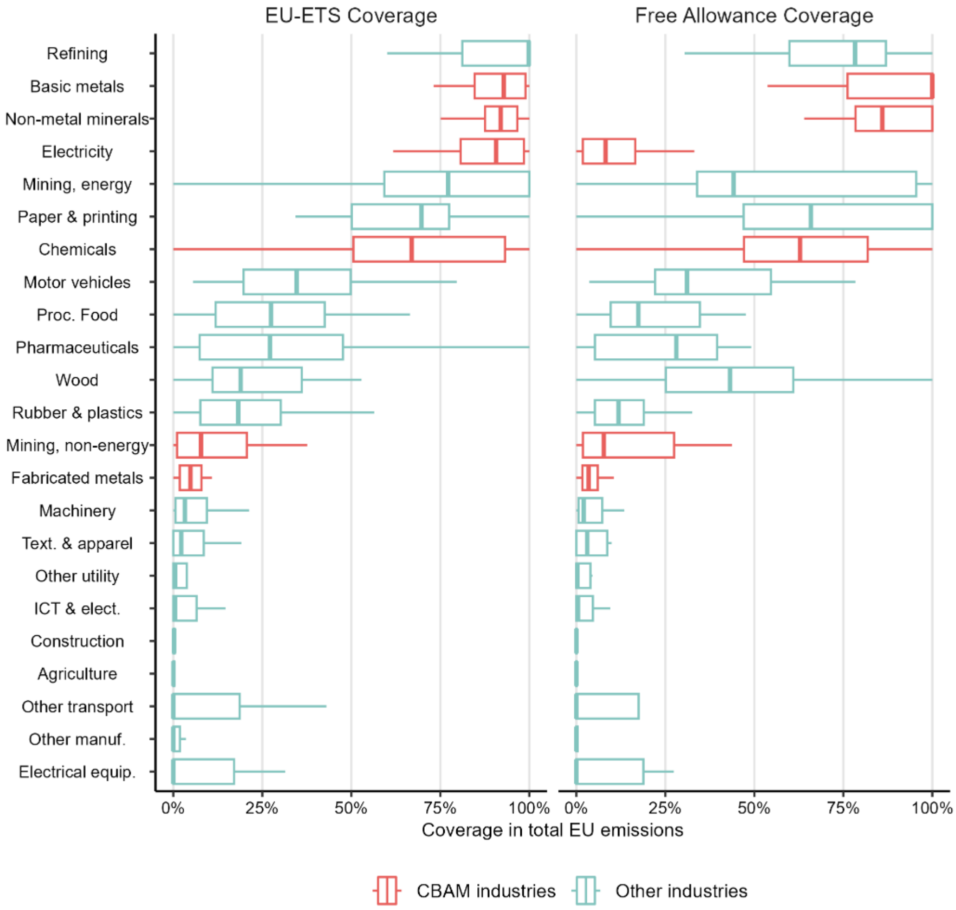
Consequently, the model assumes the European carbon price will grow by 220% ($\Delta price^{CO2}$) from the 2019 price of EUR 25 per CO_2 tonne as a consequence of the 'Fit for 55' package. The country-sector-level additional cost of ETS allowances is then defined as:

$$\Delta CostETS_{j,s} = Emissions_{j,s} * \left(share_{j,s}^{cov\ ETS} - share_{j,s}^{freeA}\right) * \Delta price^{CO2} \qquad \textbf{Equation 2}$$

Where $Emissions_{j,s}$ captures the total emissions within a country-sector, and $share_{s}^{cov\ ETS} - share_{s}^{freeA}$ is the difference between the emissions covered by the EU ETS and the ones that fall under free allowances.

Figure 3. CBAM-covered sectors combine a high EU ETS emission coverage and significant free allowances

Cross-country distribution of the share of emissions covered by EU ETS and free allowances by sector, 2019



Note: This figure plots the country distribution of EU ETS coverage and free allowance coverage by sector. The central box represents the interquartile range (IQR), spanning from the first quartile (Q1) to the third quartile (Q3). The whiskers extend from the box to demonstrate the range of typical data points within 1.5 times the IQR (Q1 - 1.5IQR to Q3 + 1.5IQR). Services sectors are dropped. Sectors in which at least one product is covered by the CBAM appear in red.
Source: EU ETS info, Greenhouse gas footprint indicators, OECD computation.

The coverage of free allowances among countries and sectors is then used as a basis to calculate the cost of removing free allowances. The reduction rate of free allowances is determined according to the specific scenario under consideration (see below). The cost associated with this reduction is equal to the increase in the European carbon price, allowing to compute the cost of removing the free allowances as follows:

$$Cost\ FreeA_{j,s} = Emissions_{j,s} * \left(share_{j,s}^{freeA,initial} - share_{j,s}^{freeA,final} \right) * price^{CO2}$$

Equation 3

Where $Emissions_{j,s}$ captures the total emissions within a country-sector, $share_{j,s}^{freeA,initial}$ represents the share of free allowances in 2019, and $share_{j,s}^{freeA,final}$ represents the share of free allowances in 2034 when all free allowances linked to CBAM goods are removed and the CBAM has been fully introduced.

Measuring the coverage of the CBAM

The second core component of the scenario analysis is the modelling of the CBAM. This section details the calculation of costs European importers would have incurred had the CBAM been implemented in full in 2022. These calculated costs should be thought of as exposure to the CBAM as they do not consider potential changes in sourcing origins or reductions in emission intensity that the CBAM might trigger. The estimated costs are central to the simulation exercise, as detailed in the following section.

The CBAM coverage ($\mathrm{Share}_{\mathrm{ijr}}^{\mathrm{CBAM}}$) in EU imports is computed based on trade flows values as observed in the Comtrade database where *j* refers to the importing (European) country, *i* to the exporting (non-European) country and *r* to the exporting sector. After mapping the CBAM products to ICIO sectors, the share is constructed as follows at the country-pair level for each exporting sector:

$$\mathrm{Share}_{\mathrm{ijr}}^{\mathrm{CBAM}} = \frac{Covered\ Import_{ijr}}{Total\ Import_{ijr}} \qquad \textbf{Equation 4}$$

Importantly, the adjustment cost paid by EU importers will be based on embedded emissions, rather than traded values. However, relying on sector-level embedded emissions comes with certain drawbacks, in particular as CBAM-covered goods might be particularly emission-intensive compared to other products within that sector. Therefore, estimations based on average sector-level emission data from the OECD Greenhouse gas Footprint Indicators are likely to underestimate the actual emissions embedded in the CBAM goods.

To address this, the emission intensity for CBAM-covered goods is corrected using the US Environmentally-Extended Input-Output (USEEIO) tables. The USEEIO table is available at the much more granular NAICS (North American Industry Classification System) level, which offers a higher disaggregation level than the ISIC Rev.4 industry classification. To adjust the emission intensity, CBAM-designated goods are mapped to NAICS sectors and emission intensity is calculated separately for CBAM-covered NAICS sectors and non-CBAM-covered NAICS sectors.

Figure 4 illustrates the emission intensities for both CBAM and non-CBAM NAICS sectors within each ISIC Rev. 4 2-digit industry, alongside the overall industry average. As expected, CBAM sectors exhibit higher emission intensities than non-CBAM sectors within each 2-digit industry. The ratio of the emission intensity of CBAM sectors to non-CBAM sectors γ_{r}, used as a correction factor, is substantial for Non-metal minerals (17.8) and relatively high for the Basic metal industry (4.7) and the Chemical industry (3.0). The correction is of lesser importance in the Mining non-energy (2.2) and Fabricated metals industry (1.4), while the entire Electricity industry is covered by the CBAM (the correction factor is 1).

The emission intensity for CBAM goods is computed by correcting the sectoral emission intensity by a correction factor as follows:

$$EI_{ir}^{CBAM} = \mathrm{EI}_{\mathrm{ir}} * \frac{\gamma_{\mathrm{r}}}{\mathrm{Share}_{\mathrm{ir}}^{\mathrm{CBAM}} * \gamma_{\mathrm{r}} + (1 - \mathrm{Share}_{\mathrm{ir}}^{\mathrm{CBAM}})} \qquad \textbf{Equation 5}$$

Where γ_{r} is the ratio of the emission intensity of CBAM products to non-CBAM products computed from the USEEIO data. The correction factor measures the ratio of the emission intensity of CBAM goods to the average emission intensity of the sector. Its derivation is detailed in Annex B under the assumption that the emission intensity ratio between CBAM and non-CBAM sectors within the same ISIC industry is the same across countries. Emission intensity is computed based on data from 2019.

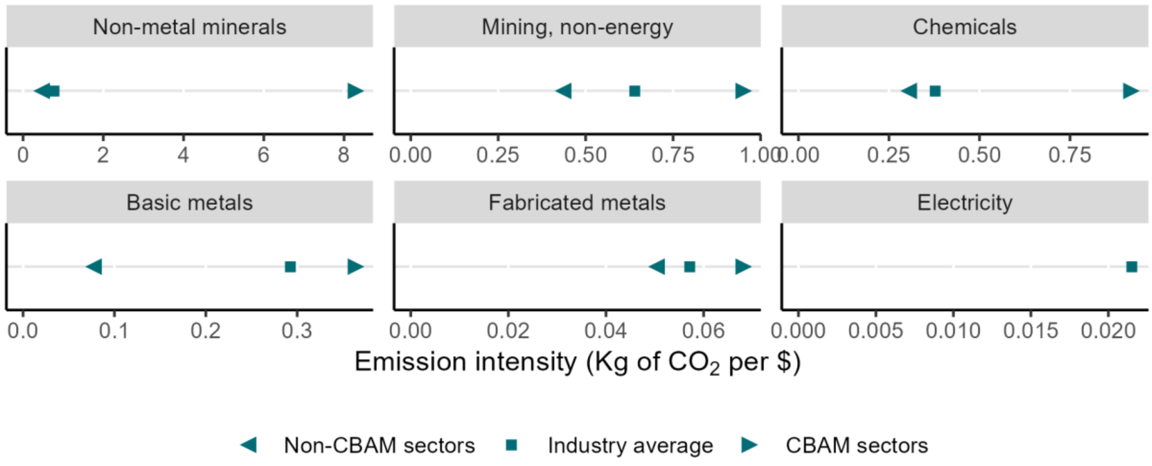
Finally, at the country-pair sector-pair level, the Scope 1 emissions covered by CBAM are computed as follows:

$$Covered\ emissions_{ijr}^{scope\ 1} = EI_{ir}^{CBAM} * Comtrade_{irj}^{\mathrm{CBAM}} \quad \text{Equation 6}$$

Where, EI_{ir}^{CBAM} is the emission per unit of gross output for CBAM goods in country *i* and sector *r*[27] and $Comtrade_{irj}^{\mathrm{CBAM}}$ is the value of the trade flow covered by CBAM from country *i* and sector *r* to country *j*[28].

Figure 4. Within ISIC sectors, CBAM goods have a higher emission intensity than non-CBAM goods, United States

CBAM NAICS sectors, non-CBAM NAICS sectors and ISIC 2-digit industry emission intensity, 2012



Note: The figure plots the emission intensity for CBAM-covered NAICS sectors vs other NAICS sectors within a respective ISIC industry for the US in 2012. The GHG gases include carbon dioxide, nitrous oxide and perfluorocarbons. Source: OECD computation based on USEEIO v2.0.

So far, the covered emissions only include Scope 1 emissions that are directly linked to the production process of the CBAM-covered goods. However, as specified in the current CBAM regulation (European Commission, 2023[18]), both Scope 2 and Scope 3 emissions are to be partially covered for certain goods[29]. In the current regulation, Scope 2 emissions are limited to emissions generated by the electricity production used in the production of CBAM-covered goods from the fertilisers and cement category. Estimating these emissions and their associated costs is a complex task, requiring comprehensive data on both the pricing and emission intensity of electricity producers in non-European countries. Similarly, measuring Scope 3 emissions is complex. The CBAM regulation defines a list of relevant precursors for each CBAM product to be considered (European Commission, 2023[33]). Based on this regulation, a methodology for quantifying Scope 2 and 3 emissions was designed and is detailed in Annex C. Figure A C.1 provides the estimates of the covered emissions associated with each scope by exporting sector.

The proposed computation for covered Scope 2 and 3 emissions increases the total emission covered by CBAM from 132 million tonnes of CO_2 equivalent to 171 million tonnes of CO_2 equivalent. In other words, 76% of embedded emissions covered by the CBAM regulation come from Scope 1 and 24% come from Scope 2 and 3 emissions. The emissions embedded in the imports of CBAM-covered fabricated metals, chemical products (i.e. fertilisers and hydrogen) and basic metals are the most impacted (Figure 5). Scope 2 emissions represent 19% of imported emissions within the Chemical sector and less than 5% in the Non-metal minerals and non-energy mining sectors. Scope 3 emissions have a large impact in Fabricated metals sector – a downstream sector that uses a lot of covered precursors – where they account for more than half of embedded emissions.

The CBAM cost for every importing and exporting country-sector pair can then be obtained directly by multiplying the imported emissions falling under the scope of the CBAM by the carbon price. Since a declarant is allowed to claim a reduction of the price corresponding to the carbon price already effectively paid in the country of origin for the declared embedded emissions, the model includes explicit carbon tax rates across non-EU ETS countries levied through carbon taxes and carbon markets.[30] Carbon pricing data relies on the 2018 Effective Carbon Rates from carbon taxes and tradeable carbon emission permits, excluding fuel excise taxes, from the OECD ECR database (see OECD (2021[75]) for methodological details). For missing countries, carbon price data is extended using the carbon price provided by the World Bank Carbon Pricing Dashboard.[31]

The model-implied CBAM levy per country-pair and sector-pair is:

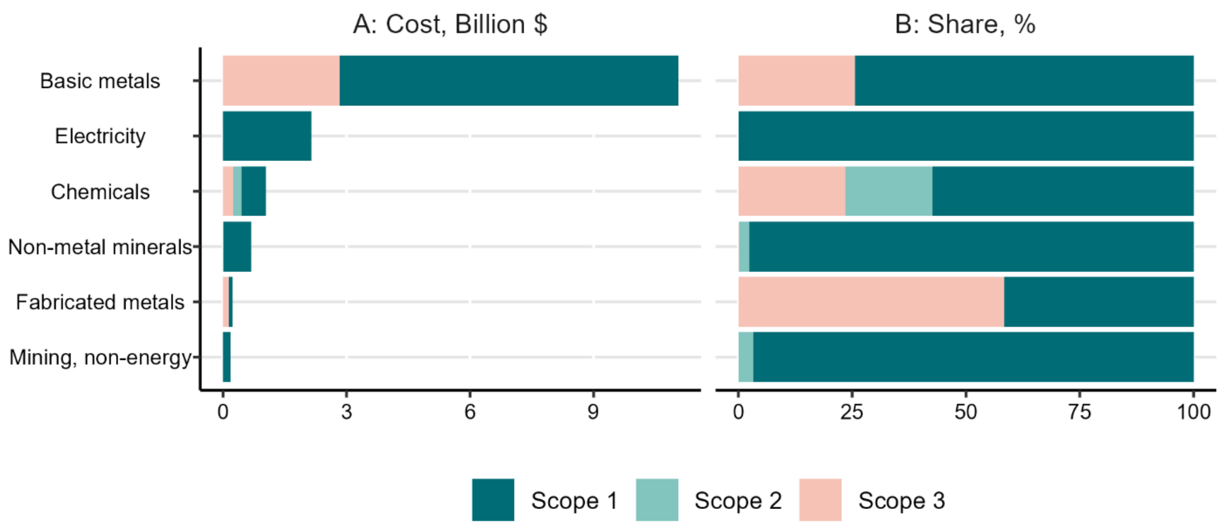
$$CBAM_{ijrs} = (p_{EU}^{CO2} - p_i^{CO2}) * Covered\ emissions_{ijrs}^{scope1} + \mathrm{Costs}_{ijr}^{\mathrm{Scope2}} + \mathrm{Costs}_{ijr}^{\mathrm{Scope3}} \quad \text{Equation 7}$$

Where p_{EU}^{CO2} is the EU ETS carbon price, p_i^{CO2} is the exporting country's effective carbon price excluding fuel excise taxes. Both $\mathrm{Costs}_{ijrs}^{\mathrm{Scope2}}$ and $\mathrm{Costs}_{ijrs}^{\mathrm{Scope3}}$ measure Scope 2 and 3 emissions and are formally defined in Annex C.

Firms importing CBAM-covered intermediary goods will be responsible for handing in the CBAM certificates. This might induce an adaptation of their sourcing strategies while passing on some of the cost to their suppliers. Due to CBAM's focus on certain product categories, the impact of the CBAM on trade flows will not be uniform across exporting sectors and exporting countries. Figure 5 shows the total modelled costs by exporting sector, while Figure 6 highlights the differences in exposure among exporting countries.

Figure 5. The CBAM would primarily be levied on Scope 1 emissions from the Basic metals sector

Simulated CBAM levy at EUR 80 per CO_2 tonne by exporting sector and emission Scope, in absolute terms (USD Billion) and share of total levy, 2022



Note: The plot represents the simulated costs of the CBAM by supplying industry and Scope based on 2022 trade flows and 2019 emission intensity per dollar. Trade flows are corrected for inflation between 2019 and 2022.
Source: Comtrade, ICIO, OECD computations.

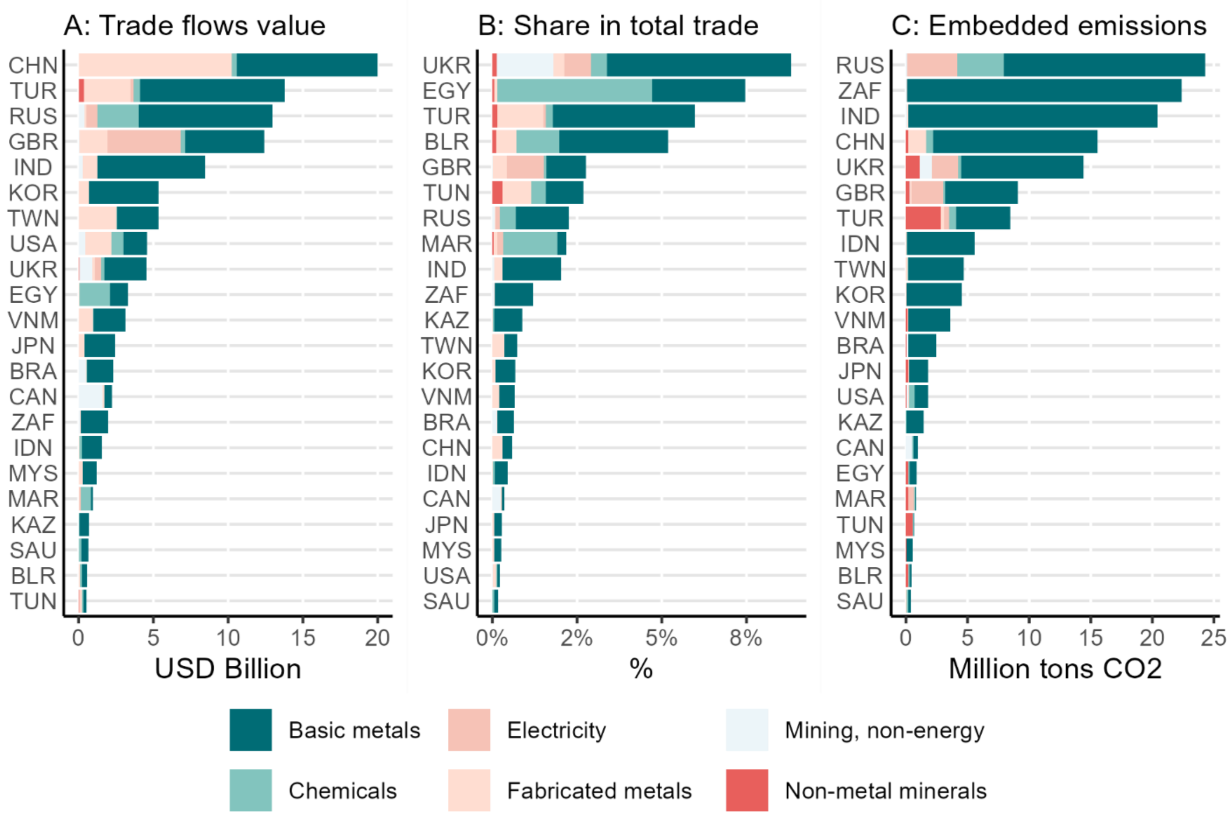
If CBAM was applied on 2022 trade flows and assuming a carbon price of EUR 80 per tonne of CO_2, the CBAM would generate EUR 14.7 billion (USD 15.3 billion) in revenue yearly. Most CBAM certificates would be levied on importers sourcing from the basic metals industry (11.0 billion USD), followed by electricity (USD 2.2 billion).

Figure 6 sheds light on the heterogeneity of the coverage of the CBAM, drawing on 2022 trade data[32]. Panels A and B respectively display the absolute and relative values of trade flows covered by CBAM by country of origin and sector while Panel C represents the corresponding Scope 1 embedded emissions.

Panel A reveals that, in absolute term, the CBAM will mostly affect goods originating from China, Türkiye, and Russia. If the CBAM had been in effect in 2022, the policy would have covered trade flows amounting to USD 20.0 billion from China, USD 13.8 billion from Türkiye, and USD 12.9 billion from Russia. Overall, the CBAM covers 0.37% of the value of global trade in goods and services and 3% of such trade from non-EU countries to the EU.

Figure 6. Metal exports to the EU are driving CBAM-covered trade and emissions

Trade and emission flows covered by the CBAM by exporting country and producing sector, 2022



Note: This plot represents the trade covered by CBAM (panel A), the covered trade in total trade of the exporting country (panel B) and the associated Scope 1 embedded emissions (Panel C) had the CBAM been in place in 2022. Each bar corresponds to the coverage by exporting countries and is split by exporting sector. The trade measures are based on Comtrade product-level data for 2022. The embedded emissions are computed based on equation 6 where the coverage is computed on 2022 data and the emission intensity is based on the 2019 ICIO data. This figure is not equivalent to the cost of the CBAM as this also depends on existing carbon pricing mechanisms in third countries.
Source: Comtrade, OECD computations.

Panel B presents the relative CBAM coverage by country of origin for the same set of countries represented in panel A, normalising covered trade flows by the country's total exports. Not surprisingly, countries with export-intensive heavy industries and substantial trade relationships with the EU have a higher share of their trade value covered by CBAM. This includes nations such as Ukraine, Belarus, and Russia, as well as certain African countries such as Egypt, Tunisia, and Morocco.

However, the CBAM will not be determined by the value of trade covered but rather by the embedded emissions linked to the production of the traded products. Panel C displays the emissions linked to the CBAM-covered trade that will determine the levy EU firms will pay to import goods covered by the CBAM. Basic metal products, already prominent in terms of trade coverage, represent an even larger share of the emissions due to the sector's high emission intensity. Additionally, there is substantial variation in the emission intensity of the same sector across different countries. Therefore, a comparison between Panel A and C reveals that a dollar spent on basic metals imports results in differing amounts of embedded emissions, varying significantly between countries like Ukraine and China, for example. Altogether, emissions embedded in imported products covered by the CBAM represent 0.31% of global emissions.

The figures for Belarus, Russia and Ukraine should be interpreted with caution, as they only partially account for the re-organisation of trade in the aftermath of Russia's war of aggression against Ukraine in February 2022. In response to this event, EU countries imposed several waves of sanctions that gradually reduced trade. As a result, imports from Russia were divided by four between the first quarter of 2022 and the second quarter of 2023 and have remained at this level since then (Eurostat, 2023[76]). Ukraine stands out with particularly high exposure to the CBAM. This exposure can be attributed to Ukraine's historical position as the world's most export-oriented steel producer. However, it is important to note that due to the war, Ukrainian steel production experienced a sharp decline of 60% in 2022 due to the damage to the Mariupol steel facility and logistical challenges, such as the blockage of Ukrainian seaports (OECD, 2022[77]). This decline may only be partially reflected in the 2022 trade data. It remains uncertain whether the EU will temporarily adjust the CBAM to account for Ukraine’s unique circumstances.

Box 1. Key assumptions and limitations of the data inputs

In the data, **carbon prices in non-EU countries do not vary across sectors**. While data is gathered to capture cross-country heterogeneity in the carbon price paid within a country, these do not take into account sectoral heterogeneity.

The structure of Comtrade data used to compute the share of CBAM-covered trade flows, $\mathrm{Share}_{\mathrm{ijr}}^{\mathrm{CBAM}}$, provides information on the sourcing country of a particular good – but not on the sourcing sector. Hence, all downstream sectors (s) are assumed to use the **same proportion of CBAM product per dollar of intermediary input from sector *r***. For all destination sectors s, $Share_{ijr}^{CBAM} = Share_{ijrs}^{CBAM}$.

The same shortcoming also limits the capacity to take into account Scope 2 and 3 emissions accurately. Similarly, to compute the share of CBAM-covered trade flows, CBAM sectors (s) are assumed to use the **same proportion of precursors per dollar**, without information on the exact quantity of inputs used in the production.

An analysis of the Prodcom[33] database, with its detailed sectoral breakdown, enables precise measurement of European CBAM-covered goods production, amounting to USD 70 billion in 2019—7% of manufactured goods sales and 2.3% of EU gross output. By matching the Prodcom-sector to their corresponding sectors in the ICIO database, it is possible to approximate the value added and employment generated by their production in the EU[34]. Using this method, the production of CBAM-covered goods is found to contribute 1.1% to EU value added and 0.6% to EU employment in 2019. However, as Prodcom data lacks input-output linkages for its detailed sectors, the policy impact assessment is conducted at the broader ICIO sector-level.

Modelling

This section presents the model used to assess the effects of the CBAM along the supply chain. The model simulates the immediate economic impacts of the policies, operating under a static framework that assumes full implementation of the policies. This approach is designed to capture the initial, first-order effects of the policies in the short run, while also exploring the heterogeneous impacts and interdependencies across different sectors and countries.

The Leontief price model with substitution

With CBAM, European firms will face a direct increase in their imported input costs. As a result, they may resort to domestic inputs that have become relatively cheaper. In turn, if they can at least partially pass-through this cost increase onto their customers, the costs of these downstream industries will increase, even if they are not targeted by CBAM. The objective of this section is to propose a simple model that allows assessing the direct and indirect effects of the CBAM, based on a description of how costs propagate through the production network. This model leverages input-output analysis tools while allowing for input substitution and quantity changes. It builds on a similar albeit simpler model by Hebbink et al. (2018[16]), which simulates the impact of a carbon levy.

The first step of the model is to simulate the propagation of costs using a Leontief price model, also known as a cost-push model (Leontief, 1936[15]). This approach simulates a change in prices, maintaining the quantity of input used and output produced constant. In this framework, the increase in costs stemming from carbon pricing (domestic or at the border) is conceptualised as an increase in the cost of value added. More precisely, the cost per unit of output induced by the CBAM is computed for each industry. Sectors directly affected by the policy raise their prices to pass on these extra costs to their customers. Sectors that use these more expensive products as inputs also have to raise their prices to cover the higher costs, passing them on to their own customers. The Leontief price model offers an analytical solution quantifying the necessary price adjustments Δp_{js} across all sectors s and country j to counterbalance both the direct cost increases attributable to the carbon price and the indirect cost increases arising from the cost transmission through the production network.

Importantly this simulation requires to make a hypothesis on the ability of firms to pass an increase in cost on their customers. In the main analysis the pass-through parameter is equal to 100%, meaning firms can fully adapt their price to compensate for an increase in their costs. For a discussion on this hypothesis please refer to Box 3.

Several modelling steps are introduced to address the limitations of the standard Leontief price model approach. First, the standard model does not allow for input substitution. However, as the policy disproportionately increases the price of emission-intensive inputs, firms are likely to adjust their production processes by reducing the emission intensity of their production and making use of inputs whose relative prices have declined.

Second, even in the short-term, efficiency gains will impact the final costs induced by an increase in the price of emissions in the EU ETS. Firms might improve the carbon efficiency of their production process, thereby reducing their emissions and the financial burden of the policy. Similarly, non-EU firms could decrease their emission intensity to soften the competitive losses in the EU market caused by the CBAM, which will result in a lower levy collected. The model takes this into account by modifying the emission intensity of an industry and the policy cost in proportion to the additional cost per tonne of CO_2 the policy induces[35]. This step is based on Dussaux (2020[78]) who finds that an increase of the carbon tax in France from EUR 45 to EUR 86 per tonne would induce a reduction in carbon emissions by 8.7% in the manufacturing sector, which implies a semi-elasticity of about -0.002 (i.e. a EUR 10 increase in the carbon tax is associated with a decline in CO_2 emissions of 2%). In the long run, firms should be able to further adapt through investments in low-carbon technologies and technological progress[36] but those changes are beyond the scope of this simulation that aims at measuring the short-term impact of the policies.

Third, in the model, input substitution is allowed between energy inputs[37] on the one hand and capital and labour on the other hand. As prices of capital and labour are fixed in the I-O framework, firms see their total input bundle cost decrease when taking into account their substitution ability, resulting in lower price increases $\Delta p_{js}'$ than initially modelled with the standard price model ($\Delta p_{js}' < \Delta p_{js}$). Substitution between non-energy intermediary inputs is not modelled at this stage.

Change in trade flows and final demand

In the next step, elasticities of substitution are introduced to allow firms and consumers to adjust to the changes in relative prices. The Leontief model focuses solely on price changes and does not take into account quantity adjustments. This is a well-known limit of the Leontief I-O analysis framework, which alternatively allows modelling quantity changes under fixed prices. In reality, firms and consumers adjust the quantities of goods they consume following a price increase. To reflect this, domestic final demand and imported quantity are adjusted according to the price elasticity as follows:

$$fd_{jr}^{dom'} = fd_{jr}^{dom} \times \left(1 + \Delta p_{jr}' \times E_{fd,r}\right)$$

Equation 8

$$Imp_{ijr}^{fin'} = Imp_{ijr}^{fin} \times \left(1 + \Delta diffprice_{ijr}^{fin} \times E_{Imp,r}\right)$$

Equation 9

$$Imp^{int'}{}_{ijr} = Imp_{ijr}^{int} \times \left(1 + \Delta diffprice_{ijr}^{int} \times E_{Imp,r}\right)$$

Equation 10

Where $fd_{jr}^{dom\prime}$ is the simulated domestic final demand in country *j* and sector *r*, $E_{fd,r}$ is the price elasticity of final demand in sector *r*, $Imp^{int\prime}{}_{ijr}$ & $Imp^{int\prime}{}_{ijr}$ is the altered import quantity of intermediate and final good from country *i* and sector *r* to country *j*, $\Delta diffprice_{ijr}$ measure the change in the difference of price between *i* and all other foreign suppliers of country *j* for goods of sector *r* and $E_{Imp,r}$ is the trade elasticity in sector *r*.

Elasticities, including trade elasticity, final demand elasticity, and the elasticity of substitution between energy and capital/labour, are derived from van der Werf (2008[79]) and Hebbink et al. (2018[16]). Figure A A.1 presents a detailed description of these elasticities.

Taking into account price elasticities is a critical step as this allows to model the impact of changes in production costs on traded quantities. Price indices allow taking into account that the quantity traded is affected not only by the change in price of the good but also by the change in price of alternative foreign suppliers of the same good. The CBAM-induced cost levied on European importers is included in $\Delta diffprice_{ijr}$ to capture the relative change in prices due to domestic climate policies (Box 2).

Box 2. Price indices for final and intermediate good import

A crucial step in the modelling exercise is to simulate how traded quantities change after the introduction of the CBAM and the simultaneous removal of free allowances. The model takes into account price changes induced by the simulated policies. The difference in prices between exporter *i* to country *j* and the relevant alternative suppliers of *j*, $\Delta diffprice^{int}_{ijr}$, is defined as:

$$\Delta diffprice^{int}_{ijr} = \left(\Delta p_{ir} + C^{CBAM}_{ijr}\right) - \Delta {p^{int}}'_{jr} \qquad \text{Equation 11}$$

Where Δp_{ir} is the change in intermediate good price in the exporting country *i* for sector *r,* and C^{CBAM}_{irs} is the CBAM cost paid by European importers, that is different from zero only for CBAM-covered goods imported from non-European countries to the EU. $\Delta {p^{int}}'_{jr}$ is a price index measuring the average change in price for all foreign suppliers of country *j*, and is defined as:

$$\Delta {p^{int}}'_{jr} = \sum_{k \neq j}^{K} \boldsymbol{w^{int}_{jkr}} \left(\left(\Delta p_{kr} + C^{\mathrm{CBAM}}_{irr}\right)\right) \qquad \text{Equation 12}$$

Where $\boldsymbol{w^{int}_{jks}}$ is the share of intermediate goods of sector *r* sourced in country *k* by country *j*.

The computation of $\Delta diffprice^{fin}_{iir}$ mirrors the computation of $\Delta diffprice^{int}_{iir}$ to the important difference that final goods are not covered by the CBAM ($C^{\mathrm{CBAM}}_{irs} = 0$).

Measuring Change in Production, Value added and emissions

The model's next step entails simulating the necessary changes in sectoral production to meet the previously simulated trade quantities and domestic demand for final goods. This is executed using an I-O Quantity model, which estimates the required amount of intermediate input to produce a given quantity of final goods, while maintaining prices and technology constant.[38] Once total production is established, value added and emissions are computed using the value added and emissions intensities of production, with adjustments to emissions intensity in the short term as mentioned above.

Lastly, the final stage involves redistributing the revenue generated from the EU ETS price increase, the removal of free allowances, and the CBAM. This revenue recycling assumes that the collected funds are redistributed at the country-level to sectors according to their contribution to the national value added. At this stage, it is not clear how the generated revenue will be spent (for example, it could be used to support firms' decarbonisation objectives). In the simulations, CBAM only constitutes a small share of the total revenue generated by the policy simulated (8%). The rest of the revenue is generated by the reduction in free allowances (49%), and the EU ETS price increase (43%), assuming a carbon price of EUR 80 per CO_2 tonne.

The potential risk of resource reshuffling: a modelling and policy implementation challenge

A BCA based on the actual carbon intensity of goods rather than on default values comes not only at the expense of increased administrative complexity and cost, but also creates the possibility of avoidance strategies such as resource shuffling.

Within-country resource shuffling – also known as `backfilling' (Fowlie, Petersen and Reguant, 2021[80]) – captures the idea that nations may domestically consume carbon-intensive products (or export them to other nations) while exporting cleaner alternatives to the CBAM market (Mehling and Ritz, 2023[81]). This aspect is not covered in the model, which does not allow for within-country-sector heterogeneity in emissions intensity across plants. Including such shuffling would require collecting additional data or making assumptions on the distribution of firms' emission intensity of production within each country. The results of this paper can be interpreted as corresponding to a hypothetical version of the CBAM in which embedded emissions would be based on country of origin default values and not on actual plant level carbon intensity of the goods.

Between-country resource shuffling implies that importers choose the country of origin of a specific input based on its emission intensity. The model incorporates this, with the limitation that it uses country-sector average emission intensity.

Downstream reshuffling is prompted by the CBAM's limited coverage of products, which is especially evident in the metals industry where the CBAM primarily affects upstream segments of extensive and intricate value chains. European importers and their trade partners might opt to trade transformed goods not covered by the CBAM, such as substituting raw steel imports with manufactured vehicle bodywork. This could, in turn, potentially affect the competitiveness of European producers of these transformed goods that will face higher input costs compared to their non-EU competitors. This aspect of the response to CBAM is well captured by the model.

Box 3. Key assumptions and limitations of the simulation

Certain parameters used in the simulation are difficult to determine, while certain underlying mechanisms remain unaccounted for in the model. To understand the impact of changes in some of these parameters on the results, sensitivity checks in Section 0 help ascertain whether the key findings are robust to changes in these parameters. This Box provides a discussion of the key assumptions and underlying limitations of the simulation.

Costs pass-through. An underlying assumption of the simulation is that carbon costs are fully passed on product prices in EU industry. Economic theory predicts that as emission allowances feed in as inputs to the production function, firms factor their cost into product prices (Coase, 1960[21]; Tietenberg, 1985[82]). In general, cost pass-through depends on the market structure, and the shape of both supply and demand curves (Demailly, 2006.[83]; Sijm, Chen and Hobbs, 2012[84]). Existing empirical literature has confirmed that pass-through rates of ETS costs vary by sector (see Cludius et al. (2020[85]) and De Bruyn et al. (2021[86]) for a review of the existing literature[39]). The literature has found that within the Electricity sector pass-through rates amount to 95-100% (European Commission Directorate General for Environment, McKinsey, and Ecofys, 2006[87]; Woo et al., 2017[88]), while the pass-through is typically lower in other sectors. The cost pass-through varies from 60-100% in the Iron and steel sector, to 20-100% for the cement sector (European Commission Directorate General for Environment, McKinsey, and Ecofys, 2006[87]; Ecofys and Vivid Economics, 2014[89]; De Bruyn et al., 2010[90]; Smale et al., 2006[91]), 0-100% for the glass sector (Ecofys and Vivid Economics, 2014[89]; Alexeeva-Talebi, 2010[92]; De Bruyn et al., 2010[90]; De Bruyn, Koopman and Vergeer, 2015[93]), 15-75% for the fertilisers sector (Ecofys and Vivid Economics, 2014[89]; Alexeeva-Talebi, 2010[92]), and 25-80% for the petrochemicals sector[40] (De Bruyn et al., 2010[90]; Alexeeva-Talebi, 2010[92]). Further, these papers also show that distinguishing between ETS cost and free allowances lead to asymmetrical reactions. For example, McKinsey and Ecofys (2006[87]) find that free allowances offset cost pass-through within power industry but less so in steel and pulp and paper industry. When interpreting the results, one should therefore keep in mind that the underlying model assumes a 100% cost pass-through in all sectors. Although this assumption may realistically reflect long-term dynamics, cost pass-through rates could be lower, particularly over short periods of time or for certain products. Focusing on Belgian firms, Bijnens and Duprez (2022[94]) estimate that, on average, businesses are able to pass on 60% of cost increases to their customers in the short-term. A sensitivity analysis based on this estimate is presented in Section 0.

Substitution between inputs. Another key assumption behind the I-O tools is that there is no substitution between intermediary inputs from different sectors and supplier pairs. This hypothesis is partially relaxed in this paper's framework as it models the substitution of intermediary input between suppliers within a given sector as well as the substitution between energy input and non-energy inputs (i.e. capital and labour). However, the ability to substitute intermediary input across sectors is not modelled in the paper. Taking this into account would require adding further structure to the model and making additional assumptions. Additionally, such substitution should be limited in the short-term as it requires changes in the production function.

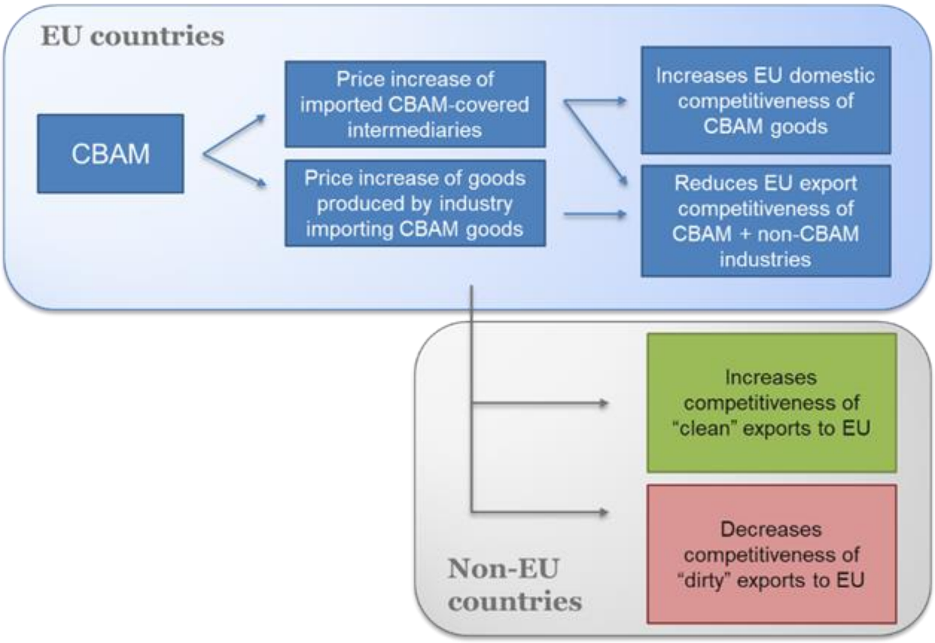
Trade elasticities. Trade elasticities are defined at the sector-level, with a mean value of -1.67 in our dataset. This parameter's precise value is subject of extensive debate and has spawned a significant body of literature. Numerous studies have utilised tariff variations to tackle the endogeneity issue that has historically hampered accurate parameter estimation. For instance Fontagné et al. (2022[95]), identified a product-level elasticity centred around -5 with a large variance across products, while Imbs and Mejean (2016[96]) estimated a sector-level value of -5.95, while highlighting substantial variations in the estimates across nations. Different studies argue that using tariff changes to identify trade elasticities does not entirely address endogeneity concerns (Boehm, Levchenko and Pandalai-Nayar, 2023[97]; Buono and Lalanne, 2012[98]). This is because the decision to impose tariffs could be influenced by pre-existing trade flow trends. Boehm, Levchenko and Pandalai-Nayar (2023[97]) introduce an innovative approach rooted in the observation that when countries modify their most favoured nation (MFN) tariffs, trading partners operating under MFN terms are subjected to arguably exogenous tariff alterations. Furthermore, this study provides elasticity estimates over various time frames, revealing that short-term product-level elasticity hovers around 0.79, while long-term estimates approach 2. These elasticities align closely with the elasticity used in this papers model and can be considered as conservative.

Capacity constraints. In real-world scenarios, industries may not always have the capacity to meet increased demand immediately, as this could involve expanding facilities, hiring more labour, or adopting new technologies. This dimension is not modelled in standard I-O models like the one used in this paper. This assumption is likely valid over the long run as production adapts to changing market conditions but is less founded over the short run.

Carbon price. The main analysis assumes a carbon price within the EU ETS of EUR 80 per tonne of CO_2. While this corresponds to levels observed in 2023 at the peak of the energy crisis, estimations of the evolution of the EU ETS carbon price vary significantly. Pietzcker, Osorio and Rodrigues (2021[99]) estimate carbon prices of EUR 129 per CO_2 tonne by 2030. The European Commission (2020[100]; 2021[36]) estimates a carbon price ranging from EUR 33 to 48 per CO_2 tonne by 2030. In Section 0 a sensitivity analysis is conducted, setting the carbon price at 150 euros.

Mechanism

Figure 7. How does the CBAM affect production and trade?



Source: Authors elaboration.

The primary impact of CBAM is to raise the prices of covered goods imported into the EU to reflect the embedded emissions of these goods, accounting for the level of carbon pricing in the producing country. The levy will be paid by European importers and not by non-European firms, resulting in a price increase of CBAM-covered goods for European importers[41]. This levels the playing field between EU- and non-EU-produced CBAM goods in the EU market. As outlined in the current legislation, the CBAM will not influence the terms of trade of CBAM goods beyond the Common Market[42].

The impact of CBAM will not be limited to its level-playing field effect within the EU market. EU firms that utilise CBAM-covered goods as intermediary input in their production will see their cost of operating increase, particularly if they rely on imported CBAM goods from non-EU partners[43]. As these costs are passed on to their customers, this will translate into a potential loss in competitiveness both in the EU market and in their export market, not only for importers of CBAM goods (a direct importer effect) but also for their customers (an indirect value chain effect). Moreover, the impact on non-European firms will vary. Products originating from countries with high emission intensities and no carbon pricing in place will see a more significant price increase and a greater loss in competitiveness compared to those originating from countries with lower emission intensities and higher carbon prices. This disparity could shift the EU's sourcing preferences towards countries with lower emission intensities, altering the relative competitiveness position of non-EU countries.

The CBAM will be implemented alongside other EU policies that will also directly affect European firms' production costs and indirectly impact the cost along the value chain. To accurately simulate the overall impact of this policy mix on value added, emissions, and carbon leakage, it is essential to examine the interactions between different policies, as proposed in the next section.

Designing policy scenarios

The analysis of the effect of the CBAM on carbon leakage and competitiveness is based on the comparison of a baseline to four scenarios, summarised in Table 3. The scenarios are employed only as benchmark references, serving as hypothetical constructs for the purpose of the analysis. The only scenario based on the EU's real policy decision is the "Full Policy Mix" scenario.

Table 3. Baseline and Policy Scenarios

		EU ETS price	CBAM	Removal of free allowances
Baseline		EUR 25	No	No (2019 free allowance endowment)
Policy Scenarios	Scenario 1	EUR 80	No	Only non-EITE sectors
	Scenario 2	EUR 80	No	Non-EITE sectors and CBAM sectors
	Full Policy Mix	EUR 80	Yes	Non-EITE sectors and CBAM sectors

Note: CBAM coverage is based on the latest EU regulation from the 10th of May 2023 (European Commission, 2023[18]). EITE sectors are defined based on the list provided by the European Commission (2019[101]).

The baseline scenario is based on the economic conditions of 2019, when EU carbon permits were priced at around 25 euros. The three policy scenarios simulate the short-term impacts of fully implementing the various policies on the 2019 global economy. This approach simplifies the reality, as both the removal of free allowances and the CBAM will be phased in gradually and are expected to become fully effective only by 2034.

Policy Scenario 1 follows the revised EU ETS regulation included in the "Fit for 55 package". In this package, emission allowances within the EU ETS are reduced by an annual rate of 4.3 % per year from 2024 to 2027 and 4.4% per year from 2028 to 2030 (Directive 2003/87/EC)[44], resulting in an increase in the price of emission allowances. This price increase is estimated to reach EUR 80 per CO_2 tonne. Importantly, the impact of the creation of the ETS2, a new emissions trading system covering the fuel use of buildings, road transport and construction is not modelled[45]. Further, in this scenario, free allowances are phased out for non-EITE sectors: according to the Directive, they will decrease after 2026 from a maximum of 30% to 0 at the end of phase 4 (2030). For EITE[46] sectors that include all CBAM industries, the system of free allowances is prolonged for another decade. These sectors receive 100% of their allocations up to a defined benchmark[47] for free to address the risk of carbon leakage.

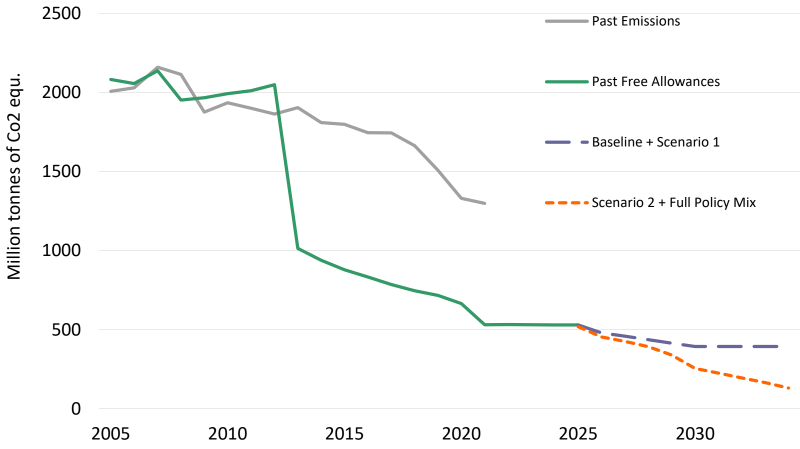
Policy Scenario 2 focuses on the case of an EU ETS price increase and the gradual removal of free allowances for both non-EITE and CBAM sectors (but not EITE non-CBAM sectors, which keep receiving free allowances). The trajectory of free allowances by type of sector is presented in Figure 8, panel A.

Lastly, the Full Policy Mix models the EU ETS price increase, the removal of free allowances for non-EITE and CBAM sectors, and the introduction of CBAM. This scenario is the closest to the one outlined in the EU regulation.

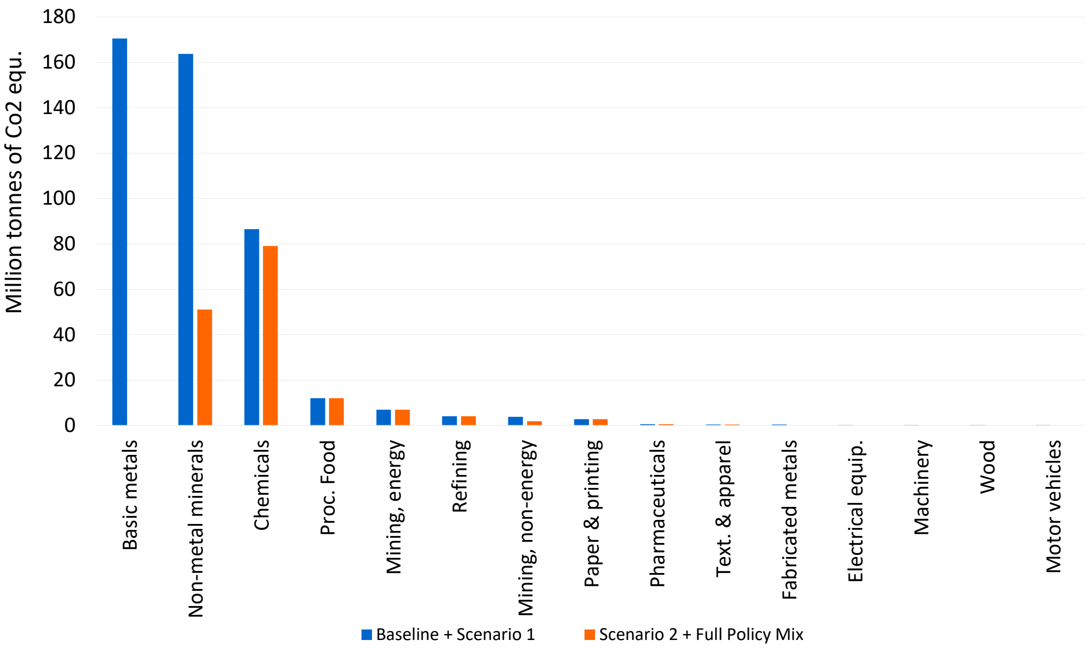
Figure 8 outlines past emissions and free allowances in the EU ETS. It presents the projected free emission allowances trajectory from 2025 onwards for (1) the Scenarios 1 and 3, which involve a removal of free allowances of non-EITE sectors only, and (2) for Scenario 2 and the Full Policy Mix Scenario, where free allowances are removed for both non-EITE sectors and CBAM sectors. In the simulation, free allowances for non-EITE sectors and CBAM sectors are set to their predicted 2034 level, when the CBAM will be fully in place (see Panels A and B below). For sectors like the Basic metal sector, this amounts to a full removal, while for other sectors that still produce non-CBAM-covered EITE goods, the reduction is only partial.

Figure 8. Projection of free emission allowances under the EU ETS by scenario

Panel A: Past emissions and free allowances with projected free allowances



Panel B: Total projected free allowances in 2034 for Baseline & Scenario 1 and Scenario 2 & Full Policy Mix Scenario



Note: In Panel (A) the figure plots past emissions and free allowances, as well as the projection of free allowances from 2025 to 2034. The projections refer to the baseline scenario and Scenario 1 with a removal of free allowances of non-EITE sectors only, and to Scenario 2 and Full Policy Mix Scenario based on a removal of free allowances for both non-EITE sectors and CBAM sectors. Panel (B) shows the total amount of free allowances in 2034 by industry for each of the policy scenarios. In this figure, Agriculture, Mining services, Rubber and plastics, ICT, Other transport, Other manufacturing, and Electricity are dropped as these sectors receive no free allowances.
Source: Past trend is based on data from EU ETS info. Projection is own computation based on European Commission (2021[73]). The factor of free allowances for CBAM sectors is retrieved from the EU CBAM regulation (European Commission, 2023[18]).

5 Results

This section presents the results from the scenario-based simulation of the CBAM introduction and the removal of free allowances. To provide a complete picture, the section first considers the aggregate impact across countries and sectors, comparing the different scenarios to the baseline. It is followed by a country and sector-level analysis focusing on the Full Policy Mix Scenario implementing both the CBAM and the removal of free allowances as specified in the current EU regulation (European Commission, 2023[18]). The section is concluded with a simulation of a possible extension of the CBAM to additional products and with different sensitivity checks.

Impact on carbon leakage and overall value added

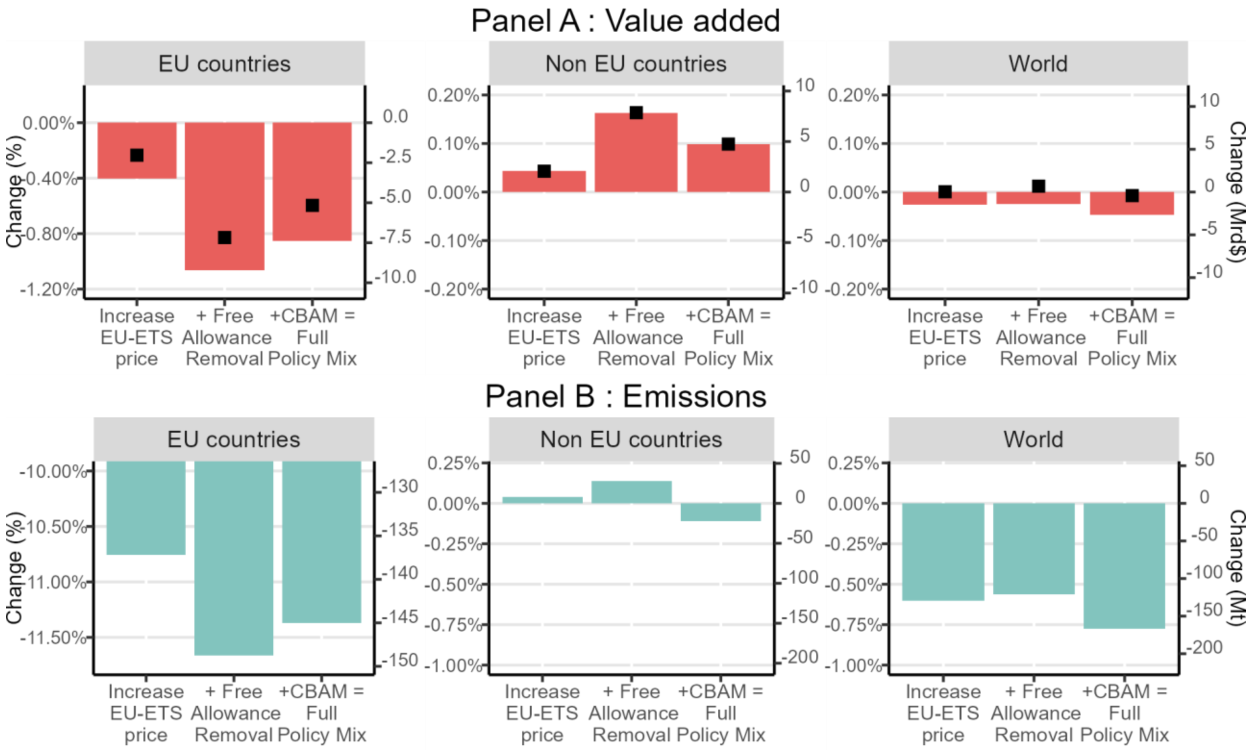
Figure 9 focuses on the macro effect of implementing the various policy scenarios across CBAM-covered industries in the EU (left graphs), in non-EU countries (centre graphs) and globally (right graphs) in the year of implementation of the policies. The top panel presents the impacts on value added. The increase of the price of emission allowances in the EU ETS (Scenario 1) leads to a reduction of EU value added of 0.40% (0.23% with revenue recycling) compared to the baseline scenario. The loss in value added in the EU more than doubles when additionally removing free allowances (1.06%, 0.76% with revenue recycling), as some production is shifted to non-EU countries (+0.16%). However, the introduction of the CBAM partially mitigates the adverse impact of removing free allowances: value added only decreases by 0.85% in EU countries. This reveals CBAM's partial effectiveness in offsetting the reduction in value added and the potential loss of competitiveness resulting from the removal of free allowances. The second part of this section provides explanations for this partial effectiveness with a sectoral analysis. Revenue recycling can further mitigate the value added decline within EU countries (0.52% with revenue recycling).

At the global level, both the removal of free allowances and the introduction of CBAM lead to an economically insignificant reduction in value added (respectively -0.024% and -0.048%). This is because the EU represents only 17.6% of global value added and because losses in value added in the EU are partly compensated by increases in value added outside the EU.

Looking at carbon emissions in EU countries, the increase of the price in the EU ETS alone results in a reduction of 10.8% (137 Mt) in CBAM industries. This is mostly due to the gain in efficiency across European manufacturers and to a lower extent to the reduction of production in the Common Market. At the same time, non-EU countries witness an increase in emissions of 0.004% (8 Mt), demonstrating the emergence of a modest carbon leakage (Table 4). The carbon leakage rate, a measure presented in Table , is equal to 5.7%. When removing free allowances, emissions in the EU decrease further (-145Mt) but also increase further outside the EU (+28 Mt), effectively amplifying carbon leakage (carbon leakage rate 18.80%). Both measures of leakage fall in the range of estimates (5% to 25%) of the *ex-ante* modelling literature summarised in Section 3. Without the CBAM, European firms import more of their emissions-intensive intermediary products from countries with higher emissions intensities. This shift can result in increased "dirty" production and, consequently, higher carbon emissions in those countries.

Figure 9. Macro-level effect across CBAM industries

Aggregate effect on value added and emissions in three policy scenarios. Black squares include the recycling of revenues levied.



Note: This plot represents the simulated value added and emission in Scenario 1 (increase in EU-ETS price and removal free allowance for non-EITE sectors), Scenario 2 (Scenario 1 + removal free allowances for EITE-CBAM sectors) and the Full Policy Mix Scenario (Scenario 2 + introducing CBAM) compared to the baseline for the six industries covered by the CBAM. All scenarios but the baseline include the removal of free allowance in non-EITE sectors. The bars and the squares represent the simulated results, respectively, before and after the last step of the simulation, in which the revenue levied in the different scenarios is allocated to European industries following their weight in final demand.
Source: OECD computations.

Table 4. Carbon leakage – CBAM industries

Change in emissions compared to the baseline scenario by region

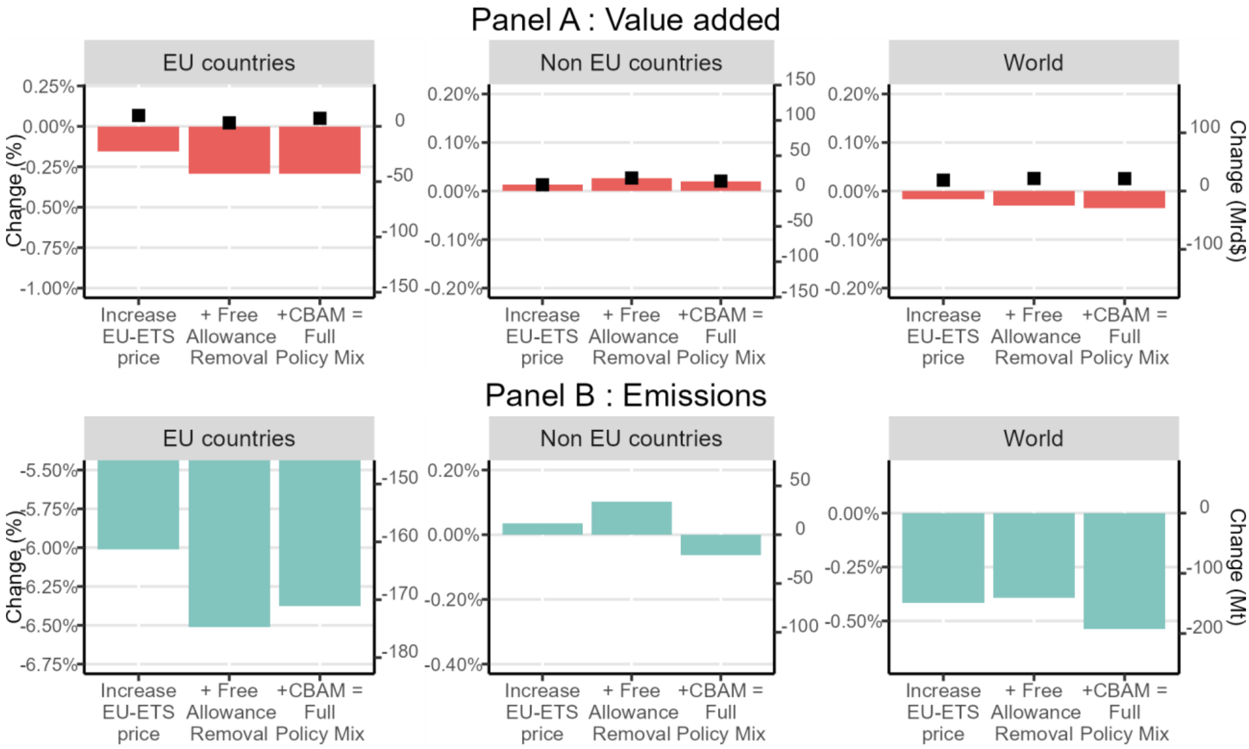
Scenario	Change EU emissions	Change Non-EU emissions	Leakage rate
Increase EU ETS price	-137 Mt	8 Mt	5.70%
+ Free Allowance Removal	-145 Mt	28 Mt	18.80%
+ CBAM = Full Policy Mix	-149 Mt	-22 Mt	-15.20%

Note: Simulated change in emissions in million tonnes CO_2 equivalent and carbon leakage rate for three policy scenarios compared to the baseline
Source: OECD computations.

In the Full Policy Mix Scenario, the results show that introducing the CBAM acts as an effective countermeasure against carbon leakage. Under this scenario, emissions within the EU decrease by 11.7% (-149 Mt). EU countries' production decreases less than in Scenario 2 without the CBAM, resulting in a slightly lower emission reduction. However, emissions in non-EU countries also decrease (by 22 Mt, a modest 0.11%). Carbon leakage disappears, and the carbon leakage rate becomes negative (-15.20%). This outcome can be attributed to a shift in demand towards "cleaner" exporting countries with relatively lower emission intensities than competitors. The third part of this section delves deeper into this by looking into country-specific effects.

Figure 10. Macro-level effect across all industries – EU countries vs. World

Aggregate effect on value added and emissions in three policy scenarios. Black squares indicate scenarios where the revenue levied is recycled.



Note: This plot represents the simulated value added and emission in Scenario 1 (increase in EU-ETS carbon price and removal free allowance for non-EITE sectors), Scenario 2 (Scenario 1 + removal of free allowances for EITE-CBAM sectors) and Full Policy Mix Scenario (Scenario 2 + introducing CBAM) compared to the baseline for all industries. All scenarios except the baseline include the removal of free allowance in non-EITE sectors. The bars and the squares represent the simulated results, respectively, before and after the last step of the simulation, in which the revenue levied in the different scenarios is allocated to European sectors according to their weight in final demand.
Source: OECD computations.

Figure 10 presents the aggregate impact across all industries in the EU, non-EU countries and globally. Within the EU, total value added is reduced by 0.15% and 0.29% in Scenario 1 and Scenario 2, respectively. When the CBAM is introduced alongside the removal of free allowances, the negative effect on aggregate value added remains stable (-0.29%), as the small gains in value added for CBAM sectors are compensated by a slight loss in the much larger non-covered sectors (-0.014%), which represent a much larger part of the economy (95% of the total value added in the EU). Examining the effects with revenue recycling, results confirm that it can effectively mitigate the effect on aggregate value added. Across the world, both scenarios exhibit minimal effects on value added when compared to the baseline scenario. These findings underline the very modest impact of EU climate policies on global value added.

Considering total emissions within EU countries, the reduction is close to 6% across the three scenarios, consistent with CBAM sectors representing 47% of EU emissions. The pattern is consistent with Figure 10:

adding the removal of free allowances slightly decreases emissions, while further introducing the CBAM leads to a slight increase.

Globally, the impact on emissions and on carbon leakage reflect the trends observed in the CBAM industries. As shown in Table 5Table , Scenario 1 induces a positive leakage of 7.4%, which escalates to 19.20% with the removal of free allowances and shifts to -12.40% with the CBAM's implementation. Overall, adding the CBAM into the policy mix boosts the global emission reductions by 36% and the Full Policy Mix Scenario achieves a global emission reduction of 0.54% compared to a scenario where no policies are implemented.

These patterns of carbon leakage align with findings from other studies on the CBAM using CGE models. In both Bellora and Fontagné (2023[19]) and Olijslagers et al (2024[64]), carbon leakage is highest when the EU ETS is implemented without free allowances, and lower when the ETS is coupled with the CBAM rather than with free allowances. This highlights that the CBAM is more effective at preventing carbon leakage than free allowances.

Table 5. Carbon leakage – All industries

Change in emissions compared to the baseline scenario by region

Scenario	Change EU emissions	Change Non-EU emissions	Leakage rate
Increase EU ETS price	-161 Mt	12 Mt	7.40%
+ Free Allowance Removal	-175 Mt	34 Mt	19.20%
+ CBAM = Full Policy Mix	-171 Mt	-21 Mt	-12.40%

Note: Simulated change in emissions in million tonnes of CO_2 equivalent and carbon leakage rate for three policy scenarios compared to the baseline
Source: OECD computations.

The effect of revenue recycling varies significantly based on specific assumptions about the allocation of these funds across different sectors or countries. These specifications are yet to be decided at the EU level. Therefore, the analysis will now focus on the impacts of the Full Policy Mix Scenario without incorporating revenue recycling, examining the combined introduction of the CBAM and the removal of free allowances.

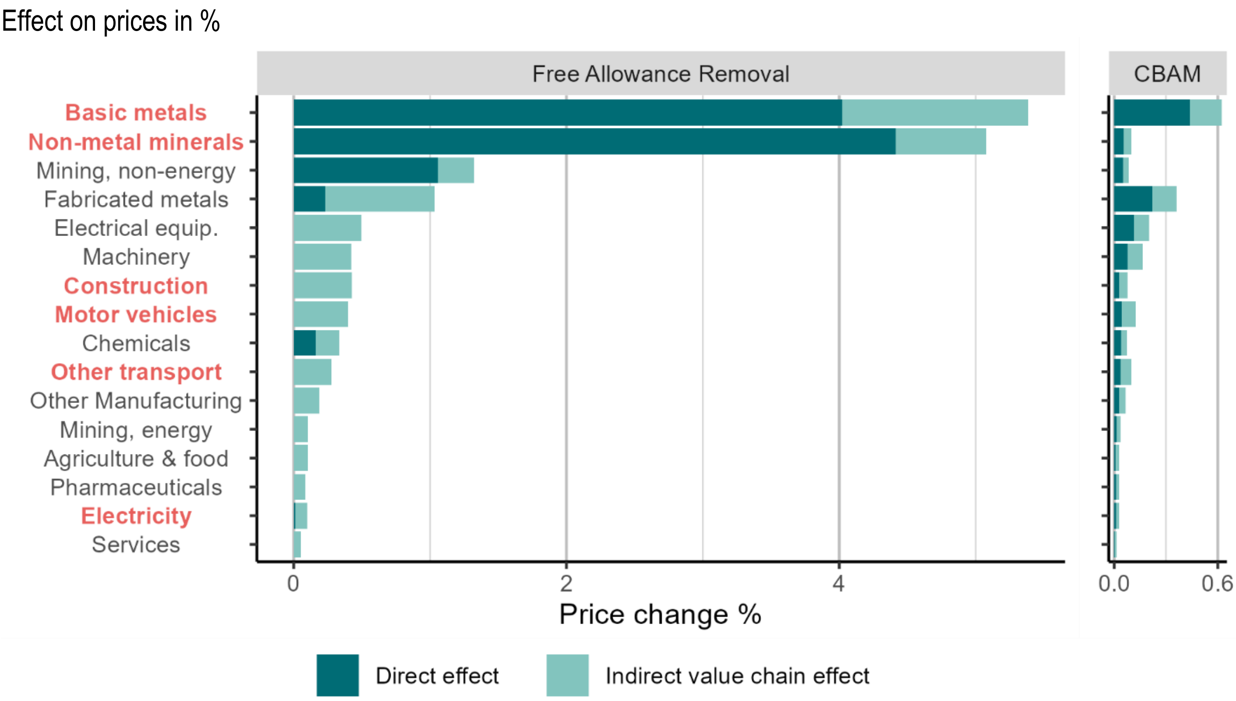
Sectoral and value chain implications of the CBAM partial coverage

The current section assesses whether the CBAM effectively achieves to mitigate the impact of removing free allowances in sectors that face intense international competition. To isolate the specific effects of the free allowance removal and the CBAM, the results compare Scenario 2 and the Full Policy Mix Scenario to Scenario 1. This approach effectively isolates these impacts by excluding the influence of the increase in EU ETS prices and the removal of free allowance in non-EITE sectors. Using the ICIO's detailed sectoral breakdown, the analysis demonstrates that the effects of the two policy scenarios vary significantly across sectors.

These heterogeneous impacts across sectors are partly explained by the sector-specific price effect of removing the free allowances and implementing the CBAM (Figure 11). The figure further differentiates between the direct effect of the policies, the indirect value chain effect (reflecting price changes passed on by suppliers higher up in the supply chain), and the input substitution effect (whereby firms substitute increasingly expensive energy inputs with capital and labour instead of increasing their prices).

The results indicate that average prices would be more significantly impacted by the removal of free allowances than by the parallel introduction of the CBAM. Covered industries that face a significant reduction in their free allowances (e.g. Basic metals, Mining non-energy, Non-metal minerals) see the largest price increase, predominantly driven by the direct effect of the policy. Conversely, in other industries, the price increases are considerably smaller and predominantly driven by the indirect value chain effect.

Figure 11. Effect on prices across EU industries – Direct vs. Indirect Value Chain Effect



Note: This graph represents the simulated effect on prices of removing free allowances (left panel) and introducing the CBAM (right panel) for all industries in EU countries. The price effects are computed by comparing the price simulated in Scenarios 2 and 3 to the price simulated in Scenario 1. The effect is decomposed into three components, and the black dot corresponds to the total impact of the policies. Names of sectors partially or fully covered by CBAM appear in red.
Source: OECD computations.

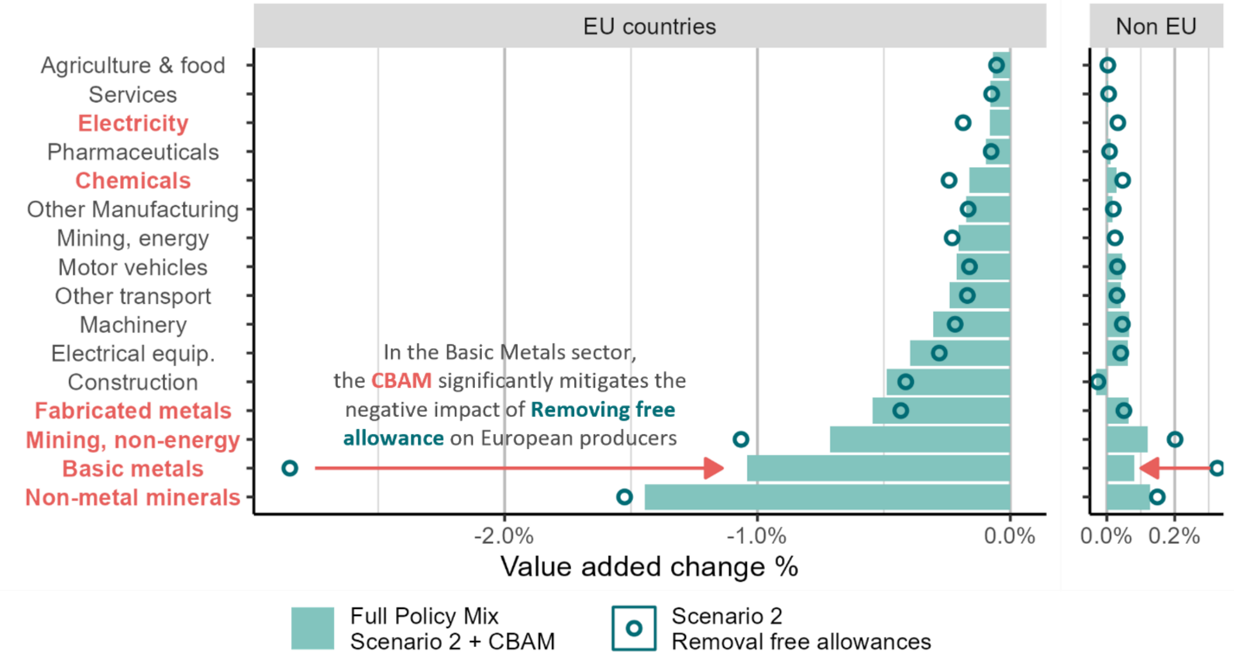
Introducing the CBAM leads to relatively modest price increases across most sectors, with changes ranging from 0 to 0.6%. Interestingly, the most notable price hikes occur in the Basic metals and Fabricated metals sectors – two sectors that are themselves "protected" by the CBAM. These sectors heavily depend on international suppliers for substantial imports of products subject to the CBAM. They are followed by industries downstream in the value chain, such as Electrical Equipment, Machinery, and Motor Vehicles, all of which are also impacted due to their reliance on metal imports. Not surprisingly, sectors further downstream exhibit a greater proportion of indirect value chain effects in their total price impact.

In both panels, the input substitution effect modelled has only a minimal effect on prices[48].

The second key factor in assessing the heterogeneous impact of the CBAM across sectors is the impact CBAM has on sectoral value added. Figure 12 presents the simulated value added effect in Scenario 2 (removal of free allowances) and in the Full Policy Mix Scenario (removal + CBAM) for European and non-European industries.

Figure 12. Effect on value added of the introduction of the CBAM and the removal of free allowances

Effect on value added of the removal of free allowance and CBAM by sector and country group



Note: The dot and the bar represent the simulated value added, respectively, in Scenario 2 (Increase in price in the EU ETS + removal of free allowance) and in the Full Policy Mix Scenario (Scenario 2 + CBAM) compared to Scenario 1 (Increase in price in the EU ETS) for all industries in EU countries (left panel) and for non-EU countries (right panel). All scenarios include the removal of free allowance in non-EITE sectors. The difference between the dot and the bar can be interpreted as the impact of implementing the CBAM. Sectors covered by the CBAM are highlighted in red and bold font on the y-axis. Services and several manufacturing sectors are grouped under the “Services” and “Other Manufacturing”.
Source: OECD computations.

Results on the Full Policy Mix Scenario show an overall small impact on value added across sectors, particularly for non-EU countries. For most of the sectors, value added declines in the EU and increases in non-EU countries, reflecting a gain in the competitiveness of the latter over the former. Nevertheless, there are important variations between sectors.

For CBAM-covered sectors, the negative effects range from about -0.01% to -1.44% on EU value added. The adverse effect of the most impacted sector, namely the Non-metal minerals sector, is attributable to its limited coverage under the CBAM, combined with the second-largest level of free allowances. Consequently, the protective measures provided by the CBAM fail to counterbalance the implications of the reduced free allowances. On the contrary, the impact of CBAM on the Basic metals sector is sizeable, reducing the loss in value added from almost three percentage points in Scenario 2 to about -1%. This effect is mirrored by a symmetric reduction (albeit smaller in magnitude as non-EU is much larger than EU) of the gains induced by the removal of free allowances for non-EU producers.

The Fabricated Metals sector stands out among CBAM-covered sectors: the introduction of CBAM leads to a decrease in its value added within the EU. This sector is highly covered by CBAM, but not significantly affected by the removal of free allowance. The adverse effect here arises primarily from the increased costs of inputs, as seen in Figure 11. The Fabricated metals sector sources a large share of inputs from the Basic metals sector, which is highly impacted by both the CBAM and the reduction in free allowances. Consequently, the rise in production costs for the Fabricated metals sector is not just due to the increased costs of its own emissions, for which the CBAM provides a cushion, but primarily stems from the inflated production costs of its main supplier, the Basic metals sector. As illustrated by this example, the CBAM only offers partial protection against these indirect cost increases by including Scope 2 and 3 emissions in its computation.[49]

This finding highlights the complex value chain mechanism that will shape the combined effect of the CBAM and the removal of free allowances. Nevertheless, it is essential to interpret these results with caution. There is a degree of uncertainty regarding the Scope 3 emissions computation used in this paper that may underestimate those emissions and the resulting CBAM levy Annex C).

Finally, sectors that are not covered by the CBAM are also impacted. Again, this can be attributed to the increase in input costs through direct and indirect value chain effects and their impact on competitiveness. This manifests in a modest reduction in value added for non-targeted sectors within Europe, such as Agriculture and Services. Consistent with the impact on prices presented in Figure 11, the Electrical Equipment, Machinery, and Motor Vehicle sectors experience a higher effect following the CBAM's introduction than other non-CBAM-covered sectors. However, these sectors concentrate a substantial part of the total negative impact in value added of the two policies in the EU: non-covered sectors represent 83% of the total value added loss for European countries.

The CBAM improves the competitiveness of carbon-efficient countries

Further decomposition of the results offers additional insights into the impact of the CBAM on different countries' value added. Figure 13 and Figure 14 show the country-level impact of the joint implementation of CBAM, the increase in carbon price and the removal of free allowances across CBAM-covered industries for non-EU and EU countries, respectively. Both figures plot the change in value added against the initial average emission intensity of production. Additionally, in Figure 13, the colour of each data point indicates the difference between the domestic carbon price and the EU ETS price and the size of the point indicates the exposure to the CBAM, as measured by the percentage of the country's exports exposed to the CBAM.

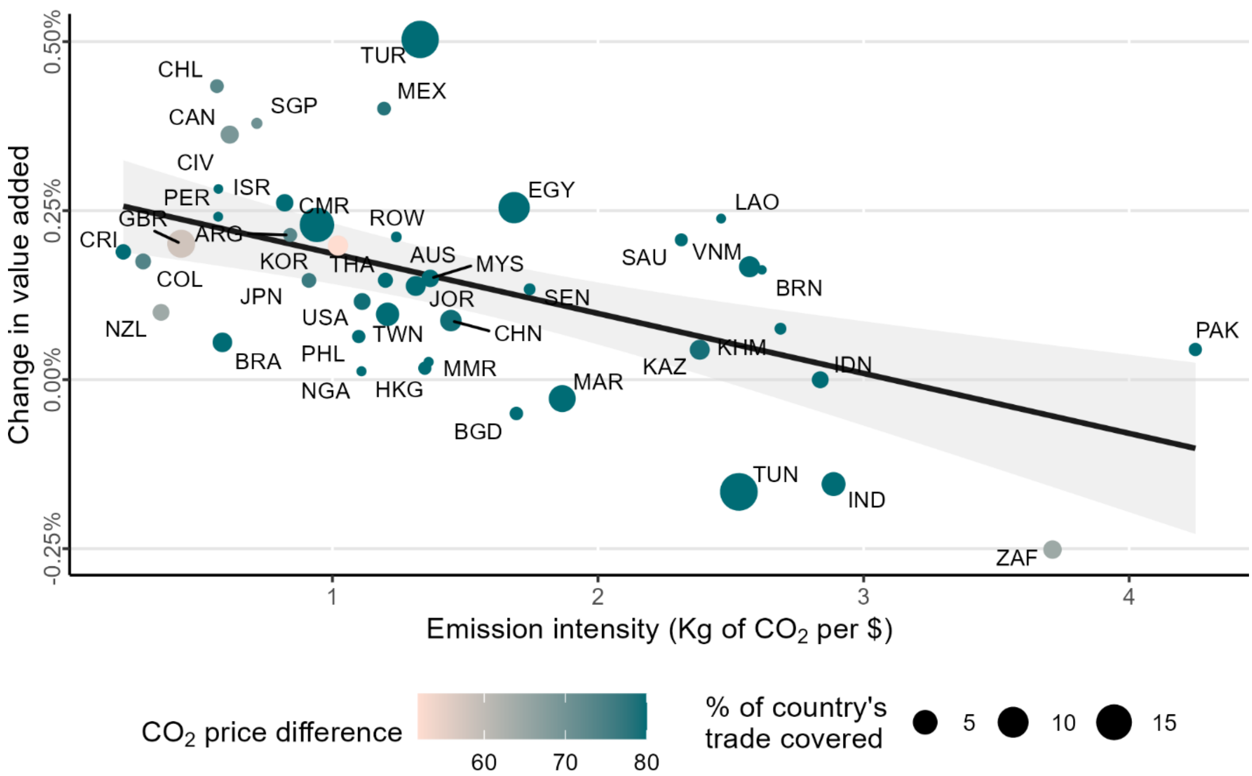
Country-level results on changes in value added indicate that the CBAM shifts demand towards countries with carbon pricing and lower emission intensity. Figure 13 presents the results for non-EU countries. On average, the changes in value added are economically modest, spanning -0.25% to +0.40% for the vast majority of countries. Most countries gain from the mix of policies implemented by the EU. Whether a country experiences a gain or a decline in value added is strongly correlated with the emission intensity of their production processes, the carbon price paid within the origin country, and the degree of exposure to EU trade.

Countries characterised by a low emission intensity in their CBAM sectors and, in some cases, existing carbon pricing frameworks – such as Türkiye, Chile, Mexico and Canada –experience a positive albeit modest increase in value added. Türkiye is an interesting example; despite its high exposure to CBAM, the impact on the value added is positive. This is driven by the low emission intensity of the Basic metal sector: Türkiye's steel industry specialises in the production of recycled steel using electric arc furnaces, a low-emitting production process[50].

Countries for which a small negative impact on value added is estimated include India, Tunisia and South Africa, with the estimated effects ranging close -0.2%. For South Africa, the effect is driven by its important export of high-emitting iron and steel products to the EU. While a slight adverse impact is projected, potential adaptation strategies within these countries could mitigate these. Such strategies may include establishing or enhancing domestic CO_2 taxation, enabling affected countries to collect revenues that would otherwise be levied on EU importers. These dynamics are not taken into consideration in the analysis.

Figure 13. Emission intensity and simulated change in value added in non-EU countries

Change in value added induced by the Full Policy Mix Scenario across CBAM industries



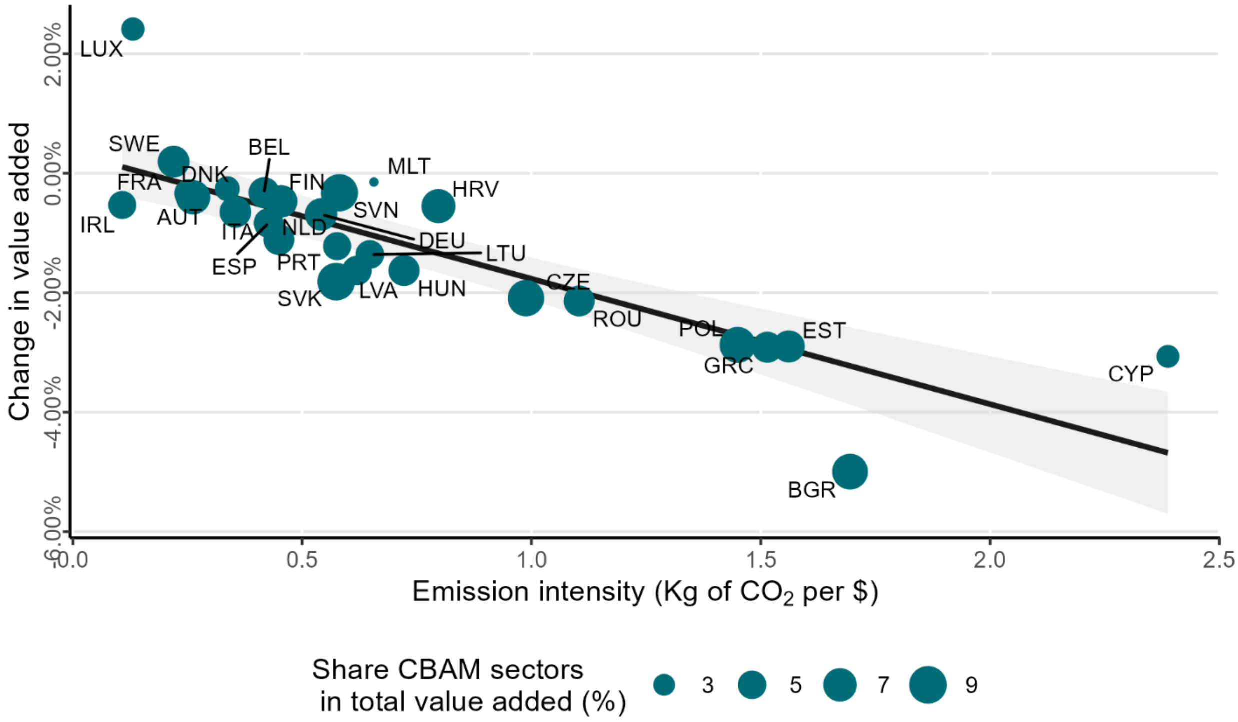
Note: This figure plots the simulated change in value added in the Full Policy Mix Scenario (increase in EU ETS price + removal of free allowance + CBAM) compared to the baseline scenario across CBAM industries in non-EU countries against the initial emission intensity in production of that country. Emission intensity is computed as the total emission of the CBAM sectors over their production. The share of trade in the intermediate goods covered by CBAM in total trade in CBAM sectors as of 2019 is mapped to the size of the data point. Additionally, the colour of each data point indicates the difference in carbon price between the local price and the EU ETS price. Ukraine, Belarus and Russia are dropped from this analysis, as well as Norway, Island, and Switzerland that are not covered by the CBAM.
Source: OECD computations

Figure A A.2 isolates the effects of removing free allowances and increasing the carbon price (Scenario 2), without implementing the CBAM. In this scenario, the link between value added impact and countries' emission intensity is much less pronounced; almost all non-EU countries experience gains in their value added and increase their production, which leads to carbon leakage. This highlights how the CBAM is able to reverse carbon leakage by shifting the gains of the EU policy mix to countries with greener production processes.

The CBAM also has a heterogeneous impact across EU countries, which highlights the effects on CBAM industries within these countries (Figure 14**)**. The effect is estimated to be slightly negative for most European countries, ranging mostly from +0.1% to -6%. The adverse effects are more pronounced in the Central and Eastern European countries, in particular Bulgaria, Cyprus, Estonia, Greece, and Poland, when compared to the EU14 countries[51]. This aligns with corroborating evidence from other studies (Magacho, Espagne and Godin, 2023[67]). When interpreting this result, it is important to consider that this part of the analysis does not factor in revenue recycling, a policy instrument that has the potential to redistribute additional revenues collected through the CBAM to countries adversely affected by the regulation.

Figure 14. Emission intensity and simulated change in value added in EU countries

Change in value added induced by the Full Policy Mix Scenario across CBAM industries



Note: This figure plots the initial emission intensity in production against the simulated change in value added in the Full Policy Mix Scenario (increase in EU ETS price + removal of free allowance + CBAM) compared to the baseline scenario across CBAM industries in EU countries. The exposure to CBAM is mapped to the size of the data point and computed as the share of the CBAM-covered sector in total value added in the country. Emission intensity is computed as the total emission of the CBAM sectors over their production.
Source: OECD computations.

Simulating the extension of the CBAM to additional products

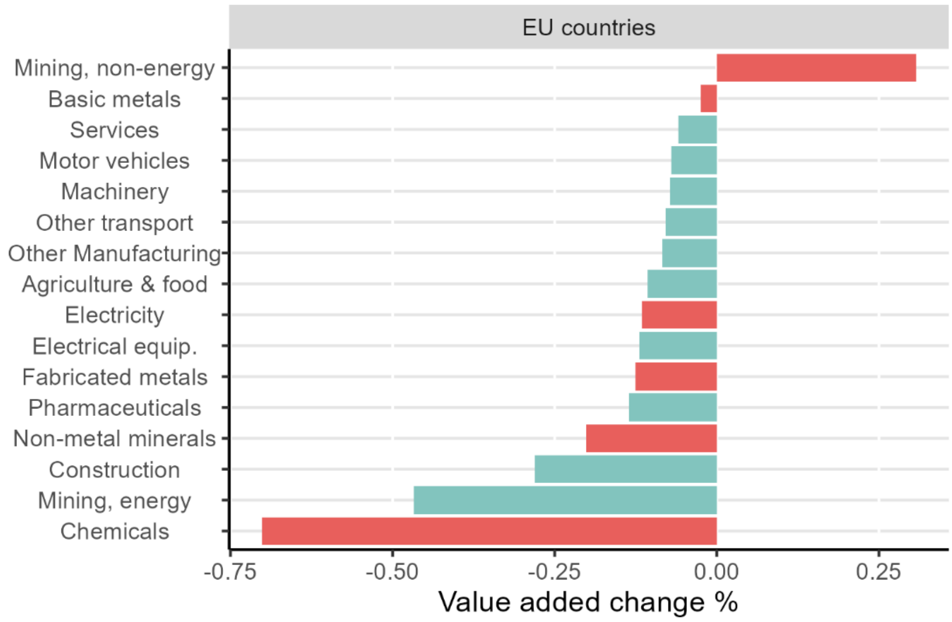
In the current CBAM regulation (European Commission, 2023[18]), the European Commission foresees a possible extension of the product scope by 2030. Hereby, priority should be given to goods that are most exposed to carbon leakage and are most carbon-intensive.

The aim of this section is to analyse the potential impact of expanding the CBAM to a hypothetical list of additional goods. In determining which products could be included in such an extension and following the criteria laid out in the CBAM regulation (European Commission, 2023[18]), emphasis is placed on goods classified as EITE, mirroring the rationale applied to the original CBAM goods. The hypothetical extended CBAM list includes 1 400 HS goods in addition to the original 150 HS goods. These additional goods constitute a supplementary 13.4% of the EU's total imports from non-EU countries, compared to the 4% coverage achieved by the original CBAM goods. Notably, these additional goods consist of intermediate goods and align with the characteristics of the current CBAM goods. However, although the extended list increases, the trade volume covered more than fourfold, Scope 1 emissions covered only double[52]. This indicates that, on average, the added goods are less carbon-intensive than those currently under the CBAM regulations.

The assessment of the extended CBAM product list is conducted for the Full Policy Mix Scenario and includes removal of free allowances for the sectors hypothetically covered by the extended CBAM[53]. Comparing the macro-level effects of the extension with those of the original CBAM list, the additional impact on value added among EU countries remains relatively modest (-0.08%). The extended CBAM scenario results in a slight further reduction in global emissions within CBAM sectors (-0.024%). It is important to note that this simulation does not consider the operational costs and feasibility of implementing a ten-fold increase in the number of goods covered by the CBAM.

Figure 15. Additional impact of a hypothetical extended CBAM on European value added, by sector

Impact on value added comparing the Full Policy Mix Scenario with the extended and original CBAM product list, without revenue recycling



Note: This plot represents the simulated value added in the Full Policy Mix Scenario (CBAM + removal of free allowances) with an extended CBAM product list compared to the Full Policy Mix Scenario with the original CBAM product list for all industries in EU countries. Services and several manufacturing sectors are grouped under the "Services" and "Other Manufacturing". Sectors covered by this hypothetical extended CBAM are in red, and non-covered sectors are in light green. Source: OECD computations.

In examining sectoral variations, Figure 15 sheds light on the incremental changes in value added resulting from the extended CBAM list compared to the original list under the Full Policy Mix Scenario. For all but one covered CBAM sector, the negative impact of the removal of free allowance dominates the positive impact of the CBAM in the EU, resulting in a small loss in value added. The only sector to exhibit a different pattern is the Mining non-energy sector, for which the protective effect of the CBAM dominates because free allowances are very limited (Figure 3). As previously, non-CBAM industries face a modest negative indirect value chain effect.

These findings suggest that achieving significant global emissions reduction would necessitate a broad expansion of the goods covered, presenting challenges in terms of both feasibility and effectiveness.

Sensitivity checks

This final subsection presents several sensitivity checks that aim to test the robustness of the results given certain methodological choices within the model. These checks look at how results change under scenarios with alternative hypotheses for (1) carbon prices, and (2) trade elasticities, and (3) cost pass-through rates[54]. While the modelling approach is based on reliable granular micro-level data, certain parameters, in particular the evolution of future carbon prices as well as the trade elasticities, are difficult to predict for the former and to measure for the latter (see Box 3 for a discussion on trade elasticities). The objective of the sensitivity checks is, therefore, to ascertain whether the key findings are robust to changes in these parameters.

The first sensitivity check examines the results' dependency on the carbon price within the EU ETS, presenting findings at a carbon price of EUR 150 per CO_2 tonne, in contrast to the EUR 80 per tonne of CO_2 assumed in the main results section. The second check uses different elasticities, multiplying the trade and domestic final demand elasticities by two. Although arbitrary, this assumption results in elasticities that are closer to the ones estimated by Fontagné et al. (2022[95]) or Imbs and Mejean (2016[96]).

The third robustness check focuses on the cost pass-through rates. As outlined in Box 1, the full cost pass-through is a critical assumption within the model. Although this assumption may realistically reflect long-term dynamics, cost pass-through rates could be lower, particularly over short periods of time or for certain products. These rates have considerable variability among products, sectors, and nations, making it challenging to identify a specific pass-through rate for each sector. Nonetheless, in an effort to explore outcomes under a lower pass-through scenario, the sensitivity check tests the effect of an average rate of 60% across all sectors when modelling the effect on prices in the Leontief price model. A reduced pass-through rate not only implies that firms importing goods under the CBAM will transfer a smaller portion of the incurred costs to consumers but also that they will absorb a greater share of these costs themselves, potentially affecting their profitability or investment capacity in the long run. This could affect in turn their ability to innovate, grow, or even survive.

For all parameter changes, Table 6 shows that the key findings hold. The removal of free allowances alone induces carbon leakage and negatively impacts European industries, and the introduction of the CBAM leads to a partial reversal of the loss in value added across European CBAM industries and cancels leakage out, leading to a reduction in global emissions.

While the main results hold, the magnitude of the effects changes close to linearly with the carbon price and the elasticities. This implies that a higher carbon price leads to larger observed effects in the Full Policy Mix Scenario. Similarly, the impact of the CBAM and the removal of free allowance are significantly reduced for the lower pass-through, albeit less linearly so.

Beyond the size of the macro effect, the resulting ranking of the most impacted industries and countries is quite stable across all sensitivity check simulations. Figure A A.3 in the appendix visually represents this consistency through a correlation heat map. This heat map contrasts the rankings by country and industry for the value added impact under the Full Policy Mix Scenario, comparing the standard parameter simulation with simulations conducted under a range of alternative parameters. All correlation coefficients are above 0.95, reflecting that while the magnitude of impact may vary based on parameter selection, the relative order of the most impacted industries and countries stays stable across both the baseline and alternative parameter simulations discussed in this section.

Table 6. The macro effect: a sensitivity analysis

Aggregate the effect on value added and emissions by comparing the effect on emissions and value added in several scenarios under alternative key parameters.

Parameters	Industry	Area	Value added (%)			Emissions (%)		
			Scenario 1	Scenario 2	Full Policy Mix Scenario	Scenario 1	Scenario 2	Full Policy Mix Scenario
Reference Simulation	CBAM Industries	EU	-0.40	-1.07	-0.85	-10.76	-11.67	-11.37
		World	-0.03	-0.02	-0.05	-0.60	-0.56	-0.78
	All industries	EU	-0.15	-0.29	-0.29	-6.01	-6.51	-6.38
		World	-0.02	-0.03	-0.03	-0.42	-0.39	-0.54
Price 150 Euro/t	CBAM Industries	EU	-0.93	-2.17	-1.80	-11.97	-13.67	-13.15
		World	-0.06	-0.06	-0.10	-0.63	-0.55	-0.85
	All industries	EU	-0.36	-0.62	-0.62	-6.81	-7.74	-7.51
		World	-0.04	-0.06	-0.07	-0.44	-0.39	-0.59
Elasticity * 2	CBAM Industries	EU	-0.81	-2.13	-1.75	-11.65	-13.47	-12.93
		World	-0.05	-0.05	-0.09	-0.62	-0.54	-0.85
	All industries	EU	-0.31	-0.59	-0.59	-6.63	-7.63	-7.38
		World	-0.03	-0.06	-0.07	-0.43	-0.38	-0.59
Pass-through 60%	CBAM Industries	EU	-0.15	-0.47	-0.33	-10.28	-10.75	-10.56
		World	-0.01	0.00	-0.02	-0.59	-0.57	-0.74
	All industries	EU	-0.04	-0.09	-0.08	-5.66	-5.91	-5.82
		World	0.00	0.00	-0.01	-0.41	-0.40	-0.51

Note: This table presents the simulated value added and emissions in Scenario 1 (increase in EU ETS emission price), Scenario 2 (removing free allowances for EITE-CBAM sectors), and the Full Policy Mix Scenario. All scenarios are compared to the baseline scenario. The simulations are conducted using several alternative parameters listed in the first column.
Source: OECD computations.

6 Conclusion

This paper combines multiple data sources to document the coverage of the EU CBAM in terms of trade flows and embedded emissions and to simulate the effect of reform of the EU ETS1 adopted as part of the 'Fit for 55' package and of the CBAM legislation on competitiveness and carbon leakage, accounting for input-output linkages. This approach considers both the direct effect on covered industries, and the indirect value chain effect on downstream and upstream industries by leveraging industry interconnections through the OECD ICIO tables. This enables to assess the heterogeneous effects of the policies on industries and countries in several policy scenarios. The central scenario models the simultaneous increase in the price of EU ETS allowances, the introduction of the CBAM and the removal of free allowances as proposed in the EU legislation (European Commission, 2023[18]). The analysis is based on an enhanced input-output model that captures how the impact of the CBAM disseminates throughout the production network.

The key finding of the paper is that the CBAM could be effective in preventing carbon leakage and contribute to reducing global emissions, but that it only partially mitigates the negative effects of higher carbon prices and free allowances removal on the value added of CBAM-protected industries and, importantly, it negatively affects downstream industries.

The introduction of the CBAM coupled with an increase of carbon price in the EU ETS and the removal of free allowances would have a relatively modest influence on overall value added, whether in EU or non-EU countries. The CBAM mitigates the loss in value added for EU industries, but only partially so. This reduced competitiveness of EU ETS sectors despite the CBAM implementation is to be expected as CBAM industries also consume CBAM-covered inputs (whose price will rise) and CBAM does not level the playing field on export markets. Redistributing levied revenues could further reduce the overall impact on EU value added.

The analysis shows that while increasing carbon prices and removing free allowances would reduce emissions by 11.7% within EU CBAM industries, they also cause a small rise in emissions outside the EU, indicating carbon leakage. The 175 million tonnes of CO_2 emissions reduction within the EU would be partially offset by an increase of 34 million tonnes in partner countries' emissions, corresponding to a carbon leakage rate of 19.2%. However, introducing the CBAM leads to a drop in emissions both within and outside the EU due to a rerouting of EU imports towards less emission-intensive sources. This shift in trade patterns reduces production in high emission economies, leading to a 36% increase in global emissions reductions compared to a scenario without CBAM (and free allowances removed) and to a 29% increase compared to a scenario where free allowances are kept (and CBAM not implemented). Across all industries, the combined policies result in a 0.5% reduction in global emissions.

The removal of free allowances and implementation of the CBAM affect EU sectors unevenly in terms of prices and value added. Sectors like Basic metals and Non-metal minerals, which previously received significant free allowances, experience substantial price hikes and value added losses of up to 2.8%. While the CBAM helps to mitigate losses for Basic metals, it offers less protection for Non-metal minerals due to its limited coverage. Indirect effects ripple through non-targeted sectors, which experience modest price increases and value added declines. These sectors, representing most of the EU economy, account for 83% of the total value added loss, highlighting the importance of indirect value chain effects in measuring the overall impact of the policies. Consequently, the macro effect across all EU industries remains identical with or without the CBAM (-0.29%), as losses in downstream sectors almost perfectly balance the gains in covered industries.

In theory, extending the CBAM coverage could address this downstream leakage issue. However, the simulation shows that a hypothetical extended CBAM-covered product list including 1 400 additional goods would make only marginal changes to value added and global emissions, suggesting that the initial list has been well selected to maximise impact while covering relatively few goods. Moreover, the indirect value chain effect still significantly impacts downstream non-CBAM industries in this scenario. Safeguarding these sectors from leakage risks would necessitate a substantial expansion of the CBAM product coverage, which may pose technical feasibility challenges.

Across non-EU countries, the average value added impact of implementing all policies is modest and positive for most countries, as their relative production costs decrease. Nevertheless, the impact varies among countries, contingent on their emission intensity in production and prevailing carbon pricing mechanisms. Since imports from countries with carbon pricing and lower emission intensity encounter a lower levy when entering the Common Market, these countries see larger gains than more emissions-intensive economies. This underlines the CBAM's potential to encourage cleaner export-oriented production globally.

The analysis could be extended in several directions. First, better data is critical. Country-specific data on sectoral emissions at a more disaggregated level would enable refining the measurement of embedded emissions in CBAM-covered products. Similarly, global input-output tables at a finer level of disaggregation would improve the measurement of upstream Scope 3 emissions covered by CBAM. Micro-level emissions data at the country-level would capture the potential for within-country resource shuffling, whereby CBAM goods produced using emissions-intensive processes are consumed domestically while the same goods produced using more efficient processes are exported to the EU. Secondly, the model focuses on short run effects. However, the true CBAM impacts will depend on the dynamic response of firms (technological change, input substitution) and of exporting countries (adoption of other BCAs, carbon pricing adoption, relabelling of fossil fuel energy taxes into carbon taxes). Incorporating endogenous technological change or policy adoption would enrich the model at the cost of relying on additional assumptions. Thirdly, the paper is silent about issues related to measurement, reporting and verification, with the model implicitly assuming accurate measurement and full compliance on the part of importers. The data collected in the first years of the CBAM implementation will be helpful to tackle these questions.

Endnote

[1] Press Release of the Canadian department of finance *"Government launches consultations on border carbon adjustments",* August 2021. https://www.canada.ca/en/department-finance/news/2021/08/government-launches-consultations-on-border-carbon-adjustments.html

[2] Consultation outcome Factsheet: UK Carbon Border Adjustment Mechanism, December 2023. https://www.gov.uk/government/consultations/addressing-carbon-leakage-risk-to-support-decarbonisation/outcome/factsheet-uk-carbon-border-adjustment-mechanism

[3] The Carbon Leakage Review was set up to explore several policy options to address carbon leakage: https://www.dcceew.gov.au/climate-change/emissions-reduction/review-carbon-leakage

[4] Several legislative proposals have been introduced in the US Congress proposing various forms of carbon border adjustments or related mechanisms (https://www.wri.org/update/4-us-congress-bills-related-carbon-border-adjustments-2023)

[5]According to the Coase Theorem (Coase, 1960[21]), in equilibrium, the firms' emissions are independent of the overall allocation of emission permits. While the ETS imposes a cost for the permit buyer, it represents an opportunity cost of the same amount for the permit seller.

[6] https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer.

[7]Commission Delegated Regulation (EU) 2019/331

[8] ''Should differences in levels of ambition worldwide persist, as the EU increases its climate ambition, the Commission will propose a carbon border adjustment mechanism, for selected sectors, to reduce the risk of carbon leakage.'' Communication from the Commission to the European Parliament, the European Council, the Council, the European economic and social committee and the Committee of the regions – The European Green Deal. COM/2019/640final, Brussels.

[9] "I welcome the political agreement reached this morning on the Commission's proposal for a Carbon Border Adjustment Mechanism. This is a central part of our European Green Deal, preventing the risk of carbon leakage. It is a huge step forward, as we raise our climate ambitions." President Ursula von der Leyen - 13/12/2022, Press Release. https://ec.europa.eu/commission/presscorner/detail/en/ip_22_7719.

[10] CBAM mainly covers CO_2 emissions. In addition, it covers nitrous oxide emissions for some fertiliser goods as well as perfluorocarbons (PFCs) for some aluminium goods.

[11] This has important implications for products such as hydrogen: not including Scope 2 emissions means that there would be no advantage in importing green over grey hydrogen.

[12] This stems from the fact that, for other CBAM-covered products (iron and steel, aluminium, and hydrogen), the EU permits Member States to partically compensate electro-intensive companies for the higher electricity costs arising from the EU ETS. Consequently, it would lack fairness and compatibility with WTO regulations to fully price Scope 2 emissions for importers while domestic producers can be partially compensated.

[13] For imported electricity covered by CBAM, embedded emissions are determined similarly through default values, unless the declarant can demonstrate a direct technical link between the installation in which the imported good is produced and the electricity generation source. Embedded indirect emissions are determined based on the average of either the emission factor of the EU electricity grid, of the country-of-origin electricity grid or of price-setting sources in the country of origin.

[14] Members of the European Economic Area are EU countries, Iceland, Liechtenstein, and Norway.

[15] In the European Commission's impact assessment (European Commission, 2021[36]), they are estimated to represent at most 0.5% of the price of an allowance (max. EUR 0.37 per tonne of CO_2) and in a Swiss study (Ecoplan, 2023[69]), they amount to at most 0.2% of the value of relevant exports/imports.

[16] Variation across estimated results might vary depending on modelling assumptions.

[17] Estimations face an endogeneity concern through the fact that regulatory stringency and pollution are simultaneously determined (Levinson, 2016).

[18] While some leakage remains after BCA implementation in CGE models, this is not the case with partial equilibrium (PE) models. Branger and Quirion (2014[39]) point out that in CGE models, a part of leakage is due to the international fossil fuel price channel, which is unaffected by BCAs, while most PE models do not feature this fossil fuel price channel.

[19] In PE models a higher output loss is due to a drop in demand for CO2-intensive materials, loss which is mitigated by general equilibrium effects.

[20] A paper by Mörsdorf (2022[113]) studies the impact of CBAM on the reduction of emissions. The paper compares three designs of the CBAM proposed by the European commission (Scope 1 versus Scope 2 emissions and rebate to exporters) in a CGE framework. The study finds that a CBAM would reduce carbon leakage to a similar extent as the current free allowance system, which it would replace.

[21] The baseline scenario used to compute this number considers an emission reduction of 55% by 2030, with the continuation of free allowances decreasing along the ETS cap.

[22] Countries not directly covered by the ICIO are aggregated in a "Rest of the World" component. As the results, the ICIO covers all world trade flows.

[23] The Greenhouse gas footprint indicators are primarily based on sectoral emissions data from Air Emissions Accounts (AEA). AEA statistics are currently available for 42 countries. If AEA statistics are not available for a country, IEA CO2 emissions from fuel combustion are first used to estimate emissions by industry using the harmonised national Use Tables at basic prices from the OECD ICIO project. Non-fuel combustion CO2 emissions and other GHG emissions by industry are filled using reference ratios. UNFCCC estimates of total GHG emissions are then used to fill the gaps of the non-fuel combustion CO2

emissions. The national total emissions are finally compared with the UNFCCC and Climate Watch databases to validate the total economy emissions for each country. For this paper, methane emissions are excluded from the total GHG emissions. Therefore, the methane gas proportion of total GHGs also needs to be estimated by country and industry. If methane emissions are not specifically reported in AEA or UNFCCC data sources, reference ratios by sector are applied from available countries.

24 Measurement errors can arise (1) due to errors in the mapping of establishments to NACE codes, and (2) due to inaccuracies in the ICIO sectoral emissions. These can occur through differences in data collection, or estimation of emissions.

25 An exception to this general rule is outlined in Article 10c of the ETS Directive, which permits a deviation from the no-free-allocation principle for electricity generation in low-income member states. Among the EU member states, only Bulgaria, Hungary, and Romania have opted to provide free allowances under Article 10c of the ETS Directive during phase 4.

26 The regulations refer to policies adopted as part of the EU's 'Fit for 55' policy package, such as emission reduction targets for sectors covered by the Effort Sharing Regulation, more stringent CO2 emissions standards for vehicles, Increase share of renewables in the energy mix (42.5% by 2030), and increase in EU-wide energy efficiency by 36% (39%) for final (primary) energy consumption in 2030, compared to 2021 (Chateau, Miho and Borowiecki, 2023[74]).

27 The gross output comes from the ICIO tables while the country-sector emissions come from the TECO2 project mentioned above.

28 $Comtrade_{irj}^{\mathrm{CBAM}}$ is defined based on 2022 data for the descriptive analyses of this section and relies on 2019 data when utilised as an input for the model. This approach ensures consistency with the base year of the ICIO (Inter-Country Input-Output) tables that is useed in our simulation exercise.

29 Scope 1 covers direct emissions from owned or controlled sources. Scope 2 addresses indirect emissions from the consumption of purchased electricity, steam, heating, and cooling. Finally, Scope 3 includes all other indirect emissions that occur in the value chain, including both upstream and downstream emissions.

30 This is in contrast to "effective carbon tax rates", which capture the total price of carbon dioxide from carbon taxes, emissions trading systems but also fuel excise taxes.

31 Regional carbon taxes or ETSs are weighted according to regional value added to compute national prices. To calculate the average explicit carbon tax rate, the national carbon tax rate is multiplied by the share of emissions covered within that country.

32 Note that the model presented in Section 4.4 and used for the simulations uses 2019 trade data to be consistent with the ICIO data.

33 PRODcom (*PRODuction COMmunautaire*) is an EU-wide survey that collects detailed data on the production of manufactured goods. It provides statistics on the physical production of goods by EU member states and is based on a specific product classification that aligns with both the EU's Combined Nomenclature (CN) and the Standard International Trade Classification (SITC).

34 CBAM goods production recorded in Prodcom is aggregated at the country ICIO-sector level. The value added and employment associated with their production are calculated using the value-added intensity

and employment intensity per dollar of gross output at the country-sector level. This approach assumes that CBAM goods generate value added and employment at the same rate as other goods within their respective sectors

[35]The loss of free allowance does not translate into efficiency gains as it has no impact on firms' marginal cost of abatement.

[36] Recent findings indicate that, over the longer term, a EUR 10 increase in carbon pricing results in an average reduction of 3.7% in CO_2 emissions from fossil fuels (D'Arcangelo, 2022[112]).

[37] Inputs from the following industries are considered as energy input: Mining and quarrying, energy producing products (D05T06); Coke and refined petroleum products (D19), Electricity, gas, steam and air conditioning supply (D35)

[38] Given that the previous modelling step has already defined the traded quantity of final demand and intermediate goods, the Input-Output Quantity model only adjusts the quantities of domestically produced and domestically exchanged intermediate inputs. Formally, this means that the I-O quantity model is run for each economy separately based on its domestic Input Output submatrix. where the final good demand vector is the sum of the domestic demand for the final good, the export of the final good, and the export of intermediary goods.

[39] Existing empirical papers use both ex-ante simulation and ex-post econometric techniques to estimate cost pass-through of emission allowances. Generally, the studies confirm that costs have been passed through in most sectors investigated. Note that the estimated cost pass-through rates, vary across studies, depending on the assumptions made, methods chosen and the data used.

[40] For some products (PE, ethylene, butadiene), the cost pass through ranges from 0 to 100% (De Bruyn et al., 2010[90]; Alexeeva-Talebi, 2010[92]; Oberndorfer, Alexeeva-Talebi and Löschel, 2010[116]).

[41] However, part of this price increase could be absorbed by the exporting party. This will depend on whether importing firms have enough market power to have their supplier reduce their margins and reduce their export prices.

[42] As discussed in the economic literature, a CBAM can include export rebates whereby the carbon levy is refunded for exported goods to level the playing field on export markets. However, the European Union has decided against implementing export rebates.

[43] As the CBAM covers the entire part of the value chain for several families of goods (e.g. steel), a firm can import CBAM goods to produce another CBAM good.

[44] For further information on Directive 2003/87/EC, see https://data.consilium.europa.eu/doc/document/PE-9-2023-INIT/en/pdf (accessed August 2023).

[45] EU ETS 2 compliance obligations are not imposed directly on building owners, vehicle owners, or other entities that are using the fuel but are targeted at the "release for consumption of fuels" to covered sectors.

[46] The Official Journal of the European Union Volume 62, 2019, L120 determines the list of the sectors deemed as exposed to leakage.

[47] The ETS Directive sets 100% of free allowances for a benchmark to be set at a level reflecting the average performance of the 10% most efficient installations in a sector or subsector in the EU (European Commission, 2011[115]).

[48] Albeit minimal the substitution is non null. The small impact is due to the very small effect of the modeled policy on the price of energy (i.e. Electricity, Mining, energy sectors). The simulated input substitution effect is larger following an increase in the price of the EU ETS because it strongly impact the cost electricity.

[49] Figure A A.2 in the appendix shows that in a scenario in which only CBAM is introduced, fabricated metals would also be negatively affected in European countries, while Basic Metals would largely benefit.

[50] Currently, steel scrap products are exempt from the CBAM. The anticipated removal of free allowances for the steel sector is likely to escalate production costs for traditional, high-emission blast furnaces. Consequently, this is expected to drive up the price of scrap steel in Europe, which is predominantly utilized in the less-emitting electric arc furnaces. This could induce an aspiration of scrap to Europe and a reshuffling of steel scrap and recycled steel to Europe while limiting the incentive of non-EU countries to transition to greener production means (Gérardin and Ferrière, 2024[119]). The steel industry in Türkiye may suffer from such reshuffling, seeing it access to a key input largely reduced. This level of granularity is beyond this modelling exercise but illustrates the complex value chain mechanism that could be at work following the introduction of the CBAM.

[51] EU14 countries are defined as countries who were members of the EU prior to 2004: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Republic of Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain and Sweden.

[52] Scope 2 and 3 emissions are not accounted for in the product of the extended list.

[53] The further removal in free allowance is computed based on EU ETS info data.

[54] The ability of firms to pass on costs induced by the simulated policies to their customers

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Annex A. Additional figures and tables

Table A A.1. List of goods captured by the CBAM under Regulation (EU) 2023/956

Good	HS Code	NAICS	NACE 4 digit	Description	Greenhouse gases
Cement	2507 00	212 324	08.12	Other kaolinic clays	Carbon dioxide
	2523 10	327 310	23.51	Cement clinkers	Carbon dioxide
	2523 21	327 310	23.51	White Portland cement, whether or not artificially coloured	Carbon dioxide
	2523 29	327 310	23.51	Other Portland cement	Carbon dioxide
	2523 30	327 310	23.51	Aluminous cement	Carbon dioxide
	2523 90	327 310	23.51	Other hydraulic cements	Carbon dioxide
Electricity	2716 00	990 000	35.11	Electrical energy	Carbon dioxide
Fertilisers	2808 00	325 311	20.15	Nitric acid; sulphonitric acids	Carbon dioxide and nitrous oxide
	2814 00	325 311	20.15	Ammonia, anhydrous or in aqueous solution	Carbon dioxide
	2834 21	325 188 325 180	20.15	Nitrates of potassium	Carbon dioxide and nitrous oxide
	3102	325 311	20.15	Mineral or chemical fertilisers, nitrogenous	Carbon dioxide and nitrous oxide
	3105	325 321	20.15	Mineral or chemical fertilisers containing two or three of the fertilising elements nitrogen, phosphorus and potassium; other fertilisers; goods of this chapter in tablets or similar forms or in packages of a gross weight not exceeding 10 kg Except: 3105 60 00 – Mineral or chemical fertilisers containing the two fertilising elements phosphorus and potassium	Carbon dioxide and nitrous oxide
Iron and steel	72	331 111 331 110 331 222	24.10 25.91	Iron and steel Except: 7202 2 – Ferro-silicon 7202 30 00 – Ferro-silico-manganese 7202 50 00 – Ferro-silico-chromium 7202 70 00 – Ferro-molybdenum 7202 80 00 – Ferro-tungsten and ferro-silico-tungsten 7202 91 00 – Ferro-titanium and ferro-silico-titanium 7202 92 00 – Ferro-vanadium 7202 93 00 – Ferro-niobium	Carbon dioxide

				7202 99 – Other: 7202 99 10 – Ferro-phosphorus 7202 99 30 – Ferro-silico-magnesium 7202 99 80 – Other 7204 – Ferrous waste and scrap; remelting scrap ingots and steel	
	2601 12	212 210	07.10	Agglomerated iron ores and concentrates, other than roasted iron pyrites	Carbon dioxide
	7301	331 110 331 111	24.10	Sheet piling of iron or steel, whether or not drilled, punched or made from assembled elements; welded angles, shapes and sections, of iron or steel	Carbon dioxide
	7302	331 110 331 111 331 511 332 999	24.10 25.91	Railway or tramway track construction material of iron or steel, the following: rails, check-rails and rack rails, switch blades, crossing frogs, point rods and other crossing pieces, sleepers (cross-ties), fish-plates, chairs, chair wedges, sole plates (base plates), rail clips, bedplates, ties and other material specialised for jointing or fixing rails	Carbon dioxide
	7303 00	331 511	24.10 24.20	Tubes, pipes and hollow profiles, of cast iron	Carbon dioxide
	7304	331 110 331 111	24.10 24.20	Tubes, pipes and hollow profiles, seamless, of iron (other than cast iron) or steel	Carbon dioxide
	7305	331 110 331 111 331 210 335 129	24.10 24.20 24.31	Other tubes and pipes (for example, welded, riveted or similarly closed), having circular cross-sections, the external diameter of which exceeds 406,4 mm, of iron or steel	Carbon dioxide
	7306	331 110 331 111 331 210 335 129	24.10 24.20 24.31	Other tubes, pipes and hollow profiles (for example, open seam or welded, riveted or similarly closed), of iron or steel	Carbon dioxide
	7307	331 511 332 919	24.10	Tube or pipe fittings (for example, couplings, elbows, sleeves), of iron or steel	Carbon dioxide
	7308	332 312 332 321 332 322 332 323	25.11 25.91	Structures (excluding prefabricated buildings of heading 9406) and parts of structures (for example, bridges and bridge-sections, lock- gates, towers, lattice masts, roofs, roofing frameworks, doors and windows and their frames and thresholds for doors, shutters, balustrades, pillars and columns), of iron or steel; plates, rods, angles, shapes, sections, tubes and the like, prepared for use in structures, of iron or steel	Carbon dioxide
	7309 00	332 420	25.29	Reservoirs, tanks, vats and similar containers for any material (other than compressed or liquefied gas), of iron or steel, of a capacity exceeding 300 l, whether or not lined or heat-insulated, but not fitted with mechanical or thermal equipment	Carbon dioxide
	7310	332 431 332 439	25.91 25.92	Tanks, casks, drums, cans, boxes and similar containers, for any material (other than compressed or liquefied gas), of iron or	Carbon dioxide

				steel, of a capacity not exceeding 300 l, whether or not lined or heat-insulated, but not fitted with mechanical or thermal equipment	
	7311 00	332 420	25.91 25.92	Containers for compressed or liquefied gas, of iron or steel	Carbon dioxide
	7318	332 722	25.94 25.91	Screws, bolts, nuts, coach screws, screw hooks, rivets, cotters, cotter pins, washers (including spring washers) and similar articles, of iron or steel	Carbon dioxide
	7326	316 993 316 998 331 110 331 222 332 618 332 999 334 417 336 991 339 910 339 911 339 912 339 994 339 995	25.91 25.92 25.93 25.94 25.99	Other articles of iron or steel	Carbon dioxide
Aluminium	7601	331 312 331 313 331 314	24.42	Unwrought aluminium	Carbon dioxide and perfluorocarbons
	7603	331 314	24 42	Aluminium powders and flakes	Carbon dioxide and perfluorocarbons
	7604	331 316 331 318	24.42	Aluminium bars, rods and profiles	Carbon dioxide and perfluorocarbons
	7605	331 318 331 319	25.93 25.99	Aluminium wire	Carbon dioxide and perfluorocarbons
	7606	331 315	24.42	Aluminium plates, sheets and strip, of a thickness exceeding 0,2 mm	Carbon dioxide and perfluorocarbons
	7607	331 315 332 999	24.42 25.92 25.99	Aluminium foil (whether or not printed or backed with paper, paperboard, plastics or similar backing materials) of a thickness (excluding any backing) not exceeding 0,2 mm	Carbon dioxide and perfluorocarbons
	7608	331 316 331 318	24.42	Aluminium tubes and pipes	Carbon dioxide and perfluorocarbons
	7609 00	332 919	24.42	Aluminium tube or pipe fittings (for example, couplings, elbows, sleeves)	Carbon dioxide and perfluorocarbons
	7610	321 991 332 312 332 321 332 322 332 323	25.11 25.12 25.99	Aluminium structures (excluding prefabricated buildings of heading 9406) and parts of structures (for example, bridges and bridge-sections, towers, lattice masts, roofs, roofing frameworks, doors and windows and their frames and thresholds for doors, balustrades, pillars and columns); aluminium plates, rods, profiles, tubes and the like, prepared for use in structures	Carbon dioxide and perfluorocarbons

	7611 00	332 420	25.29	Aluminium reservoirs, tanks, vats and similar containers, for any material (other than compressed or liquefied gas), of a capacity exceeding 300 litres, whether or not lined or heat-insulated, but not fitted with mechanical or thermal equipment	Carbon dioxide and perfluorocarbons
	7612	332 431 332 439 332 999	25.91	Aluminium casks, drums, cans, boxes and similar containers (including rigid or collapsible tubular containers), for any material (other than compressed or liquefied gas), of a capacity not exceeding 300 litres, whether or not lined or heat-insulated, but not fitted with mechanical or thermal equipment	Carbon dioxide and perfluorocarbons
	7613 00	332 420	25.29	Aluminium containers for compressed or liquefied gas	Carbon dioxide and perfluorocarbons
	7614	331 318 331 319	24.42	Stranded wire, cables, plaited bands and the like, of aluminium, not electrically insulated	Carbon dioxide and perfluorocarbons
	7616	331 319 331 523 332 112 332 618 332 722 332 999 337 920	25.50 25.99	Other articles of aluminium	Carbon dioxide and perfluorocarbons
Hydrogen	2804 10	325 120	20.11	Hydrogen	Carbon dioxide

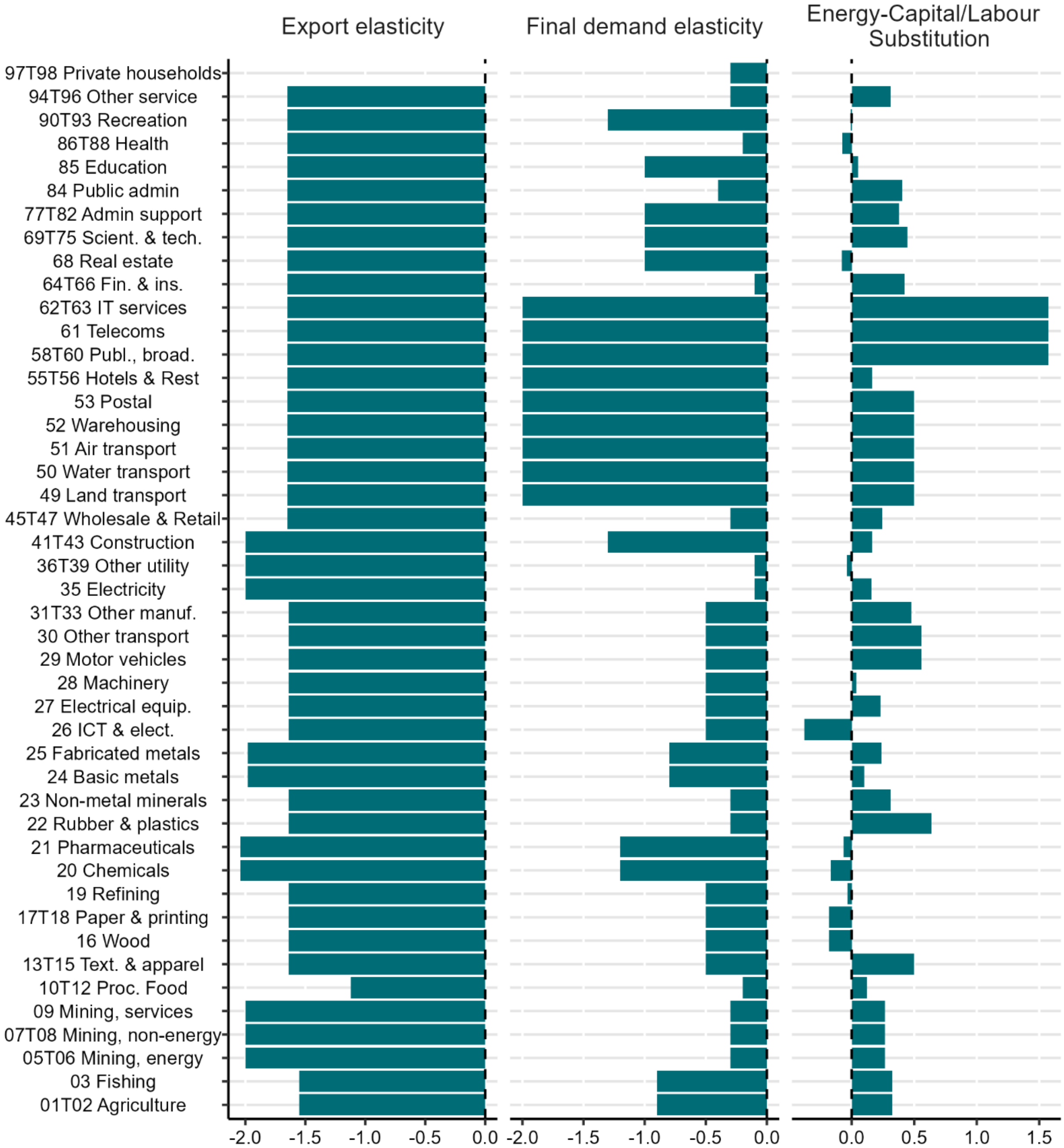
Note: The kaolinic clays (HS code 250 700) are only partially covered by the CBAM as the EU regulation considers only one of the two 8-digit Common Nomenclature products. To correct for this, the EU share of import of the covered CN8 product over the total import of kaolinic clays in 2019 from Eurostat is recovered and applied as a correction factor to trade flows of kaolinic clay.
Source: HS codes are from the latest CBAM regulation (European Commission, 2023[18]). The conversion from the HS code to the NACE Rev. 2 code is accomplished through the NAICS mapping process provided by (Pierce and Schott, 2012[102]).

Table A A.2. Phasing out of free allowances

Year	EITE non-CBAM sectors	EITE-CBAM sectors	Other sectors
2025	100%	100%	100%
2026	100%	97.5%	63.7%
2027	100%	95%	47.8%
2028	100%	90%	31.9%
2029	100%	77.5%	16.0%
2030	100%	51.5%	0%
2031	100%	39%	0%
2032	100%	26.5%	0%
2033	100%	14%	0%
2034	**100%**	**0%**	**0%**

Sources: The factor of free allowances for CBAM sectors is retrieved from the EU CBAM regulation (European Commission, 2023[18]). For EITE non-CBAM sectors and other sectors, the trajectory is from the EU ETS Revision of Phase 4.

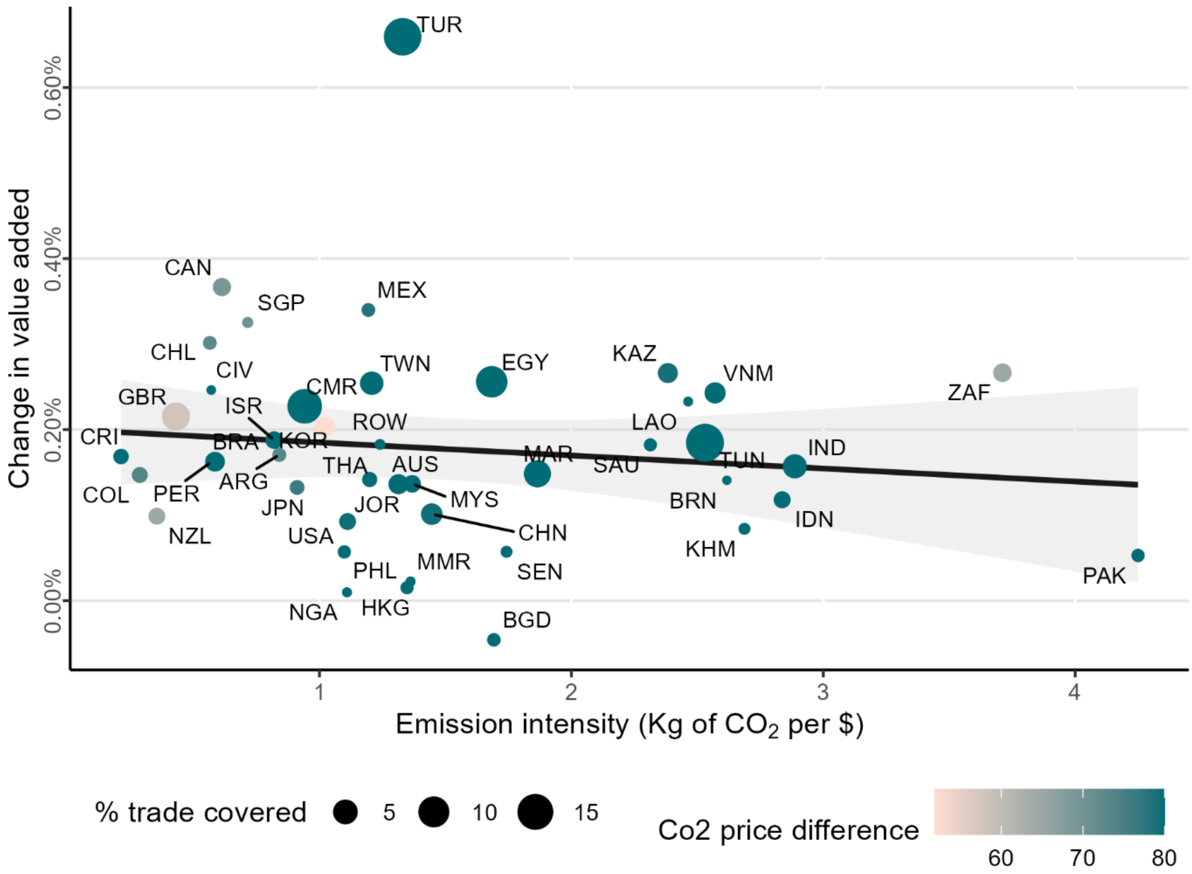
Figure A A.1. Elasticities used in the simulation



Source: van der Werf (2008[79]) and Hebbink et al. (2018[16])

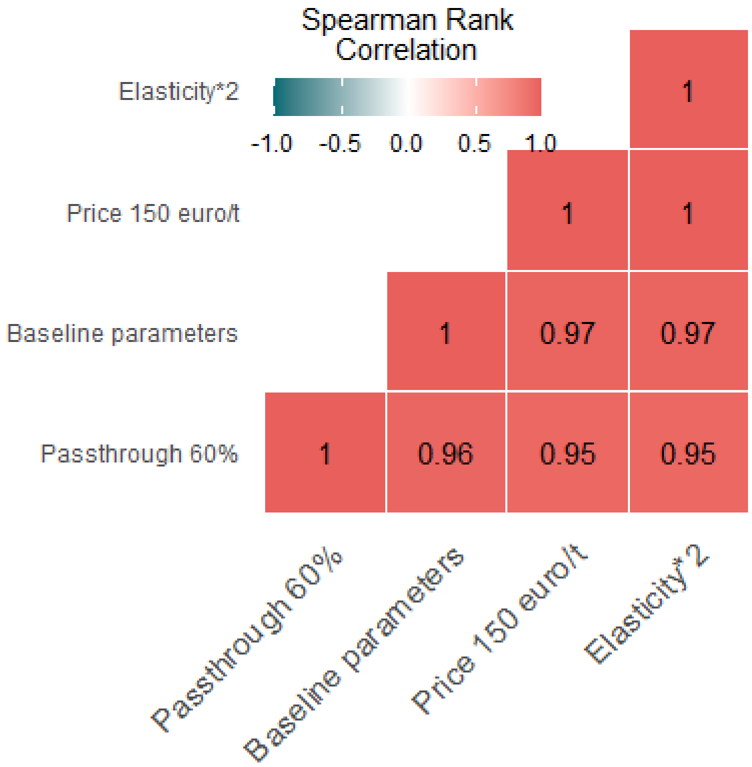
Figure A A.2. Emission intensity and simulated change in value added in non-EU countries

Change in value added across CBAM industries resulting from the reduction in free allowances and increase in carbon price.



Note: This figure plots the initial emission intensity in production in the CBAM sectors against the simulated change in value added in Scenario 2 (increase in EU ETS price + removal of free allowance) compared to the baseline scenario across CBAM industries in non-EU countries. The exposure to CBAM is mapped to the size of the data point and computed as the share of trade covered by CBAM in total trade in CBAM sectors as of 2019. Additionally, the colour of each data point indicates the difference in carbon price between the local price and the EU ETS price. Ukraine, Belarus, and Russia are dropped from this analysis, as well as Norway, Island, and Switzerland, which are not covered by the CBAM.
Source: OECD computations

Figure A A.3. Ranking correlation heat map of the impact on value added of the Full Policy Mix Scenarios across simulation with alternative parameters.



Note: The impact on value added by the Full Policy Mix Scenario has been calculated for each country and industry within our sample across four different simulations: one using baseline parameters and three others as outlined in the sensitivity check section. This plot illustrates the Spearman rank correlation matrix for the value added impact across these simulations. Each cell of the matrix displays the correlation coefficient, representing the relationship between the value added impacts of each pair of simulations.
Source: OECD computations.

Annex B. Derivation of the energy intensity correction factor

The correction factor used to compute the emission intensity of CBAM goods in Section 0 measures the ratio of the emission intensity of CBAM goods in sector r and country i to the average emission intensity in the sector. To simplify the notation, the subscript i and r are omitted.

$$\frac{emission\ intensity^{CBAM}}{emission\ intensity} =$$

Under the assumption that the CBAM export share computed from COMTRADE ($\mathrm{Share}^{\mathrm{CBAM}}$) are equal to the production share of CBAM goods in the sector:

$$= \frac{emission\ intensity^{CBAM}}{emission\ intensity^{CBAM} * \mathrm{Share}^{CBAM} + emission\ intensity^{Not\ CBAM} * \mathrm{Share}^{\mathrm{Not\ CBAM}}}$$

Taking into account that $\mathrm{Share}^{\mathrm{Not\ CBAM}} = 1 - \mathrm{Share}^{\mathrm{CBAM}}$ and $emission\ intensity^{CBAM} = emission\ intensity^{not\ CBAM} * \gamma$, where γ is the ratio of the emission intensity of the CBAM products to non-CBAM products computed from the USEEIO data :

$$= \frac{emission\ intensity^{not\ CBAM} * \gamma}{emission\ intensity^{not\ CBAM} * \gamma \ * \mathrm{Share}^{\mathrm{CBAM}} + emission\ intensity^{Not\ CBAM} * (1 - \mathrm{Share}^{\mathrm{CBAM}})}$$

$$= \frac{\gamma}{\gamma \ * \mathrm{Share}^{\mathrm{CBAM}} + \left(1 - \mathrm{Share}^{\mathrm{CBAM,}}\right)}$$

Annex C. Scope 2 and 3 emissions

This section presents the methodology to compute the Scope 2 and 3 emissions embodied in imported goods covered by CBAM (if applicable). CBAM covers Scope 2 emissions arising from the generation of electricity used in the production process of a subset of products, namely for cement and fertilisers (European Commission, 2023[18]; European Commission, 2023[33]). Embedded emissions from input materials, Scope 3 emissions, are incorporated within the CBAM scope, as long as these input materials are themselves covered by the CBAM and are included in the list of relevant precursors specified in Annex II of the CBAM regulation.

Scope 2 emissions

The cost of embodied Scope 2 emissions, $\mathrm{Cost}_{\mathrm{ir}}^{\mathrm{embodied\ em,2}}$, measures the cost of emissions associated with generating the electricity used in the production of sector 1

$$\mathrm{Cost}_{\mathrm{ir}}^{\mathrm{embodied\ em,2}} = \sum_k (p_{EU}^{CO2} - p_k^{CO2}) * Z_{irk\ elec} * \frac{Emission_{k,\ elec}}{X_{k,\ elec}}$$

where *k* and *i* are non-European countries, $Z_{irk\ elec}$ is the intermediary electricity produced in country *k* and used in the production of cement or fertilisers in country *i*. If a carbon price is paid in the electricity-originating country *k*, p_k^{CO2}, it can be deducted from the EU ETS carbon price p_{EU}^{CO2}. $\frac{Emission_{k,\ elec}}{X_{k,\ elec}}$ is the emission intensity of the electrical sector in country *k*.

The cost associated with Scope 2 emission for the trade flow from sector *j* to sector *s* is then:

$$Costs_{ijr}^{Scope\ 2} = \widetilde{Share}_{ijr}^{fertiliser\ or\ cement} * Comtrade_{irj} * \frac{\mathrm{Cost}_{\mathrm{ir}}^{\mathrm{embodied\ em,2}}}{X_{ir}}$$

Where *j* is a European country and *i* is a non-European country and r is the sector of origin producing fertiliser of cement, $Comtrade_{irj}$ is the trade flow of from country *i* and sector *r* to country *j*, $\widetilde{Share}_{ijr}^{fertiliser\ or\ cement}$ is the share of fertilisers or cement products in total import recorded between sector *r* in country *i* and origin *j*[2], and X_{ir} is the gross output of sector *r* in country *i*.

Scope 3 emissions

The cost of embodied Scope 3 emissions, $\mathrm{Cost}_{\mathrm{ir}}^{\mathrm{embodied\ em,3}}$, measures the cost associated with the emission embodied in the CBAM product produced by sector *r* in country *i* from the sector *l* producing the targeted precursors in country *k*:

$$\mathrm{Cost}_{\mathrm{ir}}^{\mathrm{embodied\ em,3}} = \sum_{l\ precursor\ of\ r} \sum_k (p_{EU}^{CO2} - p_k^{CO2}) * Z_{irkl} * \mathrm{Share}_{\mathrm{klir}}^{\mathrm{Precursor}} * emission\ intensity_{kl}^{\mathrm{Precursor}}$$

where *k* and *i* are non-European countries, Z_{irkl} is the intermediary product flow produced in country *k* sector *l* and used in country *i* and sector *r*. $\mathrm{Share}_{\mathrm{kl}}^{\mathrm{Precursor}}$ is the share of precursors in the trade flow from kl to ir based on Comtrade. If a carbon price is paid in the precursor country *k*, p_k^{CO2}, it can be deducted from the EU ETS carbon price p_{EU}^{CO2}.

To construct the emission intensity, $emission\ intensity_{kl}^{\mathrm{Precursor}}$, is adjusted for the precursor-specific emission intensity as follows:

$$emission\ intensity_{kl}^{\mathrm{Precursor}} = emission\ intensity_{kl} * \frac{\gamma_{\mathrm{k}}}{\mathrm{Share}_{\mathrm{kl}}^{\mathrm{Precursor}} * \gamma_{\mathrm{k}} + (1 - \mathrm{Share}_{\mathrm{kl}}^{\mathrm{Precursor}})}$$

where γ_k is the correction factor for emission intensity derived from the USEEIO data, which corrects for the fact that precursor goods may be more emission-intensive than other goods of their sector (see .

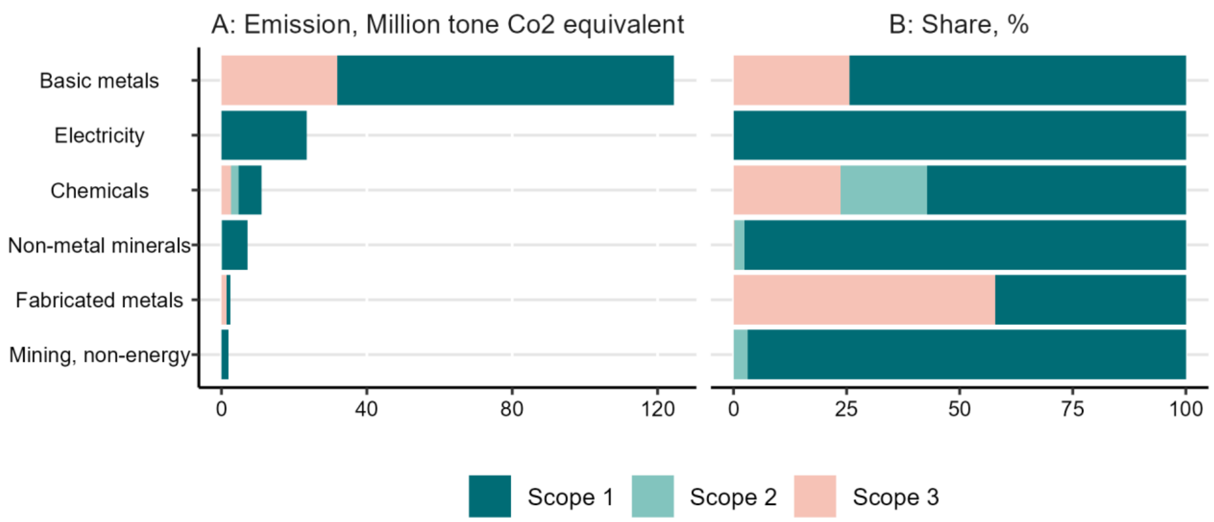
The cost associated with Scope 3 emission for the trade flow from sector *ir* to sector *js* then defined as:

$$\mathrm{Costs}_{ijrs}^{\mathrm{Scope3}} = \widetilde{\mathrm{Share}}_{\mathrm{ijr}}^{\mathrm{good\ with\ precursors}} * Comtrade_{irj} * \frac{\mathrm{Cost}_{\mathrm{ir}}^{\mathrm{embodied\ em,3}}}{X_{ir}}$$

where $\widetilde{\mathrm{Share}}_{\mathrm{ijr}}^{\mathrm{good\ with\ precursos,\ trade\ based}} = \frac{Precursor_{ijr}}{Total_{ijr}}$ is the share of goods with precursors in total trade flow from *kl* to *i* recorded in Comtrade.

Figure A C.1. The CBAM is primarily covering Scope 1 emissions from the Basic metals sector

Covered emission by exporting sector and scope, in absolute terms and share of total costs, 2022



Source: Comtrade, ICIO, OECD computations.

Annex D. Modelling approach

Modelling the gains in efficiency

The increase in emission prices due to changes in the EU ETS scheme is expected to incentivise firms within covered sectors to improve their emission efficiency. The revised emission intensity for production in country j and sector s, denoted as $EI'_{j,s}$, is computed using the following formula:

$$EI_{j,s}^{EU'} = EI_{j,s}^{EU} * (1 + \Delta price^{CO2} * \ share_{j,s}^{cov\ ETS} * \varepsilon)$$

where:

- $EI_{j,s}$ represents the baseline emission intensity of production.
- $\Delta price^{CO2} *$ denotes the change in the price of emissions in the EU ETS.
- $share_{j,s}^{cov\ ETS}$ is the proportion of emissions covered by the EU ETS for sector s in country j, reflecting the policy's partial coverage.
- ε is the semi-elasticity of emission intensity to changes in the carbon price, informed by empirical research; specifically, Dussaux (2020[78]) finds that a EUR 10 increase in carbon tax leads to a 2% reduction in emission intensity.

It is important to note that the presence and reduction of free allowances do not affect the marginal cost of emission abatement directly. Therefore, this adjustment does not influence $EI'_{j,s}$, focusing solely on price induced efficiency improvements.

In countries not covered by the CBAM, the emission intensity is also impacted by the European

Similarly, for non-EU sectors covered by the CBAM, the implementation of the policy means that a share of their emissions is now indirectly covered by the EU carbon price. Compared to most EU sectors, this share remains marginal.

$$EI_{j,s}^{CBAM'} = EI_{j,s}^{CBAM} * (1 + \Delta price^{CO2} * \ share_{j,s}^{cov\ CBAM} * \varepsilon)$$

where:

- $share_{j,s}^{cov\ CBAM}$ is the proportion of emissions covered by the CBAM. It is computed based on the Scope 1 emission embedded in the exports to the EU in total emission of the sector.

Efficiency gains resulting from the increase in EU ETS prices and the implementation of the CBAM lead to reduced costs for European importers and industries. These gains are quantitatively reflected in the adjustments to the final costs used as inputs in our model. The adjusted costs account for the improved emission intensities in both EU countries and CBAM-covered non-EU countries. The formulas for adjusting the costs based on the efficiency gains are:

- For EU countries, in sectors covered by the EU-ETS:

$$\Delta CostETS'_{j,s} = \Delta CostETS_{j,s} * \frac{EI_{j,s}^{EU'}}{EI_{j,s}^{EU}}$$

- The cost associated to exports from sectors *r* and countries *i* covered by the CBAM to an European country *j* :

$$CBAM_{ijr}{}' = CBAM_{ijr} * \frac{EI_{i,r}^{CBAM}{}'}{EI_{i,r}^{CBAM}}$$

The price model with substitution

To measure how changes in the price of emission in the EU-ETS, the reduction of free allowance and the implementation of the CBAM impact prices at the sectoral level, the analysis is based on a revisited Leontief Price model that introduces some substitution between energy input on one side and capital and labour on the other.

The aim of this step is to measure how the direct cost paid by European industries is transmitted along the value chain. The computation of the direct cost of the different policies $Cost_{j,s}$ (is described in Section 0 and 0 and in the previous appendix section3

The change in price is modelled following a revisited Leontief Price model based on (Hebbink, 2018[16]) :

$$\Delta p = L'\Delta Vc + L'.\Delta A'.p$$

ΔA t

The first term corresponds to the classical Leontief price model, where :

- ΔVc is the increase in costs per unit of output induced by the different policies computed for each sector and detailed in Section 0 and 0:

$$\Delta Vc = \frac{Cost_{j,s}}{GO_{js}}$$

- L' the Leontief inverse

The second term measure the substitution of the energy input by capital and labour. Deriving

- $\Delta A'$ measure the changes in technical coefficients matric A that take into account the substitution of energy input by capital and labour. The substitution is computed following the procedure propose in Hebbink, 2018[18] (Appendix pages 6 and 7).
- p is the price vector.

Change in trade flows and final demand

Following the change in price, change in domestic final demand and imported quantity are adjusted according to the price elasticity as follows:

$$fd_{jr}^{dom'} = fd_{jr}^{dom} \times \left(1 + \Delta p'_{jr} \times E_{fd,r}\right) \tag{8}$$

$$Imp_{ijr}^{fin'} = Imp_{ijr}^{fin} \times \left(1 + \Delta diffprice_{ijr}^{fin} \times E_{Imp,r}\right) \tag{9}$$

$$Imp^{int'}{}_{ijr} = Imp_{ijr}^{int} \times \left(1 + \Delta diffprice_{ijr}^{int} \times E_{Imp,r}\right) \tag{10}$$

where

- $fd_{jr}^{dom\prime}$ is the simulated domestic final demand in country *j* and sector *r*,
- $E_{fd,r}$ is the price elasticity of final demand in sector *r*,
- $Imp^{int\prime}{}_{ijr}$ & $Imp^{int\prime}{}_{ijr}$ is the altered import quantity of intermediate and final good from country *i* and sector *r* to country *j,*
- $\Delta diffprice_{ijr}$ measure the change in the difference of price between *i* and all other foreign suppliers of country *j* for goods of sector *r,*
- $E_{Imp,r}$ is the trade elasticity in sector *r*.

A crucial step in the modelling exercise is to simulate how traded quantities change after the introduction of the CBAM and the simultaneous removal of free allowances. The model takes into account price changes induced by the simulated policies. The difference in prices between exporter *i* to country *j* and the relevant alternative supplier of *j*, $\Delta diffprice_{ijr}^{int}$, is defined as:

$$\Delta diffprice_{ijr}^{int} = \left(\Delta p_{ir} + C_{ijr}^{CBAM}\right) - \Delta p^{int\prime}{}_{jr} \tag{11}$$

where Δp_{ir} is the change in intermediate good price in the exporting country *i* for sector *r,* and C_{irs}^{CBAM} is the CBAM cost paid by European importers, that is different from zero only for CBAM-covered goods imported from non-European countries to the EU. $\Delta p^{int\prime}{}_{jr}$ is a price index measuring the average change in price for all foreign suppliers of country *j*, and is defined as:

$$\Delta p^{int\prime}{}_{jr} = \sum_{k\neq j}^{K} \boldsymbol{w_{jkr}^{int}} \left(\left(\Delta p_{kr} + C_{irr}^{\mathrm{CBAM}}\right)\right) \tag{12}$$

where $\boldsymbol{w_{jks}^{int}}$ is the share of intermediate goods of sector *r* sourced in country *k* by country *j.*

The computation of $\Delta diffprice_{ijr}^{fin}$ mirrors the computation of $\Delta diffprice_{ijr}^{int}$ to the important difference that final goods are not covered by the CBAM ($C_{irs}^{\mathrm{CBAM}} = 0$).

Measuring Change in Production - Quantity model

The final step of the simulation requires computing the production necessary to satisfy the final demand and trade flows defined previously.

First, a new technical coefficient matrix A'' is defined. This matric essentially accounts for sectors' production function: how many units of each intermediary input are required to produce one unit of final good. As detailed before, the simulated change in price led to changes in international trade flows of intermediate goods ($Imp^{int\prime}{}_{ijr}$), reflecting that sectors are adjusting their input sourcing strategies.

However, to compensate for intermediary inputs that are not sourced from trading partners, the production function needs to adjust. Reduction in foreign sourcing is assumed to be fully offset by an equivalent increase in domestic sourcing. In our model there is no input substitution across sectors, only input substitution within sectors.

For example, if following the CBAM implementation, German car manufacturers reduce their imports of Chinese steel, they compensate by increasing their domestic consumption of German steel, so that the total quantity of steel used in the production of a car does not change.

As a results, the non-domestic elements of A'' are based on the simulated international trade flows of intermediate goods, while the domestic elements of the A''equal

$$A''{}_{ijrs} = \sum\nolimits_{i\neq j}^{I} \frac{Z_{ijrs} + \left(Imp_{ijrs}^{int} - Imp_{ijrs}^{int\,\prime}\right)}{X_{js}} \quad \forall i \neq j$$

Where Z_{ijrs} is the intermediate input sourced from country j and sector s from country i and sector r and X_{js} is the gross output of sectors in country j

The technical coefficient matrix addresses the question of 'how goods are produced' but does not answer 'how much is produced'. This is partly resolved in the previous section, where the demand for final goods ($fd_{jr}^{dom'}$, $Imp_{ijr}^{fin'}$) and of international flows in intermediate input $Imp^{int'}{}_{ijr}$.are simulated However, this answer is incomplete, as changes in any of those components will have an indirect value chain effect. For example, if demand for German cars increases, this will, in turn, increase the demand for intermediary input necessary to their production.

The Leontief demand model is used to simulate the total production while considering these input-output links. The quantity of traded intermediate and final goods is already set in the previous section; this model is run on the domestic economy alone. Formally,

$$X_j = L_j^{d'} * fd_j^d$$

Where :

- X_j is the vector of gross output in country j measuring total production,
- $L_j^{d'}$ is the Leontief inverse derived from the domestic technical coefficient matrix $A^{d''}$(made of all domestic components of A''),
- fd_j^d is composed of the domestic final demand and exports of intermediary and final goods produced in country j.

This step is an approximation. It notably disregards the international input-output linkages. Taking them into account would impact the imported quantity and require recomputing the cost of the CBAM.

[1] Fertilisers are part of the Chemical sector (D20), while Cement products are related to the Mining non-energy (D07T08) and Non-metal minerals (D23) sectors.

[2] For domestic cases (i=j), the US Environmentally-Extended Input-Output (USEEIO) tables are used to compute a domestic equivalent to $\widetilde{Share}_{ijr}^{fertiliser\ or\ cement}$.

[3]The direct cost varies across the scenarios following which policy mix is simulated $\Delta CostETS'_{j,s}, CBAM'_{ijr}, Cost\ FreeA_{j,s}$