

Analyzing CBAM's Effects on the Supply Chain: Green Growth or Green Inflation?*

Raphaël Semet
Université Paris-Saclay
raphael.semet@univ-evry.fr

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Abstract

This study investigates the economic implications of the European Carbon Border Adjustment Mechanism (CBAM). Designed as an implicit carbon tax at EU borders complementing the European Union Emissions Trading System (EU ETS), the CBAM aims to mitigate carbon leakage while supporting the EU's carbon neutrality objectives. Yet, its implementation may create supply chain distortions, with heterogeneous effects across countries and sectors in terms of carbon costs and inflationary pressures. Since the policy is yet to be implemented, some uncertainties remain regarding its design, including product coverage, carbon intensity measurement, and downstream spillovers. To address these challenges, this paper develops an import-based price model grounded in Leontief's input-output framework. Multiple regulatory scenarios are simulated to assess the short-term implications of alternative design choices. The cascading effects of compliance costs are captured by integrating an empirically estimated markup approach into producers' price-setting behavior. Accounting for market structure heterogeneity enables a detailed evaluation of how costs are distributed across countries and products. Findings indicate that while the direct costs of CBAM may remain modest in a realistic baseline scenario, methodological choices in carbon intensity estimation can substantially amplify both inflationary pressures and windfall profits.

Keywords: Carbon pricing, decarbonization, CBAM, carbon tax, emissions trading scheme, net-zero emissions, input-output, supply chain, pass-through, markup

JEL Classification: Q5, H2, E3.

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1 Introduction

Creating an instrument such as the Carbon Border Adjustment Mechanism (CBAM) echoes Europe’s ambition to become a reference model for the environmental transition toward a carbon-neutral economy. Underpinned by the Green Deal, Europe intends to keep the promises made under the Paris Agreement, that is, reducing net GHG emissions by at least 55% by 2030 compared to 1990 levels to keep global warming below 2°C. Drawing on years of experience in structural reforms, economic planning, and carbon pricing, Europe is well-positioned to achieve ambitious goals. Still, it faces several obstacles that the CBAM could help address.

The European Green Deal’s ambitions for the environmental transition require a broad rollout of public policies to reduce domestic energy consumption and enhance energy efficiency (European Commission, 2019). Achieving this goal requires overhauling the European carbon pricing system, notably by establishing a new market for previously excluded sectors (e.g., buildings and transport) and tightening the EU Emissions Trading System (EU ETS) (Pietzcker *et al.*, 2021). This involves reinforcing the key principles of carbon pricing: expanding the emissions coverage while sustaining a high carbon price. A key step toward achieving the EU ETS stringency goal would be to reassess existing exemptions, particularly the persistent over-allocation of free allowances (Martin *et al.*, 2014; De Vivo and Marin, 2018; Grubb *et al.*, 2022).

In a global context where carbon pricing policies are yet to be the norm, deviant behaviors could undermine these efforts (Felder and Rutherford, 1993; Stiglitz *et al.*, 2017). Economists fear the rise in carbon leakage—the shift of production and emissions to regions with less stringent environmental regulations—within a European economy already weakened by international competition (Draghi, 2024). While evidence of carbon leakage has been limited so far at the European level (Dechezleprêtre and Sato, 2017; Joltreau and Sommerfeld, 2019; Fontagné and Schubert, 2023), it could surge if regulatory constraints are tightened. In this respect, pricing carbon at the borders is considered the optimal tool to ensure that any regulated product imported is subject to carbon pricing under conditions equivalent to those applied to domestic production (European Commission, 2023). In addition, by implementing this instrument, Europe aims to narrow the gap in global carbon pricing and level the playing field between EU industry and foreign producers.

Although it is yet to be implemented in 2025, the CBAM directive may encounter several challenges. Historically, the primary challenge has been ensuring alignment with World Trade Organization (WTO) rules, which mandate non-discrimination and prohibit preferential treatment (Fontagné and Schubert, 2023). As a varying import tax according to foreign carbon pricing level, the regulation could contradict those principles (Horn and Mavroidis, 2011; Mehling *et al.*, 2019). The CBAM also raises questions regarding fairness for emerging countries and whether it effectively transfers a substantial share of the transition costs onto them (Cosbey, 2008; Holmes *et al.*, 2011). Imposing additional costs on imported goods would likely increase demand for domestic output and reduce import volumes. Developing countries with export-led growth patterns are likely to voice such concerns (Boute, 2024; Böhringer *et al.*, 2022) with impacts on employment and expected growth (Magacho *et al.*, 2024; Sun *et al.*, 2024). More technical aspects also surround the CBAM design. As reported by the European Commission (2023), the cascading effects of carbon pricing might extend to downstream sectors, potentially shifting the risk of carbon leakage further downstream. Interdependencies within EU supply chains may foster adverse producer behaviors, while pass-through mechanisms can further amplify supply-driven inflationary pressures. Moreover, CBAM compliance costs depend on the carbon accounting conventions used to calculate emission intensities (European Commission, 2021a). Obtaining accurate estimates

is challenging for certain products in specific regions, leading regulators to rely on default carbon intensity values rather than actual measurements. Yet, methodological choices significantly influence the instrument’s effectiveness and subsequent costs (Rocchi *et al.*, 2018; Mehling and Ritz, 2020; Zhong and Pei, 2024).

This study seeks to clarify several of these questions by looking at the global supply chain empirically. The CBAM is analyzed using input-output tables to assess interlinkages between sectors’ production and consumers’ final demand. The representativeness and flexibility of such empirical modeling afford the opportunity for an accurate evaluation of the economic impact of such a measure on the global supply chain. After presenting the main features of the policy, including its objectives, design, and key implementation challenges, we propose to read the CBAM from the global supply chain. We analyze trade patterns, downstream dependencies, carbon intensity differences, and embedded emissions transfers of CBAM sectors at the regional level. Next, the economic repercussions of the CBAM regulation are analyzed using Leontief (1936)’s cost-push price model. We simulate various scenarios under which CBAM could be implemented, highlighting different emission accounting methodologies and the range of products they would cover.

While previous studies have used IO models to assess CBAM impacts (Rocchi *et al.*, 2018; Schotten *et al.*, 2021; Magacho *et al.*, 2024), our contribution lies in integrating cascading effects via a cost-plus markup pricing structure. This approach reflects the potential for regulated producers to pass on more than their compliance costs, depending on market structure (Hall and Hitch, 1939; Hall, 1988). We propose an empirical estimation of the markups from the approach of De Loecker and Warzynski (2012) and the estimation methodology derived from Rodríguez del Valle and Fernández-Vázquez (2021). The novel price setting enables us to quantify sector-level inflationary pressures, economic cost distribution, and windfall profit estimates.

Findings suggest that the economic cost of the CBAM remains relatively limited under a realistic design, combined with an allowance price of €100/tCO₂e. This is mainly because the covered goods represent just 2% of total EU imports. Once CBAM importers pay compliance costs, the economic costs of the regulation are also of low magnitude. One of the most critical insights is the amplification of economic costs due to methodological assumptions in CBAM’s design. The substitution of actual carbon intensities with default values triples the estimated compliance costs. Only one-fifth of the total CBAM-related burden stems from direct regulatory costs, while markup effects drive the remaining 80%. Thus, the actual burden of CBAM lies not in the tax *per se* but in how market structure intermediates cost transmission. This point is reinforced by the observation that CPI effects remain substantially lower than PPI impacts, indicating that producers, particularly downstream to competitive markets, bear a greater burden than consumers. Early estimates on windfall profits suggest they are concentrated in many sectors, such as materials, utilities, and industrials. For instance, under default intensities, materials record an average profit increase of 2–9%. These findings reveal that CBAM’s effectiveness and fairness hinge not only on product coverage or tax level but critically on methodological choices, which can significantly alter cost incidence and exacerbate distributional asymmetries, undermining the policy’s environmental integrity by unintentionally rewarding market concentration.

This article is organized as follows. Section 2 reviews the main features of the policy, including its objectives, design, and key implementation challenges. Section 3 presents the methodology used to read the CBAM using input-output tables. Trade patterns, supply chain linkages, and carbon emissions at the country and product levels are estimated for the initial CBAM-covered products. Section 4 presents the CBAM modeling to assess the economic repercussions of the regulation. Section 5 provides the main findings of this study. Finally, Section 6 proposes concluding remarks.

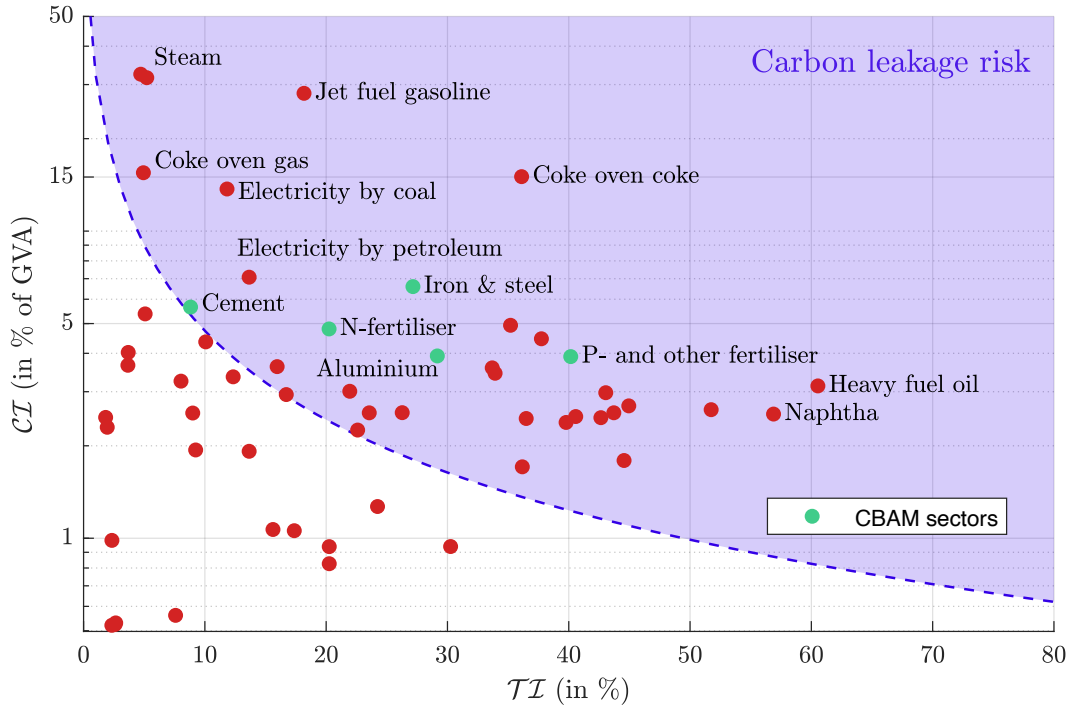
2 Designing a carbon border adjustment mechanism

2.1 The CBAM in practice

2.1.1 Objectives of the trade regulation

The remedy against carbon leakage Historically, the allocation of free allowances has mitigated the risk of carbon leakage in emission-intensive and trade-exposed sectors by exempting them from the compliance costs associated with carbon pricing schemes (Jakob, 2021). Given that heterogeneous climate commitments across countries create incentives for carbon leakage, enhanced international coordination in climate policy would reduce the likelihood of such leakage (Eyland and Zaccour, 2014). This rationale underpins the idea of a “coalition of the willing”, in which participating countries commit to emission reduction policies that are more effective and efficient when pursued collectively rather than unilaterally—a concept formalized by (Nordhaus, 2015) as the theory of climate clubs. In the absence of global cooperation, one unilateral strategy is to narrow regulatory asymmetries by subjecting imports to the same environmental standards as domestic production via a border carbon pricing mechanism (Markusen, 1975; Hoel, 1996). In light of substantial disparities in Nationally Determined Contributions (NDCs) and carbon pricing frameworks, the argument for establishing a level playing field has gained prominence over the continuation of free allocations.

Figure 1: Sector deemed at risk of carbon leakage in the EU



Source: Exiobase 2022 & Author's calculations.

This policy shift reinforces the rationale for implementing the CBAM to correct competitive distortions while upholding the credibility of climate commitments (Fontagné and Schubert, 2023). As shown in Figure 1, the inclusion of specific sectors in the CBAM is

grounded in their combined exposure to trade ($\mathcal{TI}$) and carbon intensity ($\mathcal{CI}$), two key indicators of carbon leakage risk.¹ Sectors such as aluminium, iron and steel, fertilisers, and cement are prominently positioned near or above the carbon leakage threshold, underscoring their structural vulnerability. Their concentration in this high-risk zone provides empirical justification for applying border measures that safeguard the environmental ambition of EU climate policy and the competitiveness of its most exposed industries.

Tightening the climate regulations gap Beyond addressing the risk of carbon leakage, the CBAM should also encourage the adoption of carbon pricing in foreign regions (Marcu *et al.*, 2020; Boute, 2024). Its goal is to ensure that domestic production and imports are subject to equivalent carbon pricing. The relative price increase should be proportional to the carbon content of the imported product, provided that no comparable regulation has been implemented. Therefore, imported products subject to an equivalent carbon price should not be affected by the CBAM. By design, the regulation indirectly intends to create incentives for third countries to adopt carbon pricing policies to mitigate emissions (Böhringer *et al.*, 2016; Parry *et al.*, 2021). Additionally, the EU’s extensive experience in carbon accounting and clean-technology improvements could support the implementation of carbon pricing in third countries (Perdana and Vielle, 2022). Another argument is that the CBAM may ultimately lead to revenue losses for exporting countries, thereby creating incentives to introduce their own carbon pricing mechanisms and retain fiscal revenues (Keen *et al.*, 2022; Parry *et al.*, 2021). In this light, the regulation should be understood not solely as a European initiative but as a potential driver of greater international convergence in climate policy.

2.1.2 Designing an optimal carbon border adjustment mechanism

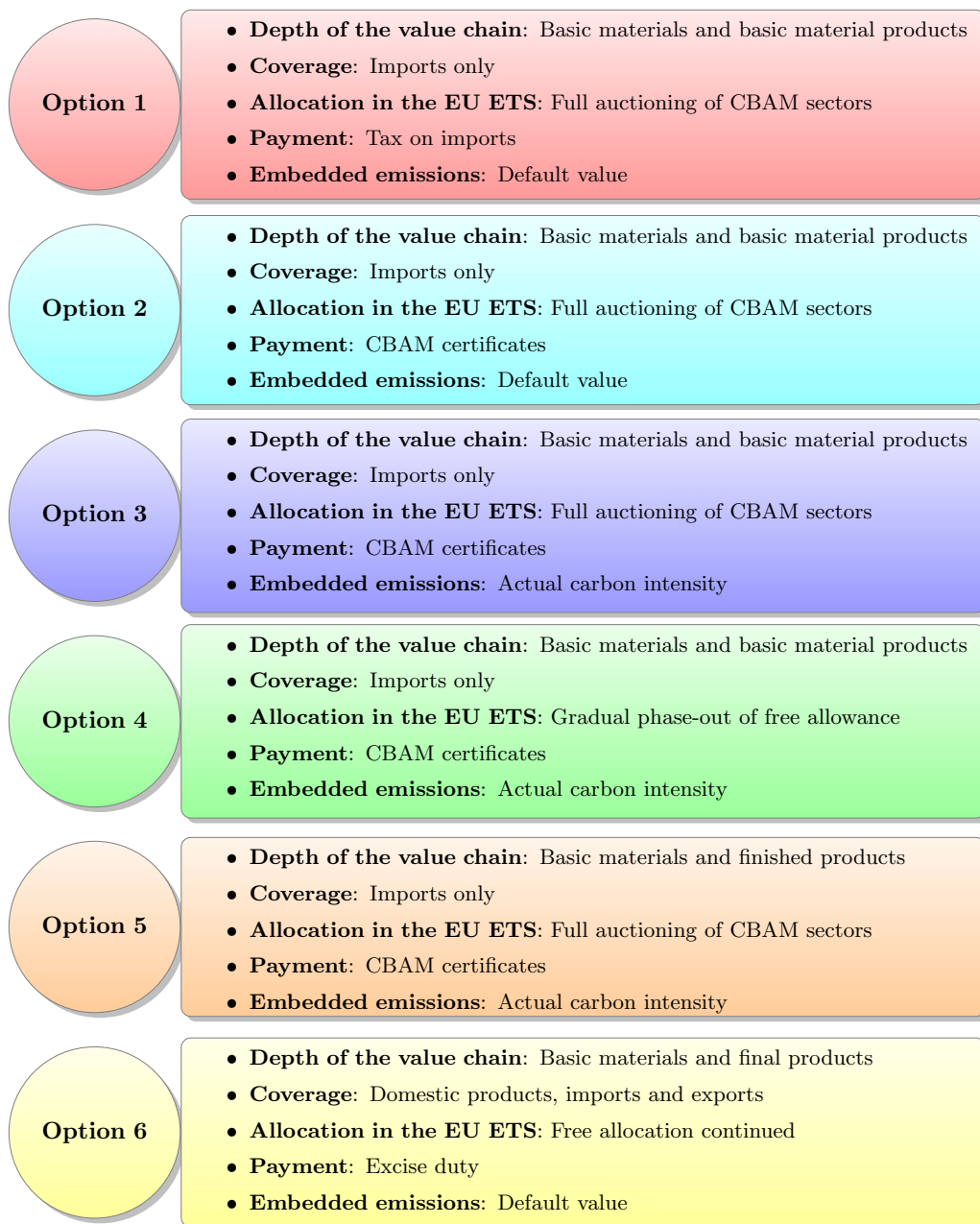
Scenarios proposal The design of the CBAM should be analyzed in a framework translating the evolving landscape of the EU ETS, notably in concordance with the “Fit for 55” package and the European Green Deal. In other words, the European pathway to reach carbon neutrality depends on external economic factors such as the energy and transport demand in line with population growth, economic and industrial activity dynamics, fuel prices, technology development, and market trends until 2050. Baseline economic scenarios² set the scene for the future of the EU ETS regarding allowance allocation.

There is no one-size-fits-all in the CBAM design. Various design features, such as sectoral coverage, embedded emissions estimation, allowance allocation, and payment methods, shape policy outcomes. In many cases, opting for one alternative over another can lead to significant trade-offs that affect the regulation’s overall efficiency. Therefore, the European Commission (2021a) proposed several options to gauge the policy’s efficiency. As presented in Figure 2, six policy options offer various approaches to five key design features: the depth of the value chain, product coverage, the allowance allocation process, the type of compliance payment, and the embedded emissions assessment. Each option differs from the other regarding one or several characteristics.

¹The detailed methodology is presented in section 4.3 on page 35.

²The baseline scenario known as the EU reference scenario 2020 (Capros *et al.*, 2021), *REF* sets the projection of macroeconomic aggregates to estimate future energy demand and subsequent GHG emissions pathway. The scenario assumes that ETS allowance allocation is given for free, remaining for sectors at high risk of carbon leakage while achieving the reduction target of 40% GHG abatement. The second scenario, known as the *MIX* scenario, accounts for the rising EU climate ambitions and aligns with a gradual decrease of the EU ETS cap in the coming years to achieve the 55% emission reduction goal by 2030. Under this scenario, the allocation of free allowances remains the main tool for dealing with the carbon leakage risk. A variant of this scenario assumes a full auctioning of allowances for CBAM sectors, which serves as a reference to test the CBAM counterfactual (*i.e.*, evaluate the CBAM impact on carbon leakage against other leakage protections).

Figure 2: Summary of the options considered for the design of the CBAM



Source: [European Commission \(2021a\)](#).

Option 3 appears as the default option since it shares all its characteristics with at least one other option. In this framework, the CBAM takes the form of CBAM certificates that the importer must buy on the market. If the surrendering mechanism is similar to the EU ETS, this market shouldn't be viewed as a cap-and-trade system since it has no cap on emissions and the price is fixed.³ Options 1 and 6 differ in this perspective. In option 1, the CBAM would apply to CBAM imports through a carbon tax. In option 6, which differs

³Setting an emissions cap would influence the EU's trade volumes, whereas allowing a dynamic price could shift carbon costs away from those established by the EU ETS ([European Commission, 2023](#)).

in many aspects compared to other options by integrating both border carbon adjustment and domestic consumption taxation, the payment is an excise duty. Regarding the depth of the value chain, the default coverage includes basic materials and basic materials products (Options 1, 2, 3, and 4). Option 5 enlarges the coverage by also including finished products. Option 6 considers emissions from all consumed products, whether from domestic production or not. As the CBAM could be viewed as an alternative to free allowance allocation, most options (Options 1, 2, 3, and 5) consider a full auctioning of allowances for CBAM sectors in the EU ETS. In option 4, the CBAM implementation is considered alongside a gradual phase-out of free allowances from 2025 to 2035. The CBAM size gets bigger proportionally as the allocation of free allowances decreases gradually. The purpose of option 4 is to adjust the implementation of the CBAM by allowing time for CBAM sectors to adapt gradually. Conversely, in option 6, free allowance allocation continues. The different options regarding the methodology used to estimate embedded emissions in CBAM compliance are split.

Most options (Options 3, 4, and 5) assume that actual carbon intensity is used to calculate the carbon costs of imports. In this case, the importer should report the accurate value of embedded emissions based on the carbon intensity estimation in third countries. Conversely, when the default method is preferred, as in the case of options 1 and 2, the carbon intensity value of imported products reflects the EU producers’ averages.

Compared to any other options, option 6 takes a more advanced approach, going beyond a pure carbon border adjustment mechanism. Imports of basic materials and products containing significant quantities of these materials would incur an excise duty. This aligns with the “destination principle” where goods are taxed where they are consumed, regardless of where they are produced. Thus, imports would face the same liability as EU-produced materials, based on the material’s weight and not on its specific production emissions. The excise duty would apply only once the product is released for consumption within borders. This option requires a robust system to monitor liability throughout the value chain.

Scope of emissions To mirror the EU ETS, emissions covered by the CBAM should follow the same ruling process. Thus, the policy mainly addresses carbon dioxide emissions (CO₂). Additionally, when it is relevant, nitrous oxide (N₂O) and perfluorocarbons (PCFs) are also subject to the EU directive. These gases are principally emitted in fertilizer making and aluminium smelting.

Regarding the scope of emission, the CBAM should focus primarily on direct emissions (Scope 1), which include emissions emitted during the production process over which the entity has direct control. Since the EU ETS also integrates emissions from electricity use, indirect emissions (Scope 2) might also be relevant to account for in the CBAM coverage. At the current stage of development, the CBAM does not account for the product’s entire carbon footprint,⁴ which includes emissions from every stage of its life cycle (Scope 3). This refers to upstream emissions, such as raw material extraction and production, and downstream emissions, such as transportation, retail, use phase, and eventual waste management.

Embedded emissions measurement The policy’s effectiveness and associated compliance costs depend on how the carbon content of imported products is measured. While the EU has standardized its carbon accounting framework, which facilitates domestic carbon intensity estimations, assessing the carbon content of foreign products can be complex and costly (Parry *et al.*, 2021; Lin and Zhao, 2023; Magacho *et al.*, 2024). As an option, default emissions values could be applied to imported products under certain circumstances.

⁴This might become an essential drawback of the regulation in terms of carbon leakage (Parry *et al.*, 2021). We discuss this point further in section 2.1.3 on page 9.

For simplicity, this default value may correspond to average EU producer levels, ensuring that imports and EU-produced goods are compared on an equal footing (e.g., in tCO₂e per tonne of material). In practice, determining the benchmark for embedded emissions can be complex, often relying on multiple stringency criteria such as best-in-class performance, the average carbon intensity of EU imports, or specific intensity deciles (Mehling and Ritz, 2020). Each approach raises concerns about fairness and effectiveness. Relying on values derived from developed countries may streamline data collection. Still, it would mechanically shift a disproportionate carbon burden onto developing countries (Magacho *et al.*, 2024; Zhong and Pei, 2024), potentially undermining the incentive structure intended to drive global abatement efforts (Mehling and Ritz, 2020). Conversely, calculating emissions at the source using actual production data may better align with principles of equitable treatment under global trade standards. Yet it introduces substantial challenges in verifying and harmonizing production standards across diverse supply chains (Rocchi *et al.*, 2018).

All in all, the regulation will likely opt to adopt default values initially to streamline the administrative process. If this method results in an overestimation of the carbon intensity of imported goods, importers will have the opportunity to provide evidence through current valuations. Therefore, the policy's effectiveness will depend on the complementarity of these two methodologies.

Product coverage In terms of product coverage, the CBAM focuses⁵ especially on basic materials and basic materials products. According to the definition of the [European Commission \(2021a\)](#), basic materials refer to derived materials from industrial processing of raw materials. They take the form of a substance or mixture of substances in a physical state. Conversely, basic materials products⁶ are products composed of one single basic material, generally produced within the entity making the basic material.

During the pilot phase of the CBAM, not all sectors within the carbon leakage list will be considered to fall under the directive. This exclusion is mainly due to some sectors' lack of product homogeneity,⁷ which creates significant uncertainties in measuring embedded emissions ([European Commission, 2021a](#)). This kind of product should not be considered in the pilot phase.⁸ As such, the [European Commission \(2023, Annex I\)](#) assumes a shortlist of homogeneous products that will be primarily targeted with their respective gaz:

- **Cement (CO₂):** kaolinitic clays, cement clinkers, white and other Portland cement, aluminous cement, and other hydraulic cements.
- **Electricity (CO₂):** electrical energy.
- **Fertilizers (CO₂ and N₂O):** nitric acid, sulphonitric acids, anhydrous ammonia, potassium nitrates, and various mineral or chemical fertilisers.

⁵Notice that an important feature is also related to practical feasibility ([European Commission, 2021a](#)). In other words, the material or product class should be clearly defined to ensure the feasibility of measuring embedded emissions and minimize the regulation's administrative burden.

⁶For example, focusing on fertilizer products, basic materials include ammonium nitrate, urea, and diammonium phosphate, each derived from nitrogen, phosphorus, or potassium. These basic materials are used to produce products such as NPK (nitrogen, phosphorus, potassium) fertilisers, which are applied directly for crop growth.

⁷For instance, refineries simultaneously produce a wide range of heterogeneous products, including gasoline, diesel, jet fuel, and petrochemicals. Each of these products has a distinct carbon intensity and production pathway, making it challenging to establish a single, standardized measure of embedded emissions across the sector.

⁸This concerns coke, mineral products, crude petroleum, food and beverages, non-ferrous metals, some chemicals, mining, wood-based panels, textiles, and nuclear fuel processing ([European Commission, 2021a](#)).

- **Iron and Steel (CO₂):** products such as ferro-silicon, iron ores, steel concentrates, sheet piling, railway or tramway track materials, tubes, pipes, hollow profiles, structural parts, reservoirs, tanks, vats, drums, screws, bolts, nuts, rivets, washers, and other articles of iron or steel.
- **Aluminium (CO₂ and PCFs):** unwrought aluminium, aluminium powders and flakes, bars, rods, profiles, wires, sheets, plates, strips, tubes, pipes, foil, reservoirs, tanks, vats, containers, casks, drums, cans, boxes, and other aluminium articles.
- **Chemicals (CO₂):** hydrogen.

We note that the electricity sector stands out as an exception under the CBAM rules. Indeed, the EU's electrical production does not receive allowances for free and shouldn't be considered at risk of carbon leakage. However, as electricity is a major source of direct and indirect emissions, the EU's ambitious climate plan could further widen the electricity cost gap between Member States and third countries. Before the complete unification of the electricity grid between countries, the CBAM should prevent incentives to buy electricity abroad and thus limit indirect carbon leakages.

2.1.3 Challenges in designing the right CBAM

Trade regulation barriers Since the beginning of discussions about adopting a CBAM regulation in Europe, one of the main obstacles has been ensuring its compliance with the General Agreement on Tariffs and Trade (GATT) of the World Trade Organization (WTO) rules and the United Nations Framework Convention on Climate Change (UNFCCC) principle of Common but Differentiated Responsibilities (Cameron and Baudry, 2023; Boute, 2024). The border tax mechanism's first drawback is aligning with the non-discrimination principle. The principle stipulates that any import shouldn't be subject to internal taxes that would be in excess of those applied in the domestic country (World Trade Organization, 1947, Article III). In other words, trade regulation cannot be discriminatory, favoring domestic markets over foreign markets. Under the most-favored-nation principle, a measure must not discriminate among imports from different WTO members (World Trade Organization, 1947, Article I). Yet, imposing higher compliance costs on carbon-intensive imports than on less carbon-intensive products could be considered discriminatory treatment (Mehling *et al.*, 2019). Some CBAM detractors are considering the proposal as a trade sanction in view of unfair protection of domestic industries to the detriment of export countries (Cosbey, 2008; Holmes *et al.*, 2011; Quick, 2021).

Nonetheless, it is possible to defend the CBAM project since the World Trade Organization (1947, Article XX) allows exceptions for measures protecting human, animal, health, life, and the conservation of natural resources. Still, the UNFCCC introduces another constraint, asserting that the CBAM applied without accounting for countries' different development levels would be discriminatory and misaligned with its principles. Indeed, the principle stipulates that an individual country's contribution to resolving the climate issue should be proportional to its historical liability and current capacity. Thus, some exemptions would be required to limit the adverse effects on economic prospects in vulnerable countries (Cosbey *et al.*, 2021; Perdana and Vielle, 2022).

To ensure regulatory compliance, the CBAM should be designed consistently with the treatment of imports and exports (OECD, 2020). The first approach follows the principle of imposing a carbon tax on imported products while exempting exported products from taxation (Monjon and Quirion, 2010). This is commonly referred to as a full carbon border adjustment and could be viewed as a consumption tax (Böhringer *et al.*, 2018). However,

such a mechanism would limit flexibility in price setting and complicate the determination of the appropriate tax level (Monjon and Quirion, 2010). Additionally, the rebate on exports would be difficult to justify in terms of environmental benefits. The second option is to mirror the EU ETS for EU imports, requiring importing installations to surrender permits corresponding to the carbon intensity of imported products at a price similar to that in the EU ETS. In this case, imported products would receive the same regulatory treatment as domestic products, making it a potentially viable option (Pauwelyn and Kleimann, 2020).

The complexity of embedded emissions, upstream and downstream supply chain

Implementing the CBAM at the level of basic materials offers the advantage of targeting relatively homogeneous imports with well-defined carbon content, thereby reducing administrative complexity. However, restricting the mechanism's scope to emissions from these upstream products may induce unintended consequences along the supply chain (Böhringer *et al.*, 2022). One risk is that non-EU producers may shift exports toward semi-finished goods outside the CBAM's coverage instead of supplying basic materials directly (Golombek *et al.*, 1995; Hoel, 1996). This substitution effect could partially offset the EU's industrial supply chain. Additionally, the increase in input costs for EU-based downstream sectors may expose these sectors to heightened leakage risk, particularly if demand for the taxed intermediate goods is elastic (European Commission, 2021a). In such cases, downstream producers could import more processed goods from third countries, which might displace emissions and the associated economic activity further downstream.

Furthermore, excluding downstream emissions may hinder the trade partners from transitioning toward cleaner energy sources. Non-EU manufacturers might optimize their processes only for basic materials, disregarding emission efficiency in subsequent steps of domestic production. They can also adopt cleaner production techniques only for EU exports while maintaining their carbon-intensive output for the rest of their trades (European Commission, 2021a). This kind of indirect carbon leakage is known as the resource shuffling issue, which may limit the mitigation potential of CBAM regarding global emissions (Mehling and Ritz, 2023).

Including semi-finished goods in CBAM could mitigate these effects, but further feasibility assessment regarding administrative efforts is required. For instance, exporters can exploit this caveat by spreading production across the global supply chain, making the embedded emissions computation task impossible. In addition, highly processed products generally involve a mixture of materials from various producers and production pathways of the global supply chain. The effect is exacerbated for steel and aluminium products, which serve as an input in several transformed products (*e.g.*, cars, machinery, or electronics equipment), making the initial use of the basic material largely diluted in the production process. Countries may avoid the CBAM's cost by keeping these steps offshore while still accessing the EU market.

The European Commission (2023) reviewed two main critical points to tackle downstream emissions. First, defining the optimal step level, or the n -tiers, of downstream production that involves producing subsequent goods using CBAM-covered products as inputs is essential. This would fall mainly on semi-finished products. Second, the carbon price level would also be critical. If the relative carbon cost of imports is low, its impact is diluted at each subsequent step of the downstream supply chain, posing little risk of carbon leakage. Conversely, with relatively high carbon prices, customers may experience a reduction in their value-added due to the additional cost, which should be taken into account.

Estimating the right pricing process of covered emissions To motivate the adoption of carbon pricing mechanisms and clean technology adoption in third countries, the compliance costs of exported products should be credited in accordance with the existing carbon pricing mechanisms. In the case of an existing pricing mechanism, the declarant may claim a rebate on the compliance cost paid. This would enforce the equalization of carbon pricing across regions while rewarding exporters who already operate under such mechanisms. For practicability purposes, only market-based instruments (*i.e.*, carbon tax and emissions trading systems) would be considered adequate in pricing emissions, but the carbon price should have been effectively paid (European Parliament, 2023b).⁹ This approach has drawn criticism, as an exclusive focus on market-based instruments may disadvantage countries pursuing alternative regulatory strategies and not align with the EU’s carbon pricing architecture. As Boute (2024) argues, conditioning CBAM compliance on adopting market-based instruments may ultimately undermine the policy’s global legitimacy and diminish its capacity to foster efficient emissions reductions. From the regulator’s perspective, this choice is justified by the need to simplify the carbon accounting system (European Parliament, 2023b). It is already challenging to compare market-based instruments due to differences in emission scopes, sector coverage, pricing mechanisms, exemptions, and offsets (Dao *et al.*, 2024). Expanding the scope of regulatory instruments to non-market-based instruments would substantially increase both the administrative burden and the uncertainty in emissions estimates (Marcu *et al.*, 2020).

2.2 Literature review on the CBAM induced costs

Since the beginning of the CBAM talks in Europe, the literature has exhaustively taken possession of the subject. At least four main literature reviews have been made on the topic (Branger and Quirion, 2014; Cosbey *et al.*, 2019; Böhringer *et al.*, 2022; Zhong and Pei, 2024), compelling over 100 published articles. While most articles in late 2010 focused more on administrative feasibility and trade regulation barriers, more recent articles have delved into the quantitative assessment of the policy’s economic, social, and environmental impacts (Zhong and Pei, 2024). These quantitative studies generally use either computable general equilibrium (CGE) or input-output (IO) models (Rocchi *et al.*, 2018; Schotten *et al.*, 2021; Magacho *et al.*, 2024).

2.2.1 The impact on carbon leakage and competitiveness

As a tool to prevent carbon leakage, the CBAM has predominantly been studied in terms of its capacity to reduce this risk effectively. However, it is challenging to verify carbon leakage mechanisms *ex-post*, advocating for very little empirical evidence of the phenomenon (Joltreau and Sommerfeld, 2019; Fontagné and Schubert, 2023). This lack of evidence in empirical studies partially results from weak historical data coverage in the case of the EU ETS. Studies are mainly concentrating on the first two trading phases during which a very low level of policy stringency (*i.e.*, free allowances allocation domination, low carbon price, high carbon offsets) was recorded (Branger *et al.*, 2016; Verde, 2020; Felbermayr *et al.*, 2024). Dechezleprêtre and Sato (2017) reviewed the literature on the impact of environmental policies and competitiveness. They found that environmental policies have an adverse effect, but are relatively small compared to the volume of trade flows. Similarly, Venmans *et al.* (2020) reviewed the empirical literature and found that the effect was not

⁹The mechanism should account for emissions generated during the production of exported products, whether from embedded carbon content or combustion, without factoring in free allowance allocation. Particular attention may also be given to any form of fossil subsidies.

statistically significant and of feeble magnitude. In contrast, some articles found a shift in embodied carbon emissions in developed countries (Peters and Hertwich, 2008). For instance, Aichele and Felbermayr (2015) found that commitments made under the Kyoto Protocol have increased embodied carbon imports by around 8%, resulting in a 3% increase in import emission intensity. Yet, Nielsen *et al.* (2021) found the opposite, suggesting that commitments do not lead mechanically to carbon outsourcing. In fact, Ferguson and Sanctuary (2019) stipulated that carbon-intensive producers' substitution from domestic to foreign inputs is rather tricky in the short run. Consequently, the effects of climate policy leakage would be relatively low in the short run.

Regarding the CBAM potential in limiting carbon leakage, most studies used *ex-ante* assessment through CGE models. Some studies estimate that the initiative will effectively tackle the carbon leakage risk (Böhringer *et al.*, 2012; Burniaux *et al.*, 2013; Branger and Quirion, 2014) and that most of the competitive loss would be restored (Kuik and Hofkes, 2010). The variation of relative prices induced by the CBAM might trigger two direct effects. First, domestic industries might benefit by producing locally as a response to the relative price increase of imported goods. However, this would ultimately increase downstream producers' intermediary input costs, which might be less competitive than similar imported products. The intensity of these two direct effects depends on the carbon content of the product, the price elasticity of demand, and the trade intensity (Bassi and Yudken, 2011). On the other hand, indirect effects are any behavior change that emerges as a solution to CBAM implementation, such as resource shuffling, bilateral trade restructuring, or climate initiatives.¹⁰

In contrast, Zhong and Pei (2024) suggested that the quantitative results of carbon leakage limit induced by the CBAM are not unanimous across studies. Most reviewed literature found no or relatively small effect (ranging from 2% to 12% with CBAM). Using empirical data from 2004, Jakob *et al.* (2013) estimated that a full CBAM —taxing imports while subsidizing exports— would increase carbon leakage for Chinese products under a European implementation. The mechanism is a shift in China's production from relatively low-carbon-intensive products to more carbon-intensive products that are not exported. Perdana and Vielle (2022) investigated the repercussions of the EU regulation on least developed countries. The results indicate that the CBAM lowers carbon leakage from 12.6% to 17% by 2040, representing a reduction of nearly one-third. Sun *et al.* (2024) estimated that the carbon leakage risk would not be reduced above 20%. They argue that the CBAM cannot offset competitiveness losses if the carbon tariff is too low, particularly given the limited price elasticities of intermediate inputs in the EU. Peterson and Schleich (2007) also found no carbon leakage reduction when imposing carbon border adjustment. Overall, these results conclude on the incapacity of such a mechanism to deter indirect carbon leakage (Cameron and Baudry, 2023).

2.2.2 The impact on trade flows, production prices, and GDP

As a carbon pricing mechanism, the CBAM would likely increase the production costs of targeted sectors. This compliance cost would primarily impact the domestic economy. Taking a large scope of product coverage (*e.g.*, ferrous and non-ferrous metals, oil, paper), Pyrka *et al.* (2020) estimated the CBAM costs in European economies. The total cost of

¹⁰The regulation can also enhance the competitive position of domestic producers, as it may encourage the adoption of climate-friendly technologies that would otherwise not emerge in the absence of such policy measures (Porter, 1991). Furthermore, environmental improvements can spill over to third countries, leading to emission reductions beyond the EU. This phenomenon, known as positive carbon leakage, operates through the innovation channel (Cameron and Baudry, 2023).

imports would increase by 1.6% in 2030, which might deter around 0.5% of European imports but widely diverge across Member States. In response, EU export prices would increase by 0.2% while export volumes would decrease by 0.7%. Nonetheless, the impact on GDP is close to zero. Using a static trade patterns framework, [Korpar et al. \(2023\)](#) also found minimal estimates. The CBAM would decrease EU exports by only 0.03%, while the EU region will slightly gain from the measure (+0.02%) at the expense of third countries with a subtle decline of 0.01% of GDP. Similar results are reported by [Sun et al. \(2024\)](#), which stated that these negligible direct effects are due to (i) a very limited product coverage, (ii) a low carbon price, and (iii) a relatively low level of extra-EU trade on the product covered. By considering effects induced by free allowances phasing out, [Bellora and Fontagné \(2022\)](#) found a 1.2% drop in GDP, mainly attributable to downstream sectors using CBAM-covered products as intermediary inputs. They highlight two opposing effects: a decline in imports from CBAM sectors and a rise in downstream imports driven by competitiveness losses. Also considering a broad range of product coverage from Exiobase, [Kuusi et al. \(2020\)](#) estimated that the CBAM would amount to 4.8% of extra-EU trade, which is 0.7% of total GDP for a €25 carbon price. For a €50 carbon price, [Schotten et al. \(2021\)](#) estimated that the CBAM would increase production cost by only 0.2% while not affecting the EU's competitiveness. Central and Eastern Europe regions are the most impacted, with the energy sector bearing the brunt of the costs. In these areas, carbon intensity exceeds Western Europe's, largely due to a heavier reliance on coal. Using WIOD tables, [Rocchi et al. \(2018\)](#) compared the economic impact of implementing a CBA by considering tariffs based on embodied emissions or avoided emissions. Findings suggest that implementing a CBA based on avoided emissions at the EU borders would mechanically impact non-metallic minerals, chemicals, and coke production but would lessen the economic impact in third countries.

By imposing an additional cost on imported goods, domestic alternatives become more competitive, likely increasing demand for domestic output and reducing import volumes or redirecting imports from economies with lower carbon intensities. Developing countries with export-led growth strategies and more carbon-intensive production technologies than the average are likely to voice such concerns. This demand shift may represent the third country's exposure to CBAM, translating into a substantial income shortfall ([Böhringer et al., 2022](#); [Sun et al., 2024](#); [Magacho et al., 2024](#)). According to [Magacho et al. \(2024\)](#), many developing countries face impacts on over 2% of their exports and 1% of their production. In particular, Eastern European nations, along with Mozambique, Zimbabwe, and Cameroon, are among those most exposed. Turkey is particularly exposed to this regulation. [Acar et al. \(2022\)](#) estimated that the measure's cost would amount to over 3% of Turkey's GDP by 2030. In terms of trade exposure, [Chepeliev \(2021\)](#) found that Ukraine will be the most impacted country, followed closely by the other European trade partners, with chemical products, iron, and steel being the most impacted products. According to [Sun et al. \(2024\)](#), India, Russia, Ukraine, South Africa, and Saudi Arabia will be the main losers, with their exports and GDP slightly declining. [Perdana and Vielle \(2022\)](#) found that the measure will be particularly harmful to least developed countries (LDCs). Welfare losses attributable to export reduction can be partially offset by making exemptions, but this becomes detrimental regarding carbon leakage. They conclude that the optimal scenario involves redistributing CBAM revenues to LDCs to support efficient energy use. Similar impacts have been found in Morocco ([Morchid et al., 2024](#)), South Korea ([Lee and Yoo, 2022](#)), and Russia ([Votinov et al., 2021](#)). Consequently, [Fouré et al. \(2016\)](#) warned that CBAM would involve trade retaliations, notably from China, India, and the USA, and, in exchange, introduce prohibitive duties. Though these effects would be rather small, [Overland and Sabyrbekov \(2022\)](#) determined a list of countries that might be particularly reluctant to implement CBAM. Conversely, some economies may benefit through increased exports driven by shifting demand. For instance,

Great Britain and Switzerland might enjoy an increase in CBAM product exports (Sun *et al.*, 2024; Korpar *et al.*, 2023).

3 Reading the CBAM from the MRIO perspective

The multi-regional input-output (MRIO) model is particularly suited for this research since it gives us a representative picture of trade interlinkages at the sector, product, and country levels. The environmental extension of MRIO is straightforward and allows many applications to evaluate climate policy implications (Perese, 2010; Kay and Jolley, 2023), notably regarding the cascading price impact on the global supply chain (Mardones and Muñoz, 2018; Roncalli and Semet, 2024). In this part, we present the basics of input-output analysis and provide descriptive results on the CBAM-covered products.

3.1 An overview of MRIO models and their extensions

Following the mathematical notation of Miller and Blair (2009), the n different sector-products¹¹ in m different regions, sell and purchase to each other through $Z_{i,j}^{r,s}$, representing the transaction matrix from sector i in region r to sector j in region s . In rows, the matrix accounts for the magnitude and source of the sector i 's output in region r , while reading in columns, the flows represent the sources and magnitudes of sector j 's input in region s .

As a national accounting framework, the table ensures that supply and demand are balanced. Supply is the sector's production or output x_i^r , while demand is represented by intermediate consumption of inputs $Z_{i,j}^{r,s}$ plus final demand $Y_i^{r,s}$. Compared to a single-economy input-output table where demand is composed of external sales (e.g., households, governments, foreign trades, and investment), the final demand in a multi-regional framework is composed of external sales from domestic and foreign regions. The following equation can represent the balance between supply and demand:

$$x_i^r = \sum_{s=1}^m \sum_{j=1}^n Z_{i,j}^{r,s} + \sum_{s=1}^m Y_i^{r,s}$$

where $z_i^r = \sum_{s=1}^m \sum_{j=1}^n Z_{i,j}^{r,s}$ depicts the total intermediary demand to sector i 's output in region r . In the multi-regional input-output case, the Z matrix is a block matrix of size $m, n \times m, n$ composed of m^2 sub-matrices of size $n \times n$. The block matrix representation in MRIO models is provided in Appendix A.1 on page 57. Compared to the single economy IO model, the MRIO model differentiates the source of final demand in the matrix Y of size $m, n \times m$. As previously stated, part of the final demand in the single-economy IO representation was devoted to exports to third countries. Direct exports from sector i in region r to region s can be retrieved by summing intermediate trade flows for input use in foreign regions and trade to satisfy foreign final demand, such that:

$$\mathcal{X}_i^{r \rightarrow s} = \sum_{j=1}^n Z_{i,j}^{r,s} + Y_i^{r,s} \quad \text{for } s \neq r$$

where $\mathcal{X}_i^{r \rightarrow s}$ represents direct bilateral exports of sector i 's output in region r to region s . For direct import of intermediate inputs of sector i in region r from region s :

$$\mathcal{M}_i^{r \leftarrow s} = \sum_{j=1}^n Z_{j,i}^{s,r} \quad \text{for } s \neq r$$

¹¹ As the input-output framework is generally associated with sectors production and interlinkages, we use the words sector-products, sectors, and products interchangeably.

Assuming that final demand can be aggregated at the sector-product level for each region r , we get $y_i^r = \sum_{s=1}^m Y_i^{r,s}$, or in matrix form: $y = Y \mathbf{1}_m$, such that $y = (y_1^1, \dots, y_n^m)$ represents the column vector of total final demand. Intermediate trade flows are commonly expressed as a ratio between $Z_{i,j}^{r,s}$ and x_j^s through $A_{i,j}^{r,s} = Z_{i,j}^{r,s}/x_j^s$. Matrix A represents the technical coefficients and is expressed as $A = \left(A_{i,j}^{r,s} \right) = Z \text{diag}(x)^{-1}$ where $Z \equiv A \text{diag}(x) = A \odot x^\top$.

Based on the main hypothesis of the Leontief model, namely, final demand is exogenous, technical coefficients are fixed, and the output level is endogenous, the following equation characterizes the basic relationship of the demand-pull quantity model $x = (I_{m,n} - A)^{-1} y$ where $I_{m,n}$ is the identity matrix of size $m, n \times m, n$. $\mathcal{L} = (I - A)^{-1}$ is known as the Leontief inverse or the total requirement matrix and defines the amount of total output from sector i in region r that is required by sector j in region s to meet its final demand. Thus, matrix A is central in any input-output applications requiring many properties check (see Appendix ?? on page ??). This set of equations comprises the demand-pull quantity model, which stipulates a clear dependence between output and final demand levels through fixed inter-sectoral dependency relationships.

The cost-push price model introduces an additional layer to the previous input-output framework. Sometimes referred to as the “*payment sectors*” (Miller and Blair, 2009, Chapter 2), the formation of total output is related to the use of primary production factors such as labor, capital, or primary energy, for instance. Let c be the number of primary inputs, and $V = \left(V_{k,j}^s \right)$ the value added matrix where the element of $V_{k,j}^s$ represents the amount of input k required to produce the output of sector j in region s . Thus, the j^{th} column sum, composed of intermediary and primary inputs (i.e., total inputs), is equal to the total output of sector j :

$$x_j^s = \sum_{r=1}^m \sum_{i=1}^n Z_{i,j}^{r,s} + \sum_{k=1}^c V_{k,j}^s$$

Summing across the c primary inputs gives the amount of total value-added from sector j in region s :

$$v_j^s = \sum_{k=1}^c V_{k,j}^s = x_j^s - \sum_{r=1}^m \sum_{i=1}^n Z_{i,j}^{r,s}$$

We denote v the column vector of total value-added $v = (v_1^1, \dots, v_n^m) = V^\top \mathbf{1}_c$. As in the quantity model, the interdependence between primary inputs and outputs can be expressed as a ratio of technical coefficients such that $B_{k,j}^s = V_{k,j}^s/x_j^s$ or $B = \left(B_{k,j}^s \right) \equiv V \text{diag}(x^\top)^{-1}$.

Let $p = (p_1^1, \dots, p_n^m)$ and $\psi = (\psi_1, \dots, \psi_c)$ be the vector of sector prices and primary inputs respectively. Then, we can specify the balance between sectors' inputs and outputs such that:

$$p_j^s x_j^s = \sum_{r=1}^m \sum_{i=1}^n Z_{i,j}^{r,s} p_i^r + \sum_{k=1}^c V_{k,j}^s \psi_k \quad (1)$$

Following [Desnos et al. \(2023\)](#), we deduce that:

$$\begin{aligned} p_j^s &= \sum_{r=1}^m \sum_{i=1}^n \frac{Z_{i,j}^{r,s}}{x_j^s} p_i^r + \sum_{k=1}^c \frac{V_{k,j}^s}{x_j^s} \psi_k \\ &= \sum_{r=1}^m \sum_{i=1}^n A_{i,j}^{r,s} p_i^r + \sum_{k=1}^c B_{k,j}^s \psi_k \end{aligned}$$

Knowing that $v = B^\top \psi$, and favoring the column vector writing, the previous equation can be expressed in matrix form:

$$p = \left(I_{m,n} - A^\top \right)^{-1} v$$

where $\tilde{\mathcal{L}} = (I_{m,n} - A^\top)^{-1}$ is the dual inverse matrix noted, representing the effect of primary input cost passed through to the intermediary prices of inputs composing output prices. Then, for any change in the value-added of sector j in region s , its output price variation is defined by:

$$\Delta p = \left(I_{m,n} - A^\top \right)^{-1} \Delta v \quad (2)$$

3.1.1 Environmental extension of the input-output model

[Leontief \(1970\)](#) introduced key methodological principles for adapting the basic input-output framework to environmental matters. In most applications, input-output models in monetary terms are augmented with environmental accounts to support national carbon accounting ([Perese, 2010](#)). The central idea is to connect carbon emissions embedded in production to the carbon footprint of final demand. This is achieved through two approaches: the output-based approach, focusing on downstream analysis, and the input-based approach, emphasizing upstream analysis.

The carbon accounting framework In order to specify a robust and comprehensive carbon accounting framework, the development of an accurate estimation of indirect emissions is required. Let's assume that only one pollutant is considered here, the GHG emissions. Let e_j^s be the direct emission level of sector j in region s expressed in tCO₂e. The direct carbon intensity is defined as the amount of CO₂e emitted per monetary unit of output:

$$d_j^s = \frac{e_j^s}{x_j^s}$$

In matrix form $d = e \text{diag}(x)^{-1}$. The total emissions level summarizes the direct and indirect emissions from the supply chain to produce one monetary unit of the j^{th} output in region s . In the case of the multi-regional input-output model, the analysis can be conducted at the country level while differentiating carbon liability between agents. We have:

$$\mathcal{E} = \text{diag}(d) (I_{m,n} - A)^{-1} Y$$

where matrix $\mathcal{E}$, of size $m, n \times m$, is the global emission matrix specifying the total emissions generated by each sector i in region r to satisfy final demand in region s . This matrix admits several accounting frameworks for cost-sharing decomposition ([Jiborn et al., 2020](#)). Read in column, the matrix sums up the consumption-based emissions (CBA):

$$\mathcal{E}_{\text{CBA}}^s = \sum_{r=1}^m \sum_{i=1}^n \mathcal{E}_i^{r,s}$$

Consumption-based emissions include all emissions associated with goods consumed in region s , regardless of where they are produced. In contrast, production-based emissions account (PBA) for all emissions generated within region r , regardless of where the resulting goods are consumed:

$$\mathcal{E}_{\text{PBA}}^r = \sum_{s=1}^m \sum_{i=1}^n \mathcal{E}_i^{r,s}$$

The elements at the cross-road between PBA and CBA represent the “*domestic-domestic*” emissions (Darwili and Schröder, 2023). It represents the domestic emissions embodied in domestic final demand:

$$\mathcal{E}_d^r = \sum_{s=1}^m \sum_{i=1}^n \mathcal{E}_i^{r,s} \quad \text{for } s = r$$

Furthermore, it is also possible to get details on emissions embodied in trade flows. As a result, we get export- and import-based emissions estimates given the source of production and destination of consumption. Denoting export-based $\mathcal{E}_{\mathcal{X}}$ and import-based $\mathcal{E}_{\mathcal{M}}$, we have:

$$\mathcal{E}_{\mathcal{X}}^r = \sum_{s=1}^m \sum_{i=1}^n \mathcal{E}_i^{r,s} \quad \text{for } s \neq r$$

$$\mathcal{E}_{\mathcal{M}}^s = \sum_{r=1}^m \sum_{i=1}^n \mathcal{E}_i^{r,s} \quad \text{for } r \neq s$$

Then, we can obtain the balance of emissions embodied in trade, which is the net difference between exports and imports of embodied emissions in trade:

$$\mathcal{E}_{\text{net}}^s = \mathcal{E}_{\mathcal{X}}^r - \mathcal{E}_{\mathcal{M}}^s \quad \text{for } r = s$$

This measure helps distinguish countries as net importers or net exporters of GHG emissions.

Illustration Let's consider an example. In Table 1, we present a simplified two regions ($\mathcal{A}, \mathcal{B}$) input-output table. Each economy is composed of two sectors (S_1 and S_2). Values of $Z_{i,j}^{r,s}, Y_j^{r,s}, x_j^r$ are expressed in € mn. The direct carbon emissions E are expressed in ktCO₂e, while the direct carbon intensities D are in tCO₂e/€ mn. For instance, the intermediary consumption $Z_{1,2}^{1,2}$ is equal to €800 mn, the final demand y_4^B is equal to \$3 bn, the output x_4 is equal to €12.5 bn, the carbon emissions level $E_{1,2}$ is equal to 20 000 tCO₂e and the direct carbon intensity $D_{1,4}$ is equal to 10 tCO₂e/€ mn.

Table 1: A two-regions, two-sectors input-output table (Example #1)

		Region $\mathcal{A}$		Region $\mathcal{B}$		$y^{\mathcal{A}}$	$y^{\mathcal{B}}$	x
		S_1	S_2	S_1	S_2			
Region $\mathcal{A}$	S_1	500	800	1 600	1 250	400	450	5 000
	S_2	500	400	1 600	625	475	400	4 000
Region $\mathcal{B}$	S_1	250	800	2 400	1 250	1 250	2 050	8 000
	S_2	100	200	800	4 375	4 025	3 000	12 500
		E	500	200	200	125		
		D	0.10	0.05	0.03	0.01		

Let's first compute the matrix of technical coefficients:

$$A = Z \text{diag}(x)^{-1} = \begin{pmatrix} 0.10 & 0.20 & 0.20 & 0.10 \\ 0.10 & 0.10 & 0.20 & 0.05 \\ 0.05 & 0.20 & 0.30 & 0.10 \\ 0.02 & 0.05 & 0.10 & 0.35 \end{pmatrix}$$

The global emissions matrix for the two regions, two sectors economy is defined by:

$$\begin{aligned} \mathcal{E} &= \text{diag}(D) (I_4 - A)^{-1} Y \\ &= \begin{pmatrix} 0.10 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.05 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.02 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.01 \end{pmatrix} \begin{pmatrix} 1.1881 & 0.3894 & 0.4919 & 0.2884 \\ 0.1678 & 1.2552 & 0.4336 & 0.1891 \\ 0.1430 & 0.4110 & 1.6303 & 0.3044 \\ 0.0715 & 0.1718 & 0.2993 & 1.6087 \end{pmatrix} \begin{pmatrix} 400 & 450 \\ 475 & 400 \\ 1250 & 2050 \\ 4025 & 3000 \end{pmatrix} \\ &= \begin{pmatrix} 243.59 & 256.40 \\ 98.31 & 101.68 \\ 87.89 & 112.10 \\ 69.59 & 55.40 \end{pmatrix} \end{aligned}$$

From the global emissions matrix, we can compute the different carbon accounts. In Table 2, we summarize the results for both regions. We take the perspective of Region $\mathcal{A}$:

$$\begin{aligned} \mathcal{E}_{\text{CBA}}^{\mathcal{A}} &= 243.55 + 98.32 + 87.89 + 69.59 = 499.39 \\ \mathcal{E}_{\text{PBA}}^{\mathcal{A}} &= 243.59 + 256.40 + 98.32 + 101.68 = 700 \\ \mathcal{E}_{\mathcal{X}}^{\mathcal{A}} &= 256.40 + 101.68 = 358.08 \\ \mathcal{E}_{\mathcal{M}}^{\mathcal{A}} &= 87.89 + 69.59 = 157.48 \\ \mathcal{E}_{\text{d}}^{\mathcal{A}} &= 243.59 + 98.32 = 341.91 \\ \mathcal{E}_{\text{net}}^{\mathcal{A}} &= 358.08 - 157.48 = 200.60 \end{aligned}$$

In a two-region set-up, imports from one region equal the exports of the other.

Table 2: Summary of carbon emissions accounting (Example #1)

	$\mathbb{E}_{\text{d}}$	$\mathbb{E}_{\text{CBA}}$	$\mathbb{E}_{\text{PBA}}$	$\mathcal{E}_{\mathcal{X}}$	$\mathcal{E}_{\mathcal{M}}$	$\mathbb{E}_{\text{net}}$
Region $\mathcal{A}$	341.9	499.4	700.0	358.1	157.5	200.6
Region $\mathcal{B}$	167.5	525.6	325.0	157.5	358.1	-200.6
Total	509.4	1025.0	1025.0	515.6	515.6	0.0

Upstream and downstream emissions Transforming the row vector D into a column vector noted $\mathcal{CI}_{\text{direct}}$, we deduce the total upstream carbon intensity of production:

$$\mathcal{CI}_{\text{total}}^{\text{up}} = \left(I_{m,n} - A^{\top} \right)^{-1} \mathcal{CI}_{\text{direct}} \quad (3)$$

In the same manner, let's consider $\mathcal{CE}_{\text{direct}}$ be the transpose of the row vector E . The previous mathematical expressions can be extended to account for absolute upstream emissions by simply multiplying by total output:

$$\mathcal{CE}_{\text{total}}^{\text{up}} = \mathcal{CI}_{\text{total}}^{\text{up}} \odot \frac{\mathcal{CE}_{\text{direct}}}{\mathcal{CI}_{\text{direct}}} = x \odot \mathcal{CI}_{\text{total}}^{\text{up}}$$

While the previous methodology informs on the output-based emissions analysis, we can also estimate the output’s decomposition in terms of input requirements (Desnos *et al.*, 2023). In this case, we are looking at the production stages based on backward sectoral linkages by moving down (*i.e.*, downstream) on the global supply chain rather than moving up (*i.e.*, upstream) by defining the technical coefficients for one monetary unit of input $\check{A}_{i,j}^{r,s} = Z_{i,j}^{r,s}/x_i^r$ where $\check{A} = (\check{A}_{i,j}^{r,s}) = \text{diag}(x^\top)^{-1} Z$ refers now to the proportion of one monetary unit produced by sector i in region r used by sector j in region s . In this sense, the model might be interpreted as “*supply-driven*”. From this reordered matrix, we pursue the same methodology as before to catch the carbon intensity of downstream production:

$$\mathbf{CI}_{\text{total}}^{\text{down}} = \left(I_{m,n} - \check{A} \right)^{-1} \mathbf{CI}_{\text{direct}}$$

The estimation of absolute carbon emissions follows the same principles as stated for the upstream analysis.

3.1.2 The Exiobase by-product tables

This study uses the latest version (2022) of multi-regional input-output (MRIO) tables from Exiobase 3 (Stadler *et al.*, 2018). The tables capture trade relationships among 44 countries and 5 rest-of-the-world regions.¹² Exiobase stands out as one of the most granular MRIO databases, detailing sectoral activities at the product level using various national accounts. Over 200 traded products are estimated to align import-export data across countries. This level of product disaggregation is well-suited for macro-level environmental analyses, particularly those aiming to inform consumption-oriented policies (Wood *et al.*, 2018). Since the CBAM targets specific products regulated under the EU ETS, our analysis relies on Exiobase’s detailed product-level data. However, a trade-off arises between regional and sectoral representativeness in multi-regional input-output (MRIO) databases. While we achieve reasonable coverage of EU ETS members (28 out of 33), Exiobase remains limited in its regional disaggregation,¹³ particularly with respect to emerging economies (Wood *et al.*, 2014).

With respect to the CBAM, the initial set of targeted products can be reasonably approximated using Exiobase. We use Exiobase’s *Cement, lime and plaster* category for cement commodities. For iron and steel, Exiobase aggregates these goods under *Basic iron and steel and of ferroalloys, and first products thereof*. Although the European Commission (2023, page 59) implicitly excludes ferroalloys, we cannot separate them from this category. Additionally, we include *Secondary steel for treatment and re-processing of secondary steel into new steel*, since the CBAM also covers the secondary fusion of iron and steel (European Commission, 2023, page 196). For aluminium, we rely on *Aluminium and aluminium product* while excluding *Secondary aluminium for treatment, Re-processing of secondary aluminium into new aluminium*, in accordance with the Commission’s guidance. We account for both *N-fertiliser* and *P- and other fertiliser* products, where nitrogen fertiliser includes nitrate, ammonia, ammonium, and urea; and phosphorus fertiliser includes diammonium and monoammonium phosphate. Although the CBAM initially targets hydrogen,¹⁴ it may be embedded in another category that cannot be identified separately in Exiobase. Finally, for the electricity market, we consider all sources,¹⁵ as well as *Steam and hot water supply services* and *Transmission services of electricity*.

¹²The complete list of regions is provided in Appendix 14 on page 59.

¹³For comparison, the GTAP database includes 134 countries, and EORA covers approximately 190.

¹⁴The inclusion of hydrogen in the CBAM underscores its strategic role in the EU energy transition.

¹⁵Geothermal; biomass and waste; coal; gas; hydro; nuclear; petroleum and other oil derivatives; solar photovoltaic; solar thermal; tide, wave, ocean; wind; and other.

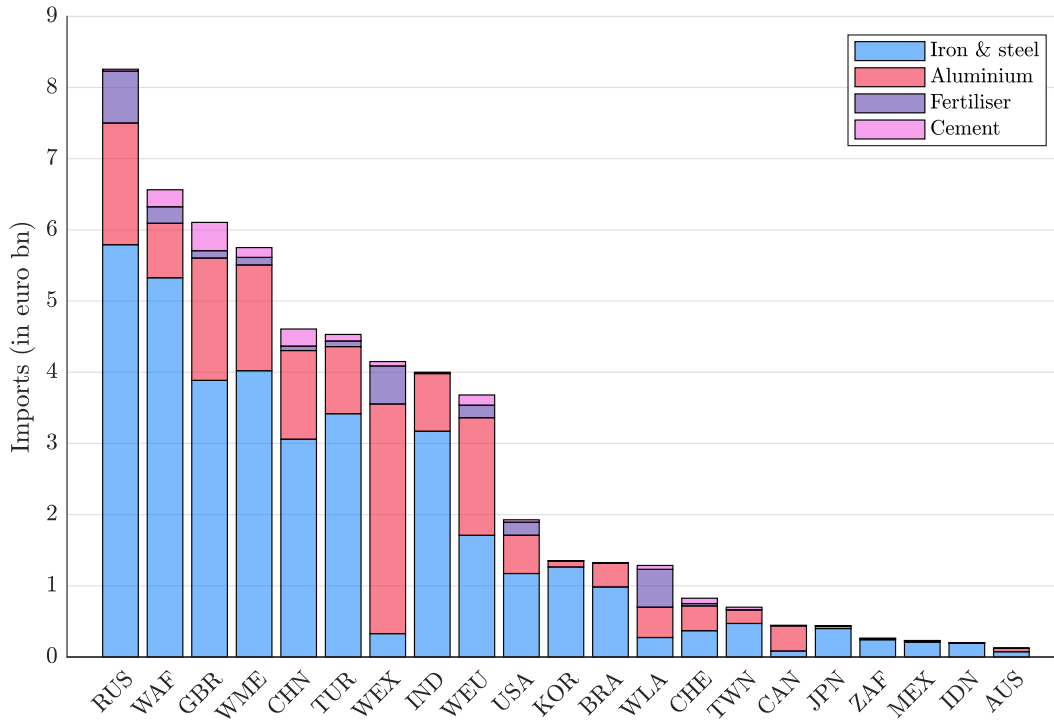
Through a social accounting matrix, Exiobase provides information on more than 400 industry-specific air emission categories derived from official statistics (e.g., Edgar, Eurostat, IPCC, EEA). Our carbon accounting framework estimates emissions based on carbon combustion.¹⁶ As the scope of the EU ETS also integrates N₂O and PFCs emissions from fertilizer and aluminium production, respectively, emissions are expressed as carbon dioxide equivalent (CO₂e).

3.2 Profiling CBAM-covered products

3.2.1 Trade analysis

At the region level In Figure 3, we illustrate total European imports of CBAM-covered products from non-EU regions. Overall, these imports amount to €56.77 bn, representing about two percent of total EU imports. Iron and steel imports drive the majority of these transactions, representing more than 65% of the total, followed by aluminium (28%). Cement and fertilisers constitute approximately 2% and 5% of CBAM imports, respectively.

Figure 3: European imports of CBAM-covered products from third countries (in € bn)



Source: Exiobase 2022 & Author's calculations.

Russia (RUS) is the largest exporter of CBAM-covered products to the EU, accounting for nearly 15% of total CBAM imports. The EU is heavily reliant on Russian iron and steel production. Russia is also providing more than 25% of total fertiliser European imports. Meanwhile, EU imports of CBAM-covered products only account for 1.8% of Russia's total exports. The African region¹⁷ ranks second, with the majority of its exports coming from

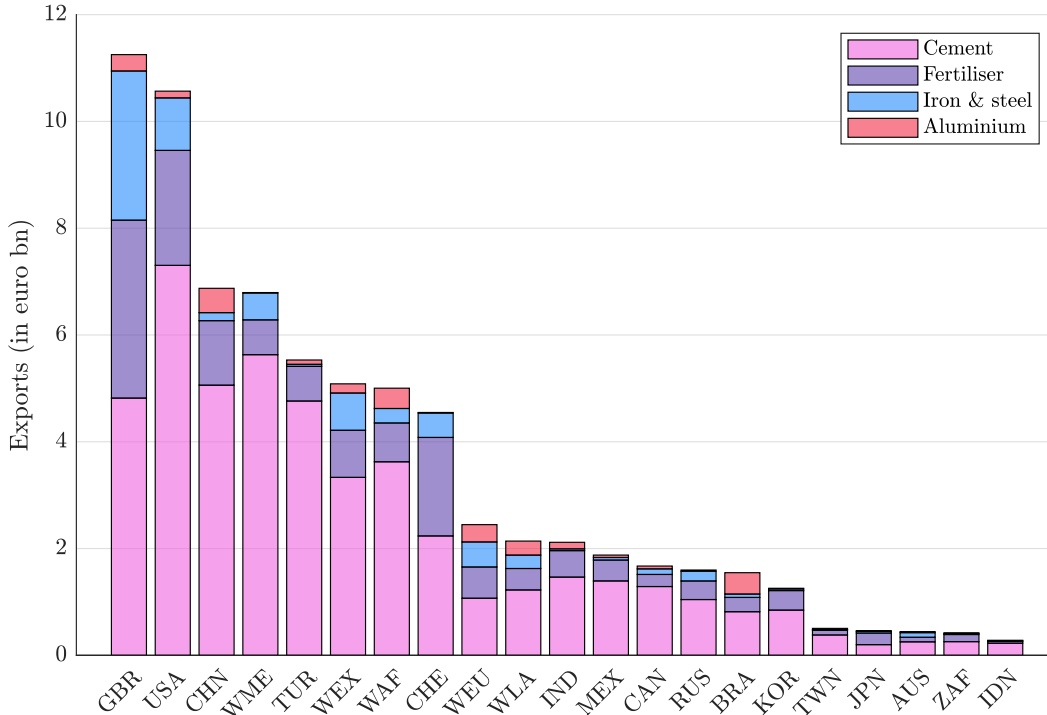
¹⁶Specifically, we use the carbon dioxide as defined by the IPCC categories 1-4 and 6-7, excluding land use, land-use change, and forestry.

¹⁷The rest of the world Africa (WAF).

iron and steel production, accounting for approximately 15% of total EU iron and steel imports. In third place, we retrieve Great Britain (GBR), exporting €6.1 bn of CBAM-covered products to the EU. Together, these three exporters supply almost 40% of total EU CBAM imports. China (CHN) ranks fifth on the list, with CBAM exports representing less than 0.2% of its total exports. Meanwhile, China largely dominates global production (see Figure 12 on page 64), particularly in iron, steel, and aluminium, contributing 50% of the total global output in these sectors. Cumulatively, it holds nearly 48% of the global production of CBAM-covered products, which is four times the combined amount of the United States (USA), Germany (DEU), and Russia (RUS). Although India (IND) is a major producer of fertilisers, it ranks only eighth among CBAM exporters. Similarly, while the United States is the world's second-largest producer, closely behind China in cement production, and accounts for 7% of global output in CBAM-covered products, it ranks only tenth among CBAM exporters.

Regarding exports of CBAM-covered products from the EU to third countries, we illustrate trade relationships in Figure 4. Total CBAM-covered exports amount to €74.51 bn, making 2.33% of total EU exports. We notice that the CBAM product export patterns are diverging in terms of product ranking and bilateral trade relationships. Cement and fertiliser products are the two main exported CBAM-covered products, accounting for 65% and 21% of total CBAM exports, respectively. Bilateral exports between the EU and third regions are particularly pronounced with Great Britain and the USA. Both regions account for approximately 17% of the total EU's cement exports. These exports only represent 0.07% and 0.27% of the total imports of these countries, respectively. China is ranked third but relatively far behind the USA, accounting for a mere 10% of total CBAM exports.

Figure 4: European exports of CBAM-covered products to third countries (in € bn)

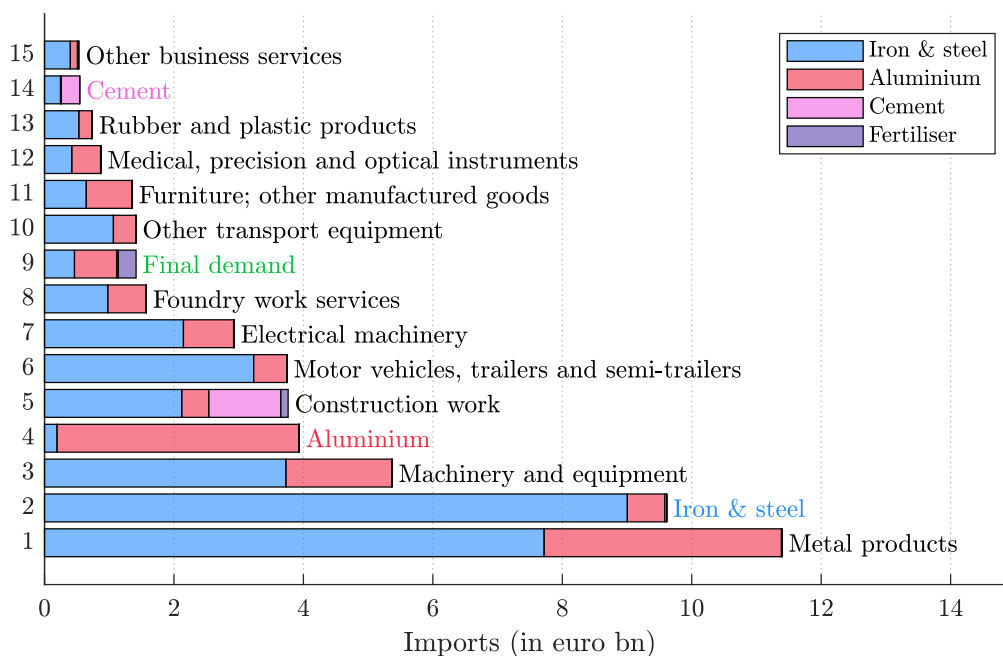


Source: Exiobase 2022 & Author's calculations.

Overall, the EU seems to be a net exporter of CBAM-covered products. In more detail, the EU is a net exporter of fertiliser and cement products but rather a net importer of iron, steel, and aluminium. If those estimates on trade relationships with respect to third countries are informative for the cost-sharing impact of the measure, we highlight a high density of CBAM-covered trade within EU borders. We illustrate this in Figures 13 and 14 on page 65. Total exports of CBAM-covered products within EU borders represent €9.9 bn, mainly driven by aluminium and fertiliser. Total imports amount to €2.5 bn and are led by aluminium, iron, and steel. In both cases, Germany is the biggest trade partner, accounting for 22% of total exports and more than 30% of total imports.

At the product level Trade relationships for CBAM-covered products should also be examined at the product level. As basic materials, these products are closely linked to both upstream production —relevant for estimating indirect emissions (*i.e.*, Scope 3 upstream)—and downstream manufacturing processes (*i.e.*, Scope 3 downstream). Therefore, understanding the trade patterns of these upstream and downstream products is essential for assessing the regulation's broader impact on global supply chains.

Figure 5: Top 15 largest importing sectors of CBAM products from third countries (in € bn)



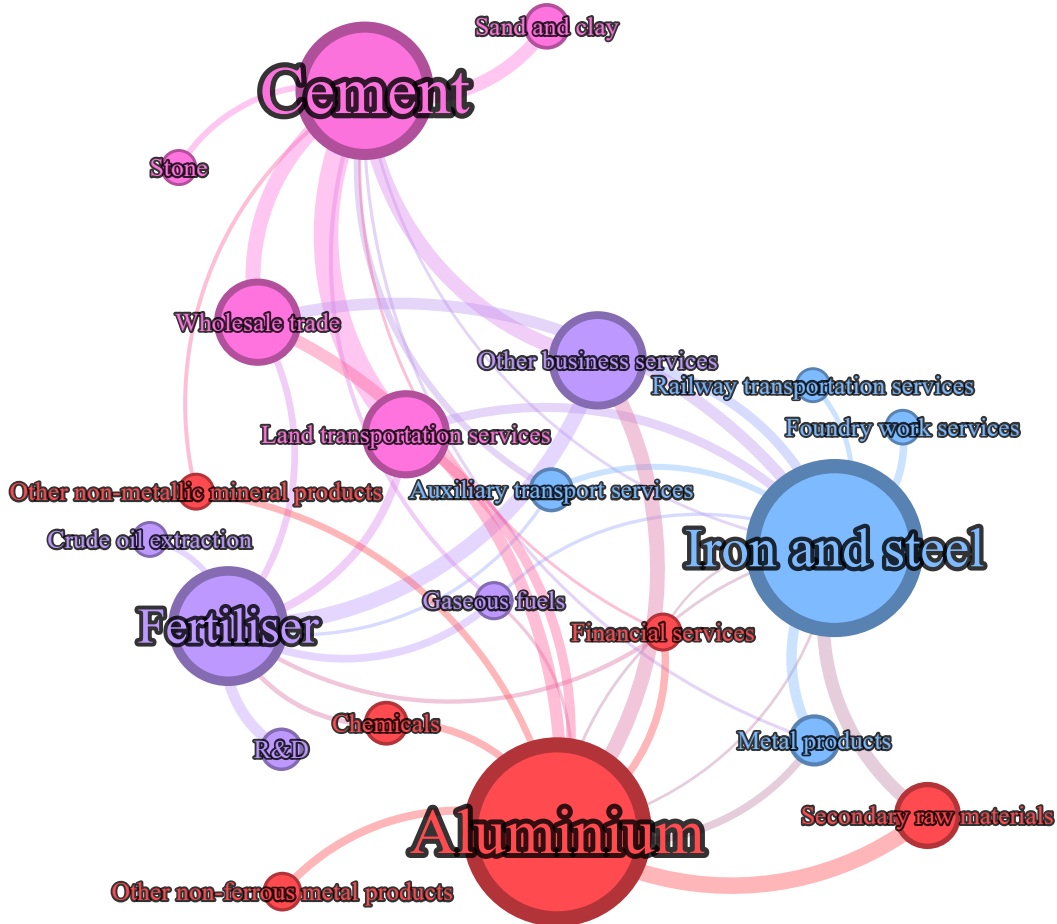
Source: Exiobase 2022 & Author's calculations.

Analyzing the CBAM at the product level helps assess which European producers will be directly impacted by the policy. It is often, albeit somewhat clumsily, assumed that the primary importers of CBAM-covered products are also producers of those products. As illustrated in Figure 5, the aggregated EU imports of these products also stem from industries that transform these basic materials into finished and semi-finished products. The primary importer is the metal products manufacturing sector, which accounts for almost €12 bn, or nearly 20% of total CBAM imports, distributed across iron, steel, and aluminium. It imports almost as much aluminium as the aluminium sector, ranked fourth. The second

sector-product on the list is the iron and steel industry, which imports nearly €9 bn of iron and steel, accounting for almost 25% of total iron and steel imports from third regions. In third place is the machinery and equipment production, which is also particularly exposed to the importation of iron and steel. In the ninth position, we observe imports of CBAM products that directly satisfy the final demand, amounting to 2.5% of the total imports.

Since the technical coefficient matrix can be represented as a network, where coefficients define the connections between product edges, trade dependencies shape the density of the supply chain (see Appendix A.2 on page 58). To illustrate the upstream structure of the CBAM product network, we provide the corresponding graph in Figure 6. The graph only includes first-tier European products, meaning only products directly contributing to CBAM intermediary use within the European region and production networks, disregarding the region's origin, are presented. Furthermore, to reduce the density of the graph and increase readiness, we filtered the initial set of links, originally composed of 198 nodes and more than 700 edges, to only 21 nodes (10%) for 42 edges (6%). Thus, the links in the figure are the most substantial regarding CBAM production. Technical coefficients determine flow sizes, while flow colors are assigned based on the biggest contribution among CBAM products.

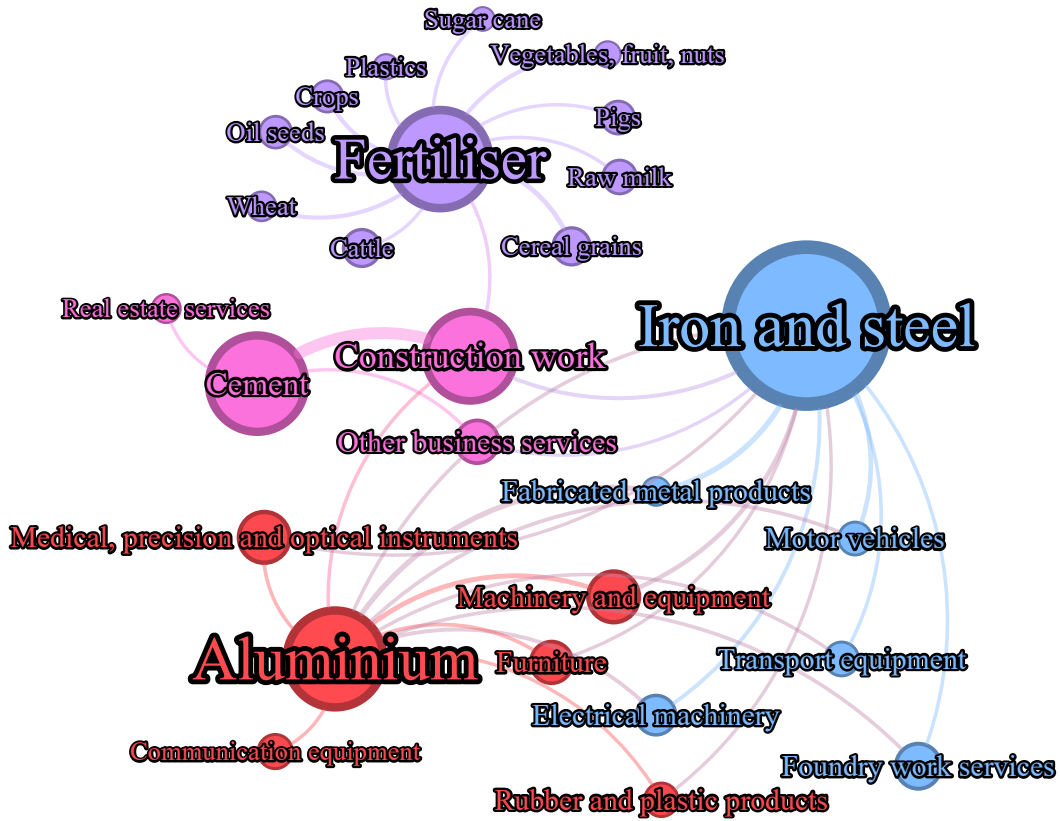
Figure 6: First-tier upstream production network of CBAM-covered products in Europe



Source: Exiobase 2022 & Author's calculations.

In this simplified network representation, cement and aluminium products share the greatest degrees of edges since they are connected with eleven products. In contrast, fertiliser production relies less on third products, with only nine connections. Five products are connected with all CBAM-covered products: *other business activities*, *land transport services*, *wholesale trade*, *gaseous fuel services*, and *financial services*. They are particularly central to CBAM production upstream. In addition to being more interconnected with CBAM-covered products, they also have the biggest individual technical coefficients. This indicates that most intermediary inputs used for CBAM production are services, especially transport services. Nonetheless, we retrieve some important goods dependent on each specific CBAM product. For instance, aluminium production requires *secondary raw materials*, *chemicals*, *metal products*, and *other non-ferrous metal products*, while cement production requires mainly *stone*, *sand*, and *clay*. We also notice a complete absence of sectors linked to power generation. Only two energy sources are required for producing fertilisers and iron and steel, namely *crude oil extraction* and *gaseous fuels*.

Figure 7: First-tier downstream production network of CBAM-covered products in Europe



Source: Exiobase 2022 & Author's calculations.

Turning to the downstream network of CBAM production in Figure 7,¹⁸ we apply the same filtering process. In total, we keep 27 nodes (14%) and 37 edges (5%). As we could have anticipated, the trade patterns in the downstream supply chain are distinct from those in the upstream one. First, sectors inclined to use CBAM-covered products as intermediary inputs

¹⁸Notice that instead of using the A matrix, we use the $\check{A}$ matrix for the downstream analysis.

are goods rather than services. Second, apart from the strong link between *construction work* and cement production, it is challenging to gauge highly influential trade dependencies. While the number of nodes retained increased, the bilateral relationships seem smaller. Notice that iron, steel, and aluminium production supply eight common products.

Construction work plays a pivotal role downstream in the CBAM production network, as it relies on all CBAM-covered products as intermediary inputs. Then we retrieve finished products such as *fabricated metal products*, *motor vehicles*, and *electrical machinery*. These products rely especially on iron, steel, and aluminium production. For fertiliser, except for the supply of plastics, all products are part of the agricultural sector. In total, fertilizer, iron, and steel production supply eleven products, but the edges of iron and steel tend to be relatively more important. Aluminium supplies twelve industries, whereas cement production serves only three, albeit with higher weights.

3.2.2 Carbon emissions analysis

Absolute emissions The breakdown of total carbon emissions from CBAM-covered products is presented in Table 3. Based on the upstream and downstream carbon accounting principles, we distinguish indirect and total emissions using these two approaches. Again, China largely dominates the carbon emissions landscape of CBAM-covered products, with roughly 3.1 GtCO₂e directly emitted in 2022, accounting for almost 60% of total CBAM-covered product emissions. These products' emissions represent around 27% of China's carbon footprint, driven mainly by iron, steel, and aluminium production. Europe ranks third, with around 220 MtCO₂e emissions in 2022, a mere 4% of the total.

Table 3: Upstream and downstream carbon emissions (in MtCO₂e) of CBAM products

Region	CE_{direct}	$CE_{indirect}^{up}$	$CE_{indirect}^{down}$	CE_{total}^{up}	CE_{total}^{down}
Australia	12.25	29.77	17.96	42.01	30.21
Brazil	96.91	44.50	30.78	141.41	127.69
Canada	24.06	24.22	15.17	48.28	39.24
China	3 164.32	2 915.18	1 704.52	6 079.50	4 868.84
Europe	220.00	229.96	162.23	449.96	382.22
India	466.00	255.12	81.21	721.12	547.22
Indonesia	54.42	20.46	9.36	74.88	63.79
Japan	89.79	328.07	181.88	417.86	271.67
Mexico	42.04	14.74	12.21	56.78	54.25
Russia	118.31	51.23	100.70	169.53	219.00
South Africa	17.08	36.84	19.37	53.92	36.45
South Korea	64.60	243.91	92.97	308.50	157.57
Switzerland	3.54	1.14	1.06	4.69	4.60
Taiwan	12.29	80.55	28.39	92.84	40.68
Turkey	70.56	25.47	15.40	96.03	85.96
Great Britain	13.08	18.31	8.23	31.39	21.30
United States	131.50	159.80	91.15	291.29	222.64
World (Africa)	216.60	119.75	69.02	336.35	285.61
World (Europe)	66.39	31.99	17.93	98.38	84.32
World (Latin America)	61.75	30.95	17.15	92.70	78.90
World (Middle East)	137.26	70.86	39.34	208.12	176.59
World (Rest of the world)	74.61	31.04	14.39	105.65	88.99

Source: Exiobase 2022 & Author's calculations.

On average, the indirect emissions of CBAM-covered products are twice as high as direct emissions, though this pattern holds for only half of the regions analyzed. East Asian countries (e.g., Taiwan, Japan, and South Korea) are particularly affected by indirect emissions, which exceed direct emissions by more than a factor of five. Upstream emissions overwhelmingly dominate when distinguishing between upstream and downstream indirect emissions. On average, upstream emissions are twice as high as downstream emissions, with India exhibiting an even stronger effect, surpassing a ratio of three. Conversely, Russia is an exception, showing a more balanced ratio between upstream and downstream emissions.

Figure 8: Bilateral flows of carbon emissions (in MtCO₂e) from CBAM products trade

EEU	0	7	11	1	8	1	1	1	2	1	2	1	2	2	0	0	0	5	2	2	4	6
GBR	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
USA	2	0	0	1	2	2	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	1
JPN	3	0	6	0	11	0	3	0	2	0	0	1	0	0	0	1	0	8	1	0	1	2
CHN	37	7	69	15	0	7	12	6	16	4	6	6	1	3	1	7	1	78	17	2	16	27
CAN	1	0	15	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
KOR	1	0	2	1	4	0	0	0	1	0	0	0	0	0	0	0	0	3	1	0	0	1
BRA	3	0	9	0	3	1	0	0	1	1	0	0	0	0	0	0	0	2	9	0	1	1
IND	11	2	11	2	5	1	1	1	0	1	1	1	0	1	0	2	0	13	2	0	5	10
MEX	1	0	11	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
RUS	9	1	6	1	4	0	1	1	1	1	0	0	0	2	0	1	0	6	1	3	2	4
AUS	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
CHE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TUR	6	1	8	0	2	1	0	1	1	0	1	0	0	0	0	0	0	2	4	1	13	13
TWN	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
IDN	1	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
ZAF	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0
WAF	10	2	14	5	36	1	3	1	11	0	3	8	0	1	3	7	2	0	5	1	9	4
WLA	2	0	4	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
WEU	10	1	3	0	2	0	0	0	1	0	5	0	0	1	0	1	0	2	1	0	3	6
WEX	3	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WME	4	1	6	1	4	1	1	1	6	0	1	3	0	1	0	1	0	5	1	0	10	0
	EEU	GBR	USA	JPN	CHN	CAN	KOR	BRA	IND	MEX	RUS	AUS	CHE	TUR	TWN	IDN	ZAF	WAF	WLA	WEU	WEX	WME

Source: Exiobase 2022 & Author's calculations.

In Figure 8, we present the matrix of bilateral flows of carbon emissions from all CBAM-covered products. In rows, we have the aggregated flows of emissions exported ($\mathcal{E}_X$), while columns depict the aggregated flows of imported emissions ($\mathcal{E}_M$). Largest values are scaled at the column level, meaning that the biggest node values are emphasized for each region as an importer. Total embedded emissions in trade from CBAM-covered products amount to 966.75 MtCO₂e in 2022. In the European region (EEU), bilateral emission flows with third countries are particularly significant, with imports amounting to 107 MtCO₂e. These emissions represent 48% of what is directly emitted domestically.¹⁹ Overall, the sources of

¹⁹When compared with domestic emissions emitted to satisfy domestic demand ($\mathcal{E}_d$), this figure would represent approximately 67%.

EU-imported emissions align with previously observed direct trade patterns. However, in this analysis, China (CHN) and India (IND) stand out as the largest contributors, together accounting for 45% of total imported emissions. This result follows the Leontief demand-driven approach, which accounts for the full scope of upstream emissions embedded in production to meet final demand, going beyond simple direct export estimates. Russia (RUS) and the African region (WAF), the two largest exporters of CBAM-covered products, follow closely, each contributing approximately 10 MtCO₂e to EU imports.

On the export side, CBAM-covered exports amount to 61 MtCO₂e in Europe, making it a net importer of CBAM-embedded emissions. Embedded emissions in EU exports represent less than 30% of CBAM-covered direct emissions. The EU region maintains the same list of trading partners as previously observed, with the USA, China, and Great Britain (GBR) accounting for approximately 45% of total emission exports. It is important to note that China (CHN) is, for many regions, the greatest exporter²⁰ of CBAM-covered products' emissions, cumulating more than 339 MtCO₂e. These embedded emissions point toward the African region and the USA, with more than 77.6 and 69 MtCO₂e, respectively. Notice that the USA absorbs, in total, 180 MtCO₂e from third regions, making it the biggest importer of CBAM-related emissions.

Carbon intensities In Table 4, we present direct and total carbon intensities of CBAM-covered products. The table highlights significant disparities in carbon intensities across regions and CBAM-covered products, underscoring the varying environmental efficiency of production processes (Verdolini *et al.*, 2012).

Across CBAM products, two distinct groups of regions emerge. On one side, the European region, Switzerland, Great Britain, the United States, and Canada consistently exhibit below-average total carbon intensities. On the other side, China, India, Turkey, Brazil, and the rest of the world's European region systematically show above-average carbon intensities. This group includes some of the largest exporters of CBAM-covered products to the EU. For example, China's total carbon intensity for iron and steel is more than twice that of the EU. In fertilizer production, India emits 1.4 times more carbon dioxide equivalent per euro of output than the EU. While demonstrating relatively moderate carbon intensities for aluminium, cement, and fertilisers, Russia still falls short of European standards. Russia's cement production generates nearly three times more emissions per euro than the EU. The African region exhibits particularly high carbon intensities in cement and fertilizer production, but shows more promising estimates for aluminium, iron, and steel production.

Cement production is the most carbon-intensive activity among CBAM-covered products, with an average direct carbon intensity of 6.4 kgCO₂e per euro of output. The European region²¹ appears to have a real advantage regarding cement production since its total carbon intensity is one of the lowest (1.37 kgCO₂e/€). In contrast, Turkey, China, the African region, and Indonesia have cement production that is particularly highly carbon intensive since they emit more than 10 kgCO₂e/€ of output. This implies that cement production in these regions emits ten times more carbon than within European borders. On the other hand, cement has the lowest indirect carbon intensity among CBAM-covered products, averaging 0.3 kgCO₂e/€. In aluminium production, significant discrepancies exist between direct and total carbon intensity estimates. The median total carbon intensity is five times

²⁰These results also reveal that a critical portion of China's emissions remains within its domestic economy. Its domestic-domestic emissions amount to 2825 MtCO₂e, or almost 60% of total downstream emissions.

²¹In Table 17 on page 63, we provide direct and total carbon intensities detail for European countries. Aluminium production is particularly carbon efficient since the median estimate of total carbon intensity is below 0.6 kgCO₂e per euro of output.

higher than the direct one, indicating that a substantial share of emissions originates upstream, particularly from third-product inputs and electricity consumption. This effect is especially pronounced in Japan, South Korea, China, Switzerland, and Taiwan. Iron and steel production is much less carbon-intensive, with an average direct carbon intensity of 0.26 kgCO₂e per euro of output. Notice that the average and median gap is also relatively small, meaning most regions have low-carbon intensities.

Table 4: Direct and total carbon intensities (in kgCO₂e/€) of CBAM products

Region	Aluminium		Cement		Fertiliser		Iron & steel	
	CI_{direct}	CI_{total}^{up}	CI_{direct}	CI_{total}^{up}	CI_{direct}	CI_{total}^{up}	CI_{direct}	CI_{total}^{up}
Australia	0.39	1.70	0.73	1.67	0.18	0.44	0.14	0.59
Brazil	1.61	3.29	7.26	7.77	0.06	0.52	1.10	1.73
Canada	0.20	0.96	5.31	5.78	0.24	0.51	0.50	1.05
China	0.17	2.43	11.70	13.45	0.29	1.20	0.75	2.01
Europe	0.26	0.82	0.91	1.37	0.50	0.89	0.28	0.79
India	0.39	1.82	7.95	9.46	0.38	1.26	2.13	3.64
Indonesia	0.13	1.23	9.25	10.98	0.14	0.40	0.26	1.08
Japan	0.01	0.62	8.75	9.60	0.15	0.67	0.25	1.74
Mexico	2.41	2.83	6.40	7.72	0.82	1.08	0.26	0.61
Russia	1.00	1.14	3.06	3.78	0.55	0.93	0.65	1.08
South Africa	5.01	7.59	3.69	5.26	0.27	6.62	0.50	1.34
South Korea	0.04	1.72	2.72	3.73	0.11	0.75	0.16	1.35
Switzerland	0.01	0.19	0.88	1.11	0.27	0.35	0.07	0.19
Taiwan	0.03	0.65	3.84	5.46	0.33	1.16	0.06	1.08
Turkey	0.35	2.24	26.24	27.63	6.33	6.53	0.39	1.22
Great Britain	0.05	0.66	0.75	1.30	0.37	0.90	0.26	0.83
United States	0.07	0.71	1.45	2.03	0.27	1.05	0.10	0.64
World (Africa)	0.40	1.55	13.99	14.95	1.19	1.67	0.36	1.28
World (America)	0.11	0.84	3.92	4.67	1.62	2.07	0.25	0.92
World (Europe)	0.49	2.74	8.41	10.32	0.68	1.80	2.77	4.06
World (Middle East)	0.50	1.71	5.87	6.58	0.90	1.46	0.24	1.07
World (ROW)	0.28	1.11	7.55	8.24	0.77	1.09	0.10	0.99
Average	0.63	1.75	6.39	7.40	0.75	1.52	0.53	1.33
Median	0.27	1.39	5.59	6.18	0.35	1.06	0.26	1.08

Source: Exiobase 2022 & Author’s calculations.

4 Estimating CBAM impact on the supply chain through MRIO modeling

In what follows, we outline the general methodology,²² used to assess policy impacts through multi-regional input-output modeling. As a European cross-border compliance mechanism targeting the carbon content of a narrow list of products, the CBAM should not be treated as equivalent to a carbon tax (Sautel *et al.*, 2022). Nonetheless, its implementation can be modeled within a framework analogous to general carbon pricing in input-output analysis. We begin by outlining the standard modeling of a carbon tax within the input-output framework, then detail the carbon cost transmission mechanism, and finally refine the approach to account for the specific compliance costs imposed on imports.

²²This study is part of a research project building on the work of Adenot *et al.* (2022), Desnos *et al.* (2023), and Roncalli and Semet (2024) and revisits several elements previously introduced in those studies.

4.1 Carbon pricing and costs transmission methods

One peculiar application of the Leontief price model is the simulation of carbon pricing cascading effects on the supply chain (Schotten *et al.*, 2021; Adenot *et al.*, 2022; Roncalli and Semet, 2024). The representation of interlinkages between sectors, products, and regions enables the study of the carbon cost diffusion among actors and the subsequent impact on prices and inflation. This carbon cost typically enters the cost-push price mechanism through value-added, capturing the price change induced by the unit compliance cost of the carbon tax (Labandeira and Labeaga, 1999; Kay and Jolley, 2023; Desnos *et al.*, 2023).²³ In this framework, producers determine output prices based on their average production costs, including primary and intermediate inputs.

By design, the cost-push pricing approach assumes a full pass-through of carbon costs to consumer prices under the premise that producers operate in perfectly competitive markets and set prices equal to average costs, thereby generating no profits. In the context of carbon taxation, this implies that producers pass on the entire carbon cost to final consumers. However, this assumption may oversimplify real-world pricing behavior. Empirical evidence indicates that some firms partially absorb carbon costs (Sijm *et al.*, 2006; Sautel *et al.*, 2022), while others may pass on more than the actual cost incurred, particularly in sectors with greater market power (Hintermann, 2016; Weber and Wasner, 2023).²⁴ This degree of cost transmission depends not only on supply and demand elasticities but also on market structure (Weyl and Fabinger, 2013).

A more realistic approach would account for markup pricing, in which firms strategically set selling prices by applying a fixed margin over costs, depending on prevailing market conditions. The theoretical foundation for this pricing behavior originates from the seminal work of Hall and Hitch (1939), who introduced the “full-cost principle” whereby prices are set as the sum of average costs and a markup reflecting firms’ market power. Building on this framework, we incorporate sector-specific pricing behavior by estimating empirical markups using the methodology developed by De Loecker and Warzynski (2012). These estimated markups are then applied to carbon tax pass-through rates to better capture the heterogeneity in cost transmission across sectors.

4.1.1 The carbon tax impact on value-added

Let’s consider a nominal upstream carbon price τ (expressed in €/tCO₂e). The absolute amount of carbon tax paid by producer j in region s is defined by:

$$T_{\text{direct},j}^s = \tau_j \mathcal{CE}_{\text{direct},j}^s \quad (4)$$

where $\mathcal{CE}_{\text{direct},j}^s$ is the absolute amount of direct emissions generated by sector j in region s . The individual carbon tax rate can be defined as:

$$t_{\text{direct},j}^s = \frac{T_{\text{direct},j}^s}{x_j^s} = \frac{\tau_j \mathcal{CE}_{\text{direct},j}^s}{x_j^s} = \tau_j \mathcal{CI}_{\text{direct},j}^s \quad (5)$$

We deduce that the direct cost can be rewritten in matrix form as $T_{\text{direct}} = x \odot t_{\text{direct}}$ where $t_{\text{direct}} = (t_{\text{direct},1}^1, \dots, t_{\text{direct},n}^m)$ is the vector of direct tax rates. The value-added approach suggests that the total amount of carbon tax comes as an additional cost for producer j .

²³More specifically, carbon pricing is assumed to affect the marginal cost of production (Sijm *et al.*, 2006).

²⁴Sautel *et al.* (2022) estimated sector-level pass-through rates ranging from 0% to 100%, whereas Hintermann (2016) documented instances of pass-through exceeding 100% in the power generation sector.

Recalling Equation (1), which provides the general formula for cost-push price setting, the tax impact can be assessed as follows:

$$p_j^s x_j^s = \sum_{r=1}^m \sum_{i=1}^n Z_{i,j}^{r,s} p_i^r + \sum_{k=1}^c V_{k,j}^s \psi_k^s + T_{\text{direct},j}^s$$

From the cost-push price model, we retrieve:

$$p_j^s = \sum_{r=1}^m \sum_{i=1}^n A_{i,j}^{r,s} p_i^r + \sum_{k=1}^c B_{k,j}^s \psi_k^s + t_{\text{direct},j}^s = \sum_{r=1}^m \sum_{i=1}^n A_{i,j}^{r,s} p_i^r + v_j^s + t_{\text{direct},j}^s$$

or in matrix form $p = (I_{m,n} - A^\top)^{-1} (v + t_{\text{direct}})$. Isolating the carbon tax effect such that $\Delta v = t_{\text{direct}}$, the output price variation is equal to:

$$\Delta p = \left(I_{m,n} - A^\top \right)^{-1} t_{\text{direct}} \quad (6)$$

The total tax cost can be deduced from the previous equation by generalizing it to the economy's total output. We have:

$$T_{\text{total}} = x \odot \Delta p = x \odot \left(I_{m,n} - A^\top \right)^{-1} t_{\text{direct}}$$

4.1.2 The markup pricing approach

Markup pricing in the cost-push model Let's assume a sector-specific factor markup $\theta_j^s \geq 1$ multiplying the average cost of production such that the price of sector j is defined by:

$$p_j^s = \theta_j^s \left(\sum_{r=1}^m \sum_{i=1}^n A_{i,j}^{r,s} p_i^r + v_j^s \right)$$

Stacking the n markups yields the diagonal matrix of markups $\Theta \equiv \text{diag}(\theta_1^1, \dots, \theta_n^m)$. We deduce that:

$$\begin{aligned} p &= \Theta \left(A^\top p + v \right) \\ p &= \left(I - \Theta A^\top \right)^{-1} \Theta v \\ p &= \tilde{\mathcal{L}}(\theta) \Theta v \end{aligned}$$

where $\tilde{\mathcal{L}}(\theta) = (I - \Theta A^\top)^{-1}$ is the markup-adjusted Leontief inverse.²⁵ With the induced cost of the carbon tax $\Delta v = t_{\text{direct}}$, the change in output price is equal to:

$$\Delta p = \tilde{\mathcal{L}}(\theta) \Theta t_{\text{direct}}$$

Assuming this form of market pricing allows us to estimate the unit margin m_j^s of sector j in region s as follows:

$$m_j^s = \left(\theta_j^s - 1 \right) \left(\sum_{r=1}^m \sum_{i=1}^n A_{i,j}^{r,s} p_i^r + v_j^s \right)$$

²⁵A unique positive solution exists if the Hawkins-Simon condition holds: $\rho(\Theta A^\top) < 1$ where $\rho(\cdot)$ denotes the spectral radius.

After the shock, the factor markup is unchanged, while the absolute margin moves one-for-one with costs:

$$\Delta m_j^s = (\theta_j^s - 1) \Delta \mathcal{C}_{\text{total},j}^s$$

where

$$\Delta \mathcal{C}_{\text{total},j}^s = \sum_{r=1}^m \sum_{i=1}^n A_{i,j}^{r,s} \Delta p_i^r + t_{\text{direct},j}^s$$

$\Delta \mathcal{C}_{\text{total},j}^s$ is capturing both the individual carbon tax cost and the input's price increase. Denoting $\Pi_j^s = x_j^s \cdot m_j^s$ the profit of the firm j , we can approximate windfall profits induced by the tax as:

$$\Delta \Pi_j^s = x_j^s (\theta_j^s - 1) \Delta \mathcal{C}_{\text{total},j}^s$$

in matrix form, we have:

$$\Delta \Pi = \text{diag}(x) (\Theta - I_{m,n}) (t_{\text{direct}} + A^\top \Delta p)$$

Empirical markups estimation We adopt the methodology outlined by [De Loecker and Warzynski \(2012\)](#), which estimates firm- or sector-specific markups without making prior assumptions about demand elasticities or the nature of market competition. This approach is grounded in the theoretical model developed by [Hall \(1988\)](#), who demonstrated that, under cost minimization, the firm's markup on any variable input (which can be freely adjusted within a given period, as opposed to capital) is the ratio of two key factors: the elasticity of output with respect to that variable input and the share of revenue allocated to the input. The model assumes that firms minimize the cost of variable inputs (e.g., labor, materials, and energy) while maintaining a given output level, which is represented by a parametric production function, typically a Cobb-Douglas production function.²⁶

From the firm's first-order condition for cost minimization, the markup²⁷ for firm j :

$$\theta_j^s = \xi_j^s \left(\frac{p_j^s Q_j^s}{\eta_j^s V_j^s} \right)$$

where P_j^s and Q_j^s are the price and the quantity of the output j in region s , V_j^s is the variable input whereas η_j^s its unit price. The parameter ξ_j is the output elasticity of that input.

In terms of implementation, several studies estimated historical markup trends from empirical data. [De Loecker et al. \(2020\)](#) used a two-step estimation of the production functions from [Olley and Pakes \(1996\)](#) with firm level data. [Colonescu \(2021\)](#) followed a similar approach but applied it to input-output data. From input-output tables, the output sold x_j and the total variable input cost of the production $\sum_{r=1}^m \sum_{i=1}^n Z_{i,j}^{r,s} + \ell_j^s$ where ℓ_j^s is the labor compensation expressed in terms of output (i.e., the variable inputs), are observed. In contrast, the parameter ξ is unavailable and should be estimated.

[Rodriguez del Valle and Fernández-Vázquez \(2021\)](#) proposed an econometric application to estimate this parameter with data from input-output tables similar to those we use in this study. Aware of the small number of observations and the theoretical constraints of

²⁶We note a likely incompatibility between the markup pricing framework and the Leontief model, as the latter assumes fixed input coefficients and does not account for variable factor proportions.

²⁷The markup is defined as P/λ , where P is the output price and λ is the Lagrange multiplier that corresponds to marginal cost. In perfectly competitive markets, a firm with a markup of 1 would set the selling price equal to its marginal cost, $P = \lambda$, generating no profit. In contrast, a firm with a markup greater than 1 exercises market power, setting $P > \lambda$. By definition, the markup cannot be less than 1.

markup estimation, their approach makes use of a generalized maximum entropy (GME) estimator to estimate the following expression:

$$\log \left(\frac{Q_{j,t}^s}{Q_{j,0}^s} \right) = \alpha_{j,t} \log \left(\frac{\Omega_{j,t}}{\Omega_{j,0}} \right) + \xi_{j,t} \log \left(\frac{V_{j,t}}{V_{j,0}} \right) + \beta_{j,t} \log \left(\frac{K_{j,t}}{K_{j,0}} \right) + \varepsilon_{j,t}$$

where $\Omega_{j,t}$ is the firm-specific Hicks-neutral productivity (De Loecker and Warzynski, 2012), $K_{j,t}$ is the capital stock of firm j at time t , and ε in an error term. As quantities in WIOD²⁸ are only available with respect to a base-year period (2010), all aggregates are expressed as deviations from that benchmark.

We follow this methodology to estimate the output elasticity parameters.²⁹ For the GME estimation, we set the number of supports at 7 for each parameter with bounds at ± 10 for the bounds of the coefficient and error. The estimation is made from the 2014 vintage of WIOD data at the sector level. Markups are then estimated at the sector level from the 2022 vintage of Exiobase data. Descriptive statistics of the estimated parameter, the mean and standard deviation of the markups across several products are presented in Table 16 on pages 61–62. On average, estimates of markups range from 1.011 for *Health and social services* to 2.855 for *Other bituminous coal*.

4.2 CBAM design and scenario construction

4.2.1 Modeling the CBAM regulation with input-output analysis

Incorporating the CBAM into the previous modeling framework requires the application of a carbon tax to specific products in certain regions while restricting its cascading effects to imports destined for Europe. However, as remarked by Sautel *et al.* (2022, Chapter 2), no established methodology exists for such an analysis. Thus, most CBAM analyses using input-output modeling have overcome this drawback by estimating direct CBAM exposure rather than the total effect on the global supply chain (Rocchi *et al.*, 2018; Schotten *et al.*, 2021; Magacho *et al.*, 2024). Thus, it is not uncommon to approximate the direct impact of the CBAM using the following equation:

$$T_{\text{direct},i}^r = \tau \mathcal{CI}_{\text{direct},i}^r \mathbf{x}_i^{r \rightarrow s} \quad \text{for } s \in \mathbf{EU} \wedge i \in \mathbf{CBAM}$$

This approximation, therefore, allows for the estimation of the CBAM compliance cost borne by EU imports. However, this static approximation fails to account for cascading effects in the supply chain since price variations remain confined to EU imports of CBAM-covered products and do not propagate downstream.

In order to preserve the integrity of the supply chain while allowing the additional CBAM compliance costs to be passed on to the various entities, the carbon tax rate must be redefined:

$$t_{\text{direct},i}^r = \begin{cases} \mathcal{CI}_{\text{direct},i}^r \Delta \tau^r & \text{if } r \notin \mathbf{EU} \wedge i \in \mathbf{CBAM} \\ 0 & \text{otherwise} \end{cases}$$

²⁸The World Input-Output Database (WIOD) is analogous to Exiobase, covering 44 countries and 56 industries.

²⁹The parameter estimation requires desegregated volumes for each sector, which are not available in Exiobase. We recover the markup estimation from Exiobase data through concordance of the two nomenclatures as in Desnos *et al.* (2023) at the cost of some assumptions regarding the year concordance. Indeed, the latest WIOD database is available for 2014.

where $\Delta\tau^s = \tau - \tau^s$ is the carbon price difference between the EU ETS and the one applied in region s . The specified tax rate reflects the EU's and third regions' carbon price gap.³⁰ To ensure that the compliance costs fall effectively and European imports, let's introduce an import's adjacency matrix $U = (U_{i,j}^{r,s})$, which flags EU imports of CBAM-covered products from third regions. In this manner, we isolate trades likely to be covered by the CBAM, namely, European imports of the products covered by the program from third countries. The adjacency matrix is defined as:

$$U_{i,j}^{r,s} = \begin{cases} 1 & \text{if } s \in \mathbf{EU} \wedge i \in \mathbf{CBAM} \wedge r \notin \mathbf{EU} \\ 0 & \text{otherwise} \end{cases}$$

Then, we can retrieve the CBAM compliance cost rate of importer j in region s :

$$c_{\text{direct},j}^s = \sum_{r=1}^m \sum_{i=1}^n U_{i,j}^{r,s} A_{i,j}^{r,s} t_{\text{direct},i}^r$$

In matrix form, we obtain:

$$c_{\text{direct}} = \mathbf{1}_{m,n}^\top (U \odot A \odot t_{\text{direct}})$$

where $c_{\text{direct}} = (c_{\text{direct},1}^1, \dots, c_{\text{direct},n}^m)$ is a row vector of size $1 \times m, n$. A typical element of this vector describes the CBAM compliance rate faced by the production j in region s . The total compliance costs amount to:

$$\mathcal{C}_{\text{direct}} = x^\top (U \odot A \odot t_{\text{direct}})$$

In this manner, CBAM compliance costs effectively fall on intermediary imports of CBAM-covered products coming from third regions. Note that when aggregated, this also corresponds to the government revenue $\mathcal{R}_{\text{total}} = \mathcal{C}_{\text{direct}}$.

Then, we can diffuse the European CBAM compliance cost throughout the supply chain. Allowing for markup pricing, the price variation is defined as:

$$\Delta p = (I - \Theta A^\top)^{-1} \Theta c_{\text{direct}}^\top$$

From the price variation, we can compute total and indirect costs for the economy:

$$T_{\text{total}} = x \odot \left[I - \Theta + (I - \Theta A^\top)^{-1} \Theta \right] c_{\text{direct}}$$

$$T_{\text{indirect}} = T_{\text{total}} - T_{\text{direct}} = x \odot \left[I - \Theta + (I - \Theta A^\top)^{-1} \Theta \right] c_{\text{direct}} - \left[x^\top (U \odot A \odot t_{\text{direct}}) \right]$$

³⁰In Table 15 on page 60, we provide the sectoral and national coverage of GHG emissions from carbon pricing programs implemented in foreign regions (Dao *et al.*, 2024). Carbon prices τ are taken from official sources (ICAP, 2023; World Bank, 2023) and reflect explicit carbon prices. We consider the following countries to have a pricing program aligned with the CBAM regulation: Chile, Iceland, Japan, Mexico (carbon tax), Singapore, South Africa, Switzerland (ETS), Great Britain (ETS), Ukraine, Kazakhstan, New Zealand, and South Korea. Carbon pricing instruments have not been implemented or abandoned outside this set of countries. In this case, imports from these countries comply with the full price of the EU ETS.

Illustration Let's consider Example #1. Assuming that Region $\mathcal{A}$ is imposing a carbon border adjustment on product S_1 to Region $\mathcal{B}$. Region $\mathcal{A}$ imposes a €100/tCO₂e on production while region $\mathcal{B}$ sets the tax rate at €10.

The tax rate is only defined for the sector covered by the carbon border adjustment in region $\mathcal{B}$:

$$t_{\text{direct}} = \begin{pmatrix} 0.0000 \\ 0.0000 \\ 0.0025 \\ 0.0000 \end{pmatrix}$$

The adjacency matrix of imports covered by the policy is defined as:

$$U = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

Then, we can compute the compliance cost rate and the total compliance costs:

$$\begin{aligned} c_{\text{direct}} &= \mathbf{1}_4^\top (U \odot A \odot t_{\text{direct}}) \\ &= \begin{pmatrix} 1 & 1 & 1 & 1 \end{pmatrix} \begin{pmatrix} 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.1250 & 0.5000 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 \end{pmatrix} \\ &= \begin{pmatrix} 0.1250 & 0.5000 & 0.0000 & 0.0000 \end{pmatrix} \end{aligned}$$

and the total compliance costs:

$$\mathcal{C}_{\text{direct}} = x^\top \begin{pmatrix} 0.1250 & 0.5000 & 0.0000 & 0.0000 \end{pmatrix} = \begin{pmatrix} 1 & 4 & 0 & 0 \end{pmatrix}$$

Assuming that markup factors are all equal to one, diffusing the compliance cost throughout the supply chain gives the following price variation:

$$\Delta p = \begin{pmatrix} 0.2324 \\ 0.6763 \\ 0.2783 \\ 0.1306 \end{pmatrix}$$

4.2.2 Scenario design

To explore the multiple repercussions that the CBAM could have on the economy, we consider several scenario analyses based on the six options elaborated by the [European Commission \(2021a\)](#). Aligned with MRIO possibilities, three aspects are particularly fit for this study: the value chain depth and the embedded emissions computation. Hence, we consider three scenarios, each leveraging the three diverging aspects.

Scenario #1 In the first scenario, we use the third option of the [European Commission \(2021a\)](#). The CBAM regulation takes the form of a CBAM market³¹ which covers the imports of basic materials and basic material products. Embedded emissions are computed using the actual carbon intensity of the exporting country. This scenario appears as the base case scenario since the previously specified MRIO model does not need to be refined.

³¹Notice that there is no methodological gap between a tax on imports or a CBAM certificate market.

Scenario #2 In the second scenario, we follow the baseline option outlined by [European Commission \(2021a\)](#), where the CBAM operates as a tax on imports of basic materials, with embedded emissions estimated using default values. In 2023, the European Commission established the framework for applying these values during the transitional period and the definitive regime. During the transitional phase, default values are calculated as global averages of carbon intensities, weighted by production volumes.³² Accordingly, direct carbon tax rates are derived using these default carbon intensity estimates:

$$t_{\text{direct},j}^s = \begin{cases} \overline{\mathcal{CI}}_{\text{direct},j} \Delta \tau^s & \text{if } s \notin \mathbf{EU} \wedge j \in \mathbf{CBAM} \\ 0 & \text{otherwise} \end{cases}$$

where

$$\overline{\mathcal{CI}}_{\text{direct},j} = \sum_{s=1}^m \left(\frac{\mathcal{CE}_{\text{direct},j}^s}{x_j^s} \right) \quad \text{for } s \notin \mathbf{EU}$$

$\overline{\mathcal{CI}}_{\text{direct},j}$ is thus defined as the aggregated carbon intensity of the j^{th} CBAM-covered product outside EU. The mean μ and standard deviation σ of default values are presented in Table 5. The estimated default values are often significantly higher than those observed in Europe (see Table 17 on page 63 for a comparison), though their dispersion appears relatively limited, as indicated by modest standard deviations. However, the estimates for cement reveal substantial uncertainty around the default value.

Table 5: Estimates of CBAM products' default values (in kgCO₂e/€)

		Aluminium	Cement	Fertiliser	Iron & steel
$\mathcal{CI}_{\text{direct}}$	μ	0.392	7.725	0.994	0.679
	σ	0.027	0.650	0.082	0.050
$\mathcal{CI}_{\text{total}}^{\text{up}}$	μ	1.523	8.742	1.474	1.542
	σ	0.084	0.710	0.107	0.089

Scenario #3 Our third scenario extends the CBAM coverage by increasing the depth of the value chain, similar to option five. To identify additional sectors for inclusion, we draw from the carbon leakage list we have estimated (see Figure 1 on page 4), following the methodology provided by the [European Commission \(2009\)](#). As shown in Table 6, this approach yields 13 additional products that meet the carbon leakage risk criteria, namely high carbon cost intensity ($\mathcal{CCI}$) and trade intensity ($\mathcal{TI}$).

4.3 Some CBAM indicators

CBAM exposure indices The CBAM impact will likely hit trade relations for the products concerned, which might have economic consequences for exporting regions. Before considering the indirect mechanisms induced by the global value chain, we estimate the region's absolute and relative exposure to CBAM.³³ Both exposure types depend on two parameters: the carbon intensity of domestic production and EU trade dependency. Here,

³²From 2026 onward, they will be replaced by country-specific averages, adjusted upward by an undefined mark-up. As this "mark-up" remains unspecified, we base our analysis on the global production-weighted averages.

³³This approach follows the indices built by the World Bank, reflecting the economic vulnerability of emerging countries to CBAM implementation. More detail is provided at <https://www.worldbank.org/en/data/interactive/2023/06/15/relative-cbam-exposure-index>.

Table 6: Products most at risk of carbon leakage (downstream analysis)

Product	$\mathcal{CI}_{\text{direct}}$	$\mathcal{CI}_{\text{total}}^{\text{up}}$	$\mathcal{CCI}$	$\mathcal{TI}$	$\mathcal{CCR}$
Coke oven coke	2.67	3.43	15.04	36.11	123.80
Gasoline type jet fuel	5.58	5.84	28.10	18.17	106.17
Bitumen	0.32	0.88	2.62	51.74	45.30
Heavy fuel oil	0.27	0.74	3.13	60.54	44.58
Naphtha	0.23	0.72	2.54	56.88	41.04
Steam and hot water supply services	6.78	7.40	32.42	4.71	34.87
Paraffin waxes	0.25	0.76	2.47	42.65	32.48
Non-specified petroleum products	0.22	0.77	4.46	37.74	28.93
Liquefied petroleum gases	0.26	0.73	2.45	36.49	26.66
Paper and paper products	0.05	0.35	1.27	24.23	8.57
Blast furnace gas	0.71	1.45	31.59	5.21	7.56
Coke oven gas	0.72	1.50	15.49	4.93	7.41
Distribution services of gaseous fuels	0.33	0.77	3.25	8.03	6.17

Source: Exiobase 2022 & Author's calculations.

we determine the additional export cost by multiplying the carbon intensity by the ETS carbon price (expressed in €/tCO₂e). Export exposure is simply the ratio between CBAM product exports to the EU over total CBAM exports. Thus, the absolute CBAM exposure index ($\mathcal{AEI}$) measures the additional cost of CBAM, adjusted by the proportion of exports to the EU market:

$$\mathcal{AEI}^r = \sum_{i=1}^n \left[\frac{\mathcal{X}_i^{r \rightarrow \text{EU}}}{\sum_{s \neq r} \mathcal{X}_i^{r \rightarrow s}} \cdot \left(\tau \mathcal{CI}_{\text{direct},i}^r \right) \right]$$

Note that the $\mathcal{AEI}$ could be refined by incorporating relative factors, such as the carbon price gap. Additionally, some regions may gain a competitive advantage due to their lower carbon intensity than Europe. The relative exposure index thus accounts for both components:

$$\mathcal{REI}^r = \sum_{i=1}^n \left[\frac{\mathcal{X}_i^{r \rightarrow \text{EU}}}{\sum_{s \neq r} \mathcal{X}_i^{r \rightarrow s}} \cdot \left(\Delta \tau^r \Delta \mathcal{CI}_{\text{direct},i}^r \right) \right]$$

where $\Delta \tau^r = \tau - \tau^r$, and $\Delta \mathcal{CI}_{\text{direct},i}^r = \overline{\mathcal{CI}}_{\text{direct},i} - \mathcal{CI}_{\text{direct},i}^r$. With this formulation, the index can take negative values, indicating a competitive advantage over EU producers.

Carbon leakage potential To define sectors at risk of carbon leakage, the quantitative methodology estimates the carbon and trade intensity of sector and sub-sectors of the EU ETS (Juergens and Barreiro-Hurlé, 2013). The carbon cost intensity of sector j can be defined as the additional costs induced by the pricing of direct and indirect emissions:

$$\mathcal{CCI}_i^r = \frac{\tau \mathcal{CE}_{\text{total},i}^r}{v_i^r}$$

In the first carbon leakage list (European Commission, 2009), this additional cost was assessed based on the total cost induced by a €30/tCO₂ carbon price, adjusted for value-added. On the trade part, the trade intensity is measured as the ratio between exports plus imports to third countries and imports plus total output:

$$\mathcal{TI}_i^r = \frac{\mathcal{X}_i^{r \rightarrow s} + \mathcal{M}_i^{r \leftarrow s}}{\mathcal{M}_i^{r \leftarrow s} + x_i^r}$$

A sector was considered at risk if it fell under certain conditions.³⁴ In the revised carbon leakage list, the criteria for identifying sectors at risk have been narrowed to the carbon leakage risk indicator, which is the product between carbon and trade intensities:

$$\mathcal{CCR}_i^r = \mathcal{CI}_{\text{total},i}^r \cdot \mathcal{TI}_i^r$$

As a rule, any sector i in region r with a score exceeding 0.2 is considered at risk of carbon leakage.

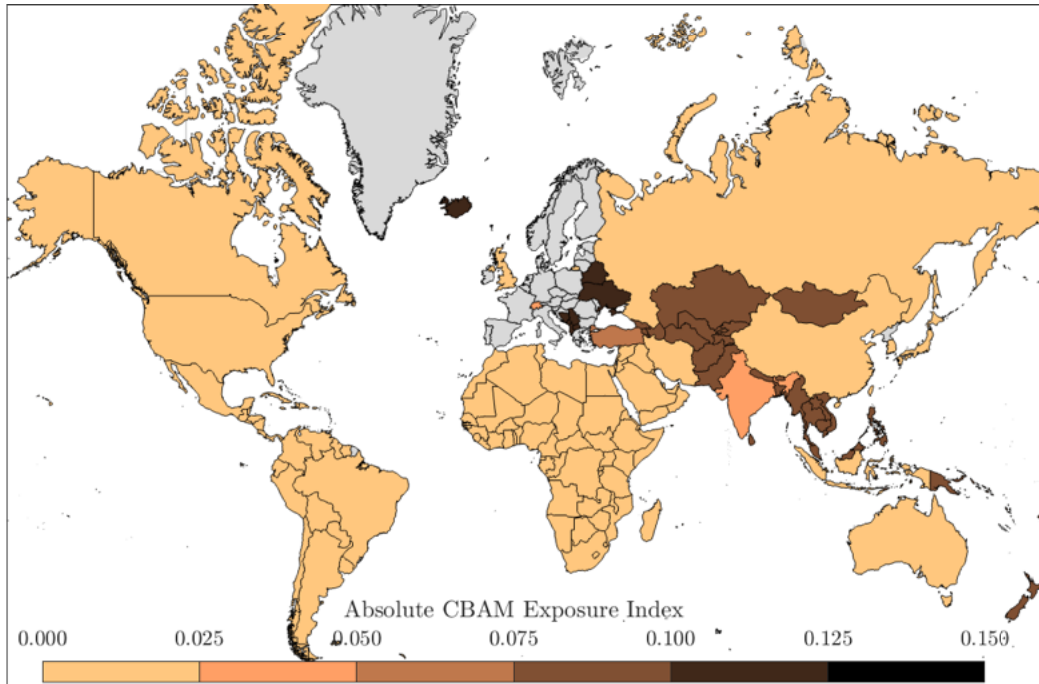
5 The economic costs of the CBAM

5.1 CBAM direct exposure

5.1.1 Absolute and relative CBAM exposure

The direct exposure of exporting regions to CBAM will primarily depend on the share of CBAM-covered products traded with European countries. While export volume largely determines exposure to the regulation, environmental efficiency (*i.e.*, carbon intensity) also plays a crucial role. These two characteristics make up the absolute CBAM exposure index,³⁵ which is detailed in the world map representation in Figure 9.

Figure 9: Absolute CBAM exposure $\mathcal{AEI}$ of third countries in 2022



Source: Exiobase 2022 & Author's calculations.

In absolute terms, very few regions face critical exposure to the regulation. This is primarily because more than 50% of regions have a CBAM-covered export dependency on

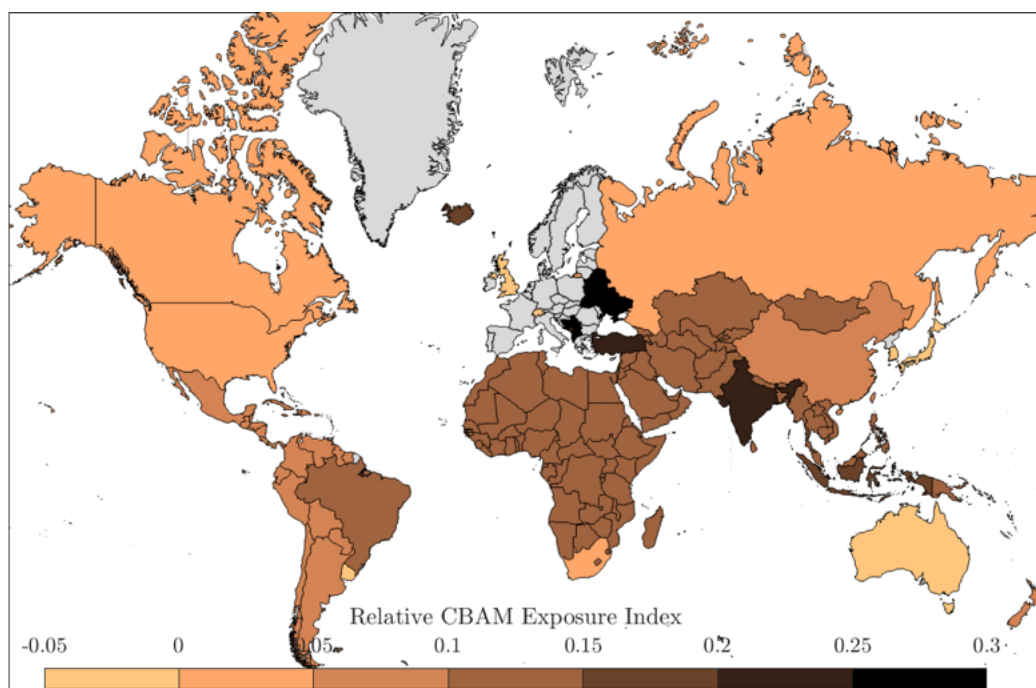
³⁴If (i) $\mathcal{CCI} > 5\% \wedge \mathcal{TI} > 10\%$; (ii) $\mathcal{CCI} > 30\%$; or (iii) $\mathcal{TI} > 30\%$.

³⁵Remember that the higher the index, the higher the product of the two components and, therefore, the higher the exposure.

Europe of less than 10% of their total CBAM exports. Exposure is highly concentrated in non-EU specific areas, particularly Ukraine, Belarus, Iceland, and Albania. In addition to their strong trade ties with the EU, these countries rank among the least carbon-efficient in CBAM-covered production. By contrast, the United Kingdom and Switzerland, though heavily dependent on the EU for imports (over 50%), tend to exhibit relatively low carbon intensities. Meanwhile, several South and Central Asian countries, grouped under the “rest of the world” region, appear particularly exposed to CBAM regulation through trade.

While absolute exposure provides a first approximation of the impact of CBAM on foreign economies, it is possible to refine this measure by taking relative factors into account. The measure of trading volume remains the same, but the environmental exposure is likely to be slightly modified according to the presence or absence of implemented carbon pricing policies. In addition, the difference between domestic carbon intensity and that recorded in Europe could also favor the exporting economy. This improvement is taken into account in our relative CBAM exposure index³⁶ in Figure 10.

Figure 10: Relative CBAM exposure REI of third countries in 2022



Source: Exiobase 2022 & Author's calculations.

Taking this relative indicator, we notice substantial differences in exposure. Even if the regions most affected by regulation remain the same as before, we note, in particular, an overexposure of African and Middle Eastern regions. They are relatively more exposed than other regions due to their nonexistent carbon pricing programs, which favor detrimental carbon intensities in CBAM-covered productions. On the South American continent, Brazil is also relatively more exposed than previously suggested. It records a carbon intensity of CBAM-covered products that is three times greater than that of the EU. For India, which is relatively more exposed than previously, the ratio amounts to five. In contrast, some

³⁶Note that negative values are possible in this case since the carbon intensity and the carbon price at which emissions are priced are from differences between domestic and EU estimates.

countries enjoy a marked advantage over their EU competitors (e.g., Australia, Uruguay, South Korea, and Japan). Great Britain and Switzerland tend to be more carbon-efficient than their European counterparts in producing CBAM goods.

5.1.2 Economic cost exposure of third regions to CBAM

In Table 7, we present the ten most impacted countries with their respective economic cost exposure to the CBAM across various scenarios. Direct costs are expressed as a percentage of the regional total output. Overall, CBAM economic impacts are very small, representing less than 0.1% of global production value. The most exposed regions are the rest of the world's European (WEU) region, Turkey (TUR), and Russia (RUS), with the African region (WAF) and India (IND) also appearing in the top five.

Table 7: Direct economic cost exposure (in % of total output) to CBAM

Rank	Scenario 1		Scenario 2		Scenario 3	
	World	0.052%	World	0.175%	World	0.067%
1	WEU	1.515%	TUR	2.121%	WEU	2.003%
2	TUR	0.623%	WEU	2.074%	RUS	0.684%
3	RUS	0.318%	RUS	1.951%	TUR	0.680%
4	IND	0.208%	WME	0.676%	IND	0.221%
5	WAF	0.152%	WAF	0.615%	WEX	0.211%
6	WEX	0.152%	IND	0.463%	WAF	0.173%
7	WME	0.142%	TWN	0.322%	WME	0.171%
8	BRA	0.092%	BRA	0.299%	ZAF	0.100%
9	TWN	0.060%	ZAF	0.278%	BRA	0.100%
10	ZAF	0.059%	WEX	0.266%	TWN	0.073%

In Scenario #1, the total cost of the measure is the lowest, representing 0.052% of global output production. The rest of the world's European region is particularly exposed to CBAM, with about 1.52% of its production value subject to additional costs. When default carbon intensity values are assumed, the total cost increases to 0.175% of global production value. In this scenario, Turkey is especially exposed, with direct exposure amounting to 2.112% of its production value, followed by the rest-of-the-world European region (2.074%) and Russia (1.951%). Turkey exports CBAM-covered products more than the rest of the world's European region, albeit at a relatively lower carbon intensity. One consequence of Scenario# 2 is that direct cost exposure becomes less differentiated by technology, placing greater emphasis on export volume over carbon efficiency. A trend that undermines the economic rationale of carbon pricing (Mehling and Ritz, 2020). Scenario 3, which extends the CBAM scope to downstream products, produces results similar to Scenario 1, with direct exposure rising by less than 6%.

Overall, the economic pressure exerted by the CBAM on the EU's main trade partners remains minimal. Extending the policy to downstream products only marginally increases exposure in third regions. However, methodological differences between actual and default carbon intensity estimates can significantly affect results, with compliance costs tripling under default values. Despite this, regional rankings remain stable across scenarios, emphasizing the key role of trade intensity in basic materials. From the standpoint of direct cost exposure, regions without carbon pricing mechanisms may incur modest income losses, which ultimately translate into fiscal revenues repatriated to the EU.

5.2 CBAM impact on the supply chain

5.2.1 Economic costs at the regional level

Keeping trade patterns and final demand levels constant, the direct exposure of third countries translates into compliance costs for EU importers. These costs materialize as additional expenditures through the purchase of CBAM certificates. Table 8 summarizes the total and net economic costs of the CBAM, as well as the revenues generated across scenarios. In the base-case scenario (Scenario #1), total costs represent 0.70% of the EU (EEU) total output value. Revenues from compliance certificates account for 0.15% of output, reducing the net economic cost to 0.55%. Bulgaria (BGR) is the most affected, with total costs reaching 2% of its output value. Romania (ROU) and Poland (POL) follow, with net costs of around 1% of their respective outputs. Under a framework aligned with official guidelines and using actual carbon intensity values to compute compliance costs, the reform has almost no impact on 85% of European countries.

Table 8: Regional CBAM revenue, total and net costs by scenario (in % of total output)

	Scenario #1			Scenario #2			Scenario #3		
	T_{total}	T_{net}	$\mathcal{R}_{\text{total}}$	T_{total}	T_{net}	$\mathcal{R}_{\text{total}}$	T_{total}	T_{net}	$\mathcal{R}_{\text{total}}$
World	0.14%	0.12%	0.03%	0.87%	0.73%	0.15%	0.19%	0.15%	0.03%
EEU	0.70%	0.55%	0.15%	4.25%	3.39%	0.86%	0.94%	0.74%	0.20%
BGR	2.05%	1.32%	0.73%	5.90%	4.32%	1.58%	2.24%	1.46%	0.78%
ROU	1.29%	1.02%	0.27%	5.96%	4.64%	1.32%	1.65%	1.31%	0.33%
POL	1.27%	1.01%	0.25%	7.28%	5.88%	1.40%	1.79%	1.41%	0.38%
ITA	1.08%	0.85%	0.23%	8.13%	6.27%	1.85%	1.37%	1.08%	0.29%
LTU	0.89%	0.64%	0.26%	3.63%	2.73%	0.90%	1.04%	0.75%	0.28%
ESP	0.99%	0.83%	0.16%	4.41%	3.33%	1.07%	1.21%	1.02%	0.19%
BEL	0.91%	0.54%	0.37%	6.33%	3.30%	3.02%	1.17%	0.72%	0.45%
CZE	0.92%	0.82%	0.10%	6.12%	5.45%	0.67%	1.18%	1.06%	0.12%
GRC	0.85%	0.48%	0.37%	4.02%	2.52%	1.50%	1.41%	0.82%	0.60%
SVK	0.86%	0.76%	0.09%	4.80%	4.34%	0.46%	1.05%	0.95%	0.11%
NLD	0.77%	0.58%	0.20%	3.20%	2.62%	0.58%	1.08%	0.79%	0.28%
HRV	0.75%	0.47%	0.28%	2.19%	1.96%	0.23%	2.32%	1.12%	1.20%
HUN	0.77%	0.63%	0.14%	4.12%	3.64%	0.48%	0.93%	0.77%	0.16%
LVA	0.72%	0.57%	0.15%	2.51%	1.96%	0.56%	0.91%	0.74%	0.17%
SVN	0.68%	0.52%	0.16%	3.31%	2.75%	0.56%	1.20%	0.90%	0.30%
LUX	0.67%	0.38%	0.29%	5.12%	2.67%	2.45%	0.79%	0.48%	0.32%
NOR	0.64%	0.46%	0.18%	4.84%	3.77%	1.07%	0.75%	0.55%	0.20%
PRT	0.64%	0.49%	0.15%	4.47%	3.27%	1.20%	0.75%	0.59%	0.16%
EST	0.60%	0.48%	0.12%	3.21%	2.58%	0.62%	0.80%	0.65%	0.15%
FIN	0.59%	0.47%	0.12%	4.98%	3.96%	1.02%	0.94%	0.76%	0.18%
DEU	0.53%	0.45%	0.08%	3.50%	3.07%	0.44%	0.73%	0.62%	0.11%
AUT	0.46%	0.41%	0.05%	2.66%	2.42%	0.23%	0.59%	0.54%	0.06%
DNK	0.41%	0.29%	0.13%	2.66%	1.99%	0.67%	0.55%	0.38%	0.17%
MLT	0.38%	0.29%	0.10%	1.24%	1.11%	0.13%	0.66%	0.51%	0.15%
FRA	0.39%	0.30%	0.09%	2.06%	1.81%	0.25%	0.54%	0.40%	0.13%
SWE	0.36%	0.32%	0.05%	2.56%	2.27%	0.29%	0.59%	0.48%	0.11%
IRL	0.34%	0.26%	0.08%	2.08%	1.63%	0.45%	0.55%	0.40%	0.15%
CYP	0.23%	0.16%	0.07%	2.44%	2.09%	0.35%	0.40%	0.30%	0.10%

In Scenario #2, total aggregated compliance costs increase sixfold, rising from 0.70% to 4.25% of total European output. The underlying assumptions regarding compliance cost calculation significantly alter the distribution of costs across European countries. Italy (ITA) emerges as the most affected, bearing a burden equivalent to 8% of its total output. Under this scenario, the economic cost landscape shifts notably: 70% of European countries now face total costs exceeding 3%. These figures reflect that most EU imports of CBAM-covered products originate from relatively low-carbon producers. When compliance costs are instead based on global average default values, the costs rise substantially. In Scenario #3, total CBAM costs for European countries show a modest increase compared to Scenario #1. With all other factors held constant, extending the scope to additional sectors at risk of carbon leakage, the regulation imposes a cost nearing 1% of total production. As shown in Table 9, the cost increase associated with the broader product coverage is primarily driven by indirect effects rather than direct compliance costs. While the direct cost rises by only 0.05 percentage points, indirect costs increase by 20%, creating a gap ($\Delta T = T_{\text{indirect}} - T_{\text{direct}}$) of 0.54%. This suggests that Scenario #3 is shaped mainly by firm-level markups amplifying indirect cost transmission.

Table 9: Regional CBAM costs decomposition by scenario (in % of total output)

	Scenario #1			Scenario #2			Scenario #3		
	T_{direct}	T_{indirect}	ΔT	T_{direct}	T_{indirect}	ΔT	T_{direct}	T_{indirect}	ΔT
World	0.03%	0.12%	0.09%	0.15%	0.73%	0.58%	0.03%	0.15%	0.12%
EEU	0.15%	0.55%	0.41%	0.86%	3.39%	2.52%	0.20%	0.74%	0.54%
BGR	0.73%	1.32%	0.59%	1.58%	4.32%	2.75%	0.78%	1.46%	0.68%
ROU	0.27%	1.02%	0.76%	1.32%	4.64%	3.32%	0.33%	1.31%	0.98%
POL	0.25%	1.01%	0.76%	1.40%	5.88%	4.48%	0.38%	1.41%	1.04%
ITA	0.23%	0.85%	0.61%	1.85%	6.27%	4.42%	0.29%	1.08%	0.79%
LTU	0.26%	0.64%	0.38%	0.90%	2.73%	1.83%	0.28%	0.75%	0.47%
ESP	0.16%	0.83%	0.68%	1.07%	3.33%	2.26%	0.19%	1.02%	0.83%
BEL	0.37%	0.54%	0.17%	3.02%	3.30%	0.28%	0.45%	0.72%	0.26%
CZE	0.10%	0.82%	0.72%	0.67%	5.45%	4.78%	0.12%	1.06%	0.94%
GRC	0.37%	0.48%	0.11%	1.50%	2.52%	1.02%	0.60%	0.82%	0.22%
SVK	0.09%	0.76%	0.67%	0.46%	4.34%	3.88%	0.11%	0.95%	0.84%
NLD	0.20%	0.58%	0.38%	0.58%	2.62%	2.04%	0.28%	0.79%	0.51%
HRV	0.28%	0.47%	0.19%	0.23%	1.96%	1.73%	1.20%	1.12%	-0.09%
HUN	0.14%	0.63%	0.49%	0.48%	3.64%	3.17%	0.16%	0.77%	0.61%
LVA	0.15%	0.57%	0.42%	0.56%	1.96%	1.40%	0.17%	0.74%	0.57%
SVN	0.16%	0.52%	0.37%	0.56%	2.75%	2.19%	0.30%	0.90%	0.60%
LUX	0.29%	0.38%	0.08%	2.45%	2.67%	0.21%	0.32%	0.48%	0.16%
NOR	0.18%	0.46%	0.28%	1.07%	3.77%	2.70%	0.20%	0.55%	0.35%
PRT	0.15%	0.49%	0.34%	1.20%	3.27%	2.07%	0.16%	0.59%	0.42%
EST	0.12%	0.48%	0.35%	0.62%	2.58%	1.96%	0.15%	0.65%	0.50%
FIN	0.12%	0.47%	0.36%	1.02%	3.96%	2.94%	0.18%	0.76%	0.58%
DEU	0.08%	0.45%	0.38%	0.44%	3.07%	2.63%	0.11%	0.62%	0.52%
AUT	0.05%	0.41%	0.36%	0.23%	2.42%	2.19%	0.06%	0.54%	0.48%
DNK	0.13%	0.29%	0.16%	0.67%	1.99%	1.32%	0.17%	0.38%	0.21%
MLT	0.10%	0.29%	0.19%	0.13%	1.11%	0.98%	0.15%	0.51%	0.36%
FRA	0.09%	0.30%	0.21%	0.25%	1.81%	1.56%	0.13%	0.40%	0.27%
SWE	0.05%	0.32%	0.27%	0.29%	2.27%	1.98%	0.11%	0.48%	0.37%
IRL	0.08%	0.26%	0.18%	0.45%	1.63%	1.17%	0.15%	0.40%	0.25%
CYP	0.07%	0.16%	0.09%	0.35%	2.09%	1.74%	0.10%	0.30%	0.20%

On average, indirect costs account for roughly 80% of total CBAM costs, implying that only one-fifth of the burden is due to the regulation. Industry markups drive this amplification effect: on average, firms multiply their initial compliance costs nearly fourfold. In our baseline scenario (Scenario #1), indirect costs exceed direct costs by 0.41 percentage points of total output at the European level. Yet, in extreme cases, indirect charges can soar to ten times the level of direct costs. The use of default emissions values intensifies this trend even further. In this scenario, average indirect costs jump to 3.39% of output versus 0.86% for direct costs. This snowball effect multiplies the direct cost by a factor of five on average. Across EU members, we observe large gaps between countries: Poland and the Czech Republic (CZE), for example, face indirect costs of 5.88% and 5.45%, respectively, compared to direct costs under 1%.

5.2.2 Impact on inflation

Imposing environmental tariffs on imports will likely raise producer prices in the short run. Over time, trade adjustments may emerge, partially offsetting the inflationary impact. Still, firms with limited export exposure with inelastic supply may pass on a substantial share, or even more, of the carbon costs to downstream consumers. As value chains become denser, these input price distortions can intensify, reshaping overall price structures.

Modeling sector-wide price settings with markups allows us to capture how carbon costs cascade through the supply chain. In Table 10, we provide the producer π_{PPI} and consumer π_{CPI} price indices at the country level. We only present the 15 biggest estimates ranked according to their π_{PPI} values. The price variations are, in any case, more pronounced for European producers than for consumers. PPI is generally 1.3 times greater than CPI. In scenario #1, the general price index in Europe increases by 0.75% for the PPI and only by 0.59% for the CPI. The most affected countries mirror those with the highest output-cost burdens, with minor shifts in their ranking when measured by the CPI rather than the PPI.

Table 10: Producer (π_{PPI}) and consumer price index (π_{CPI}) estimates by scenario

Rank	Scenario #1			Scenario #2			Scenario #3		
	Region	π_{PPI}	π_{CPI}	Region	π_{PPI}	π_{CPI}	Region	π_{PPI}	π_{CPI}
	World	0.15%	0.12%	World	0.93%	0.75%	World	0.20%	0.17%
	EEU	0.75%	0.59%	EEU	4.57%	3.41%	EEU	1.01%	0.78%
1	BGR	2.24%	1.95%	ITA	8.76%	6.01%	HRV	2.77%	3.00%
2	ROU	1.45%	0.99%	POL	7.92%	5.92%	BGR	2.45%	2.11%
3	POL	1.38%	1.07%	BEL	7.15%	5.20%	POL	1.96%	1.56%
4	ITA	1.16%	0.83%	BGR	6.59%	4.97%	ROU	1.83%	1.25%
5	LTU	1.06%	0.81%	ROU	6.50%	5.57%	GRC	1.56%	1.19%
6	ESP	1.06%	0.75%	CZE	6.36%	4.76%	ITA	1.46%	1.05%
7	BEL	1.00%	0.79%	LUX	5.99%	4.40%	SVN	1.33%	1.07%
8	CZE	0.95%	0.72%	NOR	5.48%	3.79%	ESP	1.29%	0.91%
9	GRC	0.93%	0.70%	FIN	5.43%	3.74%	BEL	1.29%	1.03%
10	SVK	0.89%	0.79%	SVK	4.99%	4.48%	LTU	1.22%	0.92%
11	HRV	0.85%	0.79%	PRT	4.88%	3.56%	CZE	1.22%	0.93%
12	NLD	0.84%	0.69%	ESP	4.67%	3.60%	NLD	1.17%	0.95%
13	HUN	0.83%	0.67%	GRC	4.47%	2.70%	SVK	1.10%	0.96%
14	LVA	0.79%	0.58%	HUN	4.33%	3.45%	FIN	1.02%	0.75%
15	LUX	0.77%	0.74%	LTU	4.08%	3.44%	LVA	0.99%	0.72%

Under Scenario #2, the introduction of default values based on global carbon intensity dramatically increases the burden on some specific countries where PPI inflation exceeds 7%. Our measure of the CPI suggests that in this scenario, the direct repercussion could lead to a 3.41% increase in consumer prices at the European level. It is precisely via this cost transmission that inflation would intensify, although its impact on households would be smaller since their consumption baskets are less exposed to these cost pressures. Interestingly, when comparing scenarios #1 and #3, the widening gap between PPI and CPI implies that including additional products from the carbon leakage list disproportionately affects producers more than consumers.

5.2.3 Economic costs at the sector level

Incorporating markups into firms' price-setting behavior enables a sector-level breakdown of cost-sharing to assess the economic impact of the CBAM. European products are categorized using the Global Industry Classification Standard (GICS), allowing for the identification of sectors most exposed to the regulation and those exerting the greatest economic influence. In Table 11, we present the distribution of direct and indirect compliance costs across sectors. As expected, the Materials sector bears the highest direct costs relative to output, increasing from 0.68% in Scenario #1 to nearly 5% in Scenario #2, with a strong correspondence between direct and indirect cost burdens. In contrast, most other sectors are primarily affected by indirect costs. Notably, Financials, Real Estate, and Information Technology display particularly high indirect-to-direct cost ratios, with the latter two averaging 55 and 23 times their respective direct costs. In Scenario #3, CBAM's impact becomes more pronounced for Energy, the only case where direct costs exceed indirect ones, mirroring earlier findings for Croatia. Despite this distinctive feature, Scenario #3 remains broadly consistent with Scenario #1, with the primary difference being a substantial increase in indirect costs in the latter.

Table 11: European direct and indirect costs across sectors by scenario

	Scenario #1		Scenario #2		Scenario #3	
	T_{direct}	T_{indirect}	T_{direct}	T_{indirect}	T_{direct}	T_{indirect}
Communication Services	0.01%	0.22%	0.12%	1.31%	0.02%	0.33%
Consumer Discretionary	0.06%	0.50%	0.49%	3.26%	0.08%	0.67%
Consumer Staples	0.12%	0.64%	0.10%	2.56%	0.16%	0.87%
Energy	0.06%	0.35%	0.42%	2.23%	0.95%	0.64%
Financial	0.00%	0.27%	0.00%	1.50%	0.01%	0.42%
Health Care	0.02%	0.18%	0.16%	1.16%	0.03%	0.25%
Industrial	0.15%	0.60%	0.68%	3.67%	0.18%	0.80%
Information Technology	0.01%	0.24%	0.06%	1.49%	0.02%	0.36%
Materials	0.68%	1.13%	4.81%	7.57%	0.82%	1.49%
Real Estate	0.01%	0.38%	0.03%	1.93%	0.01%	0.52%
Utilities	0.05%	0.55%	0.20%	3.34%	0.21%	0.84%

In Table 12, we decompose the price variation induced by these effects across sectors and scenarios. The standard deviation, denoted σ , and the mean, μ , are computed at the sector level and further break down the variation at the product level. Interestingly, we remark that the sector with the greatest average price variation in the base-case scenario is Consumer Staples, where prices increase by 1.15% on average with a high variation of 2.67%. Hence, price variations are not limited to the scope of sectors thought to be directly impacted

by CBAM (*i.e.*, Materials and Industrial). Nonetheless, when examining the respective contributions of these sectors to the PPI and the CPI (see Figure 15 on page 66), we observe that they primarily influence the PPI. Conversely, sectors such as Consumer Staples and Industrials exhibit a stronger contribution to the CPI.

Table 12: Standard deviation $\sigma(\Delta p)$ and mean $\mu(\Delta p)$ of sector prices in Europe by scenario

	Scenario #1		Scenario #2		Scenario #3	
	$\mu(\Delta p)$	$\sigma(\Delta p)$	$\mu(\Delta p)$	$\sigma(\Delta p)$	$\mu(\Delta p)$	$\sigma(\Delta p)$
Communication Services	0.27%	0.24%	1.45%	1.81%	0.40%	0.29%
Consumer Discretionary	0.52%	0.69%	3.68%	7.80%	0.77%	0.88%
Consumer Staples	1.15%	2.67%	2.80%	2.86%	1.46%	2.72%
Energy	0.50%	0.92%	3.36%	10.11%	1.22%	1.46%
Financial	0.29%	0.19%	1.59%	0.92%	0.48%	0.39%
Health Care	0.52%	0.61%	3.29%	3.60%	0.68%	0.68%
Industrial	0.86%	0.95%	5.49%	7.20%	1.18%	1.07%
Information technology	0.30%	0.18%	1.77%	1.07%	0.45%	0.23%
Materials	0.98%	1.98%	5.79%	13.31%	1.41%	2.31%
Real estate	0.50%	0.28%	2.42%	1.10%	0.75%	0.49%
Utilities	0.67%	0.77%	4.04%	10.22%	1.17%	1.72%

In Scenario #2, the heterogeneity of price shifts intensifies. While Materials and Industrial exhibit the largest average price increases, Utilities also experience a significant rise, with a mean increase of around 4% and a standard deviation exceeding 10%. Although the Energy sector exhibits a more modest average price increase, intra-sectoral variation still reaches 10%, reflecting the significant burden on importers of relatively low-carbon fuels when default emission factors are applied. In this scenario, the Consumer Staples sector experiences smaller price increases than discretionary goods, but with greater dispersion. Conversely, Scenario 3 shows lower price shifts, yet the same four sectors (*i.e.*, Materials, Energy, Industrial, and Utilities) remain the most affected.

We finally look closer at the windfall profits of sectors induced by markups. In Table 13, we present within each sector and for each scenario the average profit $\mu(\Delta \pi)$, its standard deviation $\sigma(\Delta \pi)$, and the 95% percentile range $Q_{95\%}$. Under the baseline scenario, average windfall profits remain modest in every sector: from 0.05% of gross output in Communication Services to 0.42% in Materials, closely followed by Consumer Staples. Dispersion is also limited ($\sigma(\Delta \pi) < 1.3\%$) and $Q_{95\%} < 1.6\%$. In other words, the baseline scenario behaves like an efficient tax on energy-intensive imports: it raises prices proportionally to the verified carbon content. It leaves little room for market power to generate profits.

Switching to default intensities in Scenario #2 multiplies the average surplus by about a factor of five across the board: Energy, Industrial, and Materials now post on average windfall rates between 1.59% and 2.33%, while even financial firms breach the half-percent mark. The standard deviation and the 95th percentile confirm that the current mechanism drives higher averages and larger within-group spreads. Utilities, for instance, jump from $\sigma(\Delta \pi) = 0.40\%$ and $Q_{95\%} = 0.97\%$ in Scenario #1 to $\sigma(\Delta \pi) = 6.47\%$ and a $Q_{95\%} = 5.09\%$ when default values apply. Hence, under this methodological approach, the total CBAM cost largely overshoots the true carbon cost, creating a rent that oligopolistic importers can keep as windfall profits. Scenario #3 halves those figures relative to #2. Extending the product list while retaining actual intensities compresses the tail (*i.e.*, no group shows a 95th percentile above 3%) but the dispersion remains noticeably wider than in the baseline. Meanwhile, an interesting result is for Energy, which is expected to have an important

Table 13: Estimates of windfall profits across European sectors by scenario

	Scenario #1			Scenario #2			Scenario #3		
	$\mu(\Delta\Pi)$	$\sigma(\Delta\Pi)$	$Q_{95\%}$	$\mu(\Delta\Pi)$	$\sigma(\Delta\Pi)$	$Q_{95\%}$	$\mu(\Delta\Pi)$	$\sigma(\Delta\Pi)$	$Q_{95\%}$
Communication Services	0.05%	0.08%	0.23%	0.29%	0.50%	1.65%	0.08%	0.12%	0.28%
Consumer Staples	0.40%	1.24%	1.59%	0.91%	1.54%	3.27%	0.50%	1.29%	1.87%
Consumer Discretionary	0.15%	0.24%	0.68%	1.03%	2.27%	4.12%	0.23%	0.35%	0.91%
Energy	0.16%	0.33%	0.61%	1.11%	3.58%	3.27%	0.40%	0.81%	1.65%
Financial	0.11%	0.15%	0.45%	0.55%	0.69%	1.97%	0.18%	0.29%	0.72%
Health Care	0.11%	0.21%	0.40%	0.70%	1.14%	3.28%	0.14%	0.25%	0.54%
Industrial	0.24%	0.34%	0.84%	1.59%	2.50%	5.80%	0.34%	0.42%	1.18%
Information Technology	0.08%	0.10%	0.24%	0.44%	0.56%	1.36%	0.11%	0.13%	0.38%
Materials	0.42%	0.79%	1.54%	2.33%	4.77%	9.44%	0.60%	0.92%	2.09%
Real Estate	0.27%	0.16%	0.58%	1.37%	0.86%	3.23%	0.42%	0.34%	0.94%
Utilities	0.28%	0.40%	0.97%	1.75%	6.47%	5.09%	0.47%	0.78%	1.55%

market power. Its average windfall profit increases from 0.16% (Scenario #1) to 1.11% (Scenario #2) and stabilizes at 0.40% under the extended scope. The relatively moderate tail ($Q_{95\%} = 3.27\%$) suggests that EU fuel distributors may face limited room to inflate margins once upstream fossil inputs are already covered by the ETS. Estimates suggest that this sector is not the primary driver of the carbon cost pass-through.

The results highlight two distinct channels behind these windfall profits. Coverage enlargement (Scenario #3 vs. #1) raises average windfalls by only 0.2–0.3 percentage points, whereas default intensities add roughly 1–2 percentage points and amplify the extreme tail by a factor of three to five. Hence, the methodology embedded in the CBAM compliance cost estimation, rather than the mere extension of the scope, is the dominant driver of excess profits.

6 Conclusion

In the coming years, the EU should increase its mitigation policies’ ambitions to reach carbon neutrality. Carbon pricing remains the cornerstone of this transformation, largely due to sustained efforts in the European carbon market to become the leading global benchmark. Yet, despite the global surge in carbon pricing adoptions, Europe still acts unilaterally in its environmental initiatives. Its heightened ambition regarding the expansion of the mechanism to include sectors benefiting from exemptions compels it to tighten the rules to level the playing field and avoid carbon leakage. Long-standing debates over border carbon adjustments culminated in the adoption of the CBAM. In this chapter, I examine the main economic implications of the regulation through the lens of the global supply chain.

Input-output techniques are used to analyze the underlying effects of the CBAM measure on the global supply chain. Several scenarios are constructed to enhance the design assumption surrounding the CBAM implementation. We consider compliance cost estimation using default values while extending product coverage to items at high risk of carbon leakage, alongside a baseline scenario based on actual values and standard product coverage. The CBAM modeling approach incorporates a markup in the producer’s price setting, estimated from empirical data. Accordingly, CBAM compliance costs borne by European importers can be passed through to downstream customers at an intensity exceeding the initial carbon burden. This approach allows for estimating the first-order effects of the regulation on economic costs, inflation, and windfall profits across countries, sectors, and products.

CBAM-covered products account for approximately 1.24% of global GDP, with a predominant concentration in China but also Europe. Findings suggest that the direct impact

of the CBAM on non-European countries is very limited, mainly because the goods concerned amounted to €56 billion in 2022, representing only 2% of EU imports. The iron and steel sector dominates (65% of imports), followed by aluminium (28%), primarily exported by Russia, Africa, and Great Britain, which together account for 15% of combined flows. Although China is the largest producer (48% of CBAM products' total production) and the leading carbon emitter (60% of CBAM products' global emissions), it ranks only fifth among the largest EU exporters. Yet, together with India, China contributes nearly 45% of the total emissions embedded in EU imports. This represents almost 48% of Europe's direct domestic emissions from CBAM-covered production. This difference partly reflects higher carbon intensities, with iron and steel emitting twice as much and cement ten times as much as in the EU. Upstream transport and downstream finished goods manufacturing show the most substantial ties to these products, with downstream sectors warranting close attention due to potential carbon leakage. Additionally, since upstream emissions are nearly twice those downstream, the risk of resource shuffling cannot be ruled out.

Although the economic impacts of the CBAM appear limited at first glance, particularly under a close-to-reality scenario with a carbon price of €100/tCO₂e and a coverage representing only 2% of EU imports (€56 bn in 2022), the underlying cost dynamics reveal more complex vulnerabilities. Compliance costs remain relatively small, but their amplification through CBAM's methodological assumptions, particularly the substitution of verified emissions for default intensities, can triple the estimated economic burden. Results show that only 20% of this burden stems from direct regulatory costs, with the remaining 80% driven by markups along the value chain, disproportionately affecting downstream firms whose indirect costs can reach ten times the original tax. Input-output modeling highlights that the burden distribution is heavily mediated by market structure: while producers in competitive sectors bear most of the cost (as seen by larger PPI than CPI effects), oligopolistic sectors like Materials, Utilities, and Industrial benefit from windfall profits, up to 9% in the most extreme cases. These findings suggest that CBAM's effectiveness hinges not only on product coverage or tax level but critically on methodological choices. These choices may alter cost incidence, exacerbate distributional asymmetries, and risk undermining the policy's environmental integrity.

The results are subject to several limitations. First, our short-term analysis assumes fixed production functions and final demand. As the CBAM is rolled out, supply, demand, and trade structures will likely change dramatically. Those adjustments are unlikely to be captured in our modeling framework. Second, using aggregated sector-level monetary values may obscure essential dynamics. Without physical quantity data, our default emissions values may diverge fundamentally from those ultimately adopted by the regulator. Third, our markup-based pricing approach relies on assumptions that may not fully align with those underlying input-output modeling. A bridge between empirical and theoretical foundations must be reached to improve this model further. Furthermore, the estimation of markups draws on data with different economic structures and time periods, potentially biasing some sector-level results.

Despite these caveats, the study provides insights that can inform regulators as they refine the CBAM's design. The results confirm that the chosen methodology for calculating compliance costs will affect the economic impact of CBAM, especially for importers. We therefore recommend using actual, sector-specific emissions data when estimating these costs to preserve CBAM's environmental integrity. These methodological choices have a greater effect on economic outcomes than product coverage: broadening CBAM coverage to include products at high risk of carbon leakage would add only marginal extra costs. While CBAM's environmental efficacy remains to be demonstrated, its economic costs should not stand in the way of implementation.

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A Technical appendix

In some cases, the A matrix may not be sub-stochastic due to the intermediary demand of some sectors greater than their total output: $\sum_{j=1}^n Z_{i,j} > x_i$. However, the input-output Leontief model requires several assumptions of the matrix A (Peterson and Olinick, 1982), notably that each industry spends no more than it receives: $\sum_{j=1}^n a_{i,j}x_j \leq x_i$. This creates elements of matrix $A_{i,j}$ being greater than unity.³⁷ As in the Exiobase input-output table at the sector level, the composition of the final demand for products is the cause of this issue, since it encompasses changes in inventories and valuables that can take negative values. As suggested by Desnos *et al.* (2023), one way to obtain a better estimate of the technical coefficients is to replace the net output x_i by the total intermediary demand when the condition $\sum_{j=1}^n Z_{i,j} > x_i$ is satisfied:

$$x_i \leftarrow \max \left(x_i, \sum_{j=1}^n Z_{i,j}, \sum_{j=1}^n Z_{j,i} \right)$$

In total, 264 values are corrected from the $9\,800 \times 1$ column vector.

Sparsity To further ensure that matrix A is conformed to calculations, we analyze the nonnegative matrix A using the sparsity ratio. This ratio estimates the number of elements with values less than or equal to a specific threshold ϵ divided by the total number of elements:

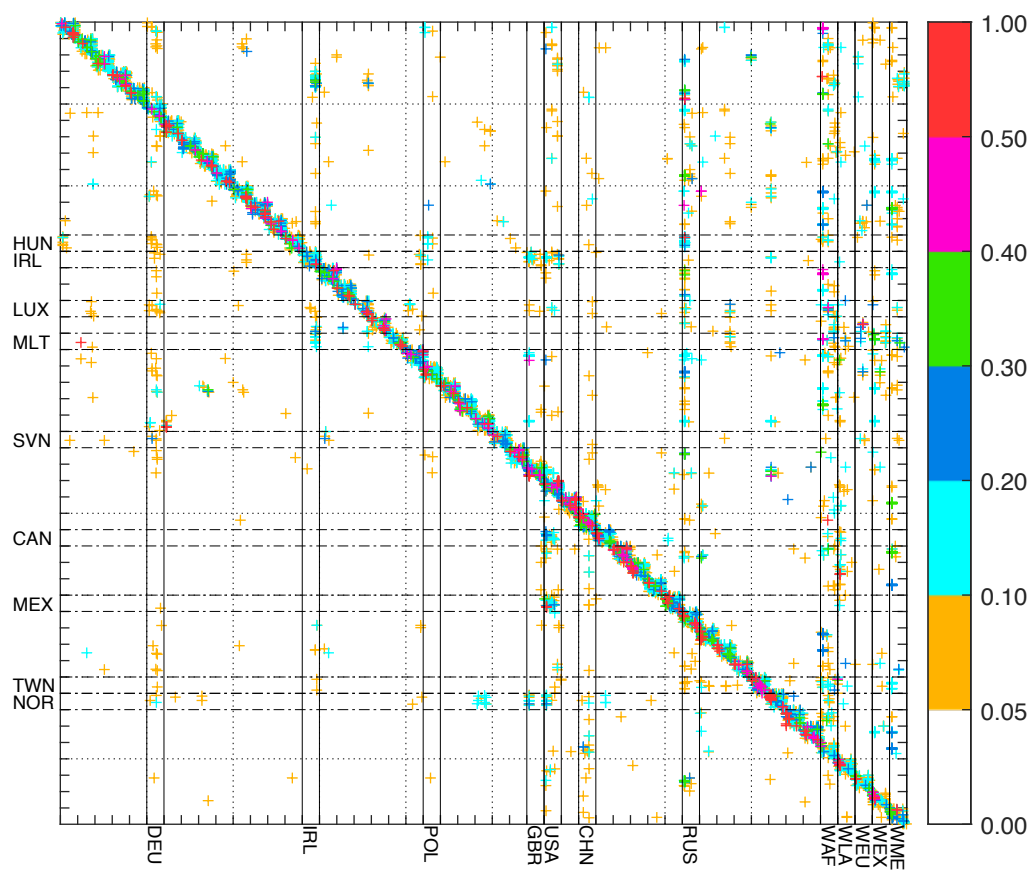
$$\text{sparsity}(A, \epsilon) = \frac{\#\{A_{i,j} < \epsilon\}}{\text{card } A}$$

When $\epsilon = 0$, the sparsity ratio is the zero-sparsity of A which estimates the number of zero-valued elements. Considering $\epsilon = 0$, $\epsilon = 10^{-9}$, and $\epsilon = 10^{-3}$, we obtain sparsity ratios of 64.99%, 72.24% and 99.55% respectively. These estimates are relatively high compared to the sectoral version of Exiobase 2022. Desnos *et al.* (2023) found a zero-sparsity ratio of matrix A ($7\,987 \times 7\,987$) around 35%, two times less than the by-product input-output matrix. The increased number of elements from the by-sector to the by-product matrix gives rise to a surge in sparsity.

To better illustrate the sparsity of the A matrix, we present in Figure 11 the sparsity pattern of the global supply chain. Each cross presented in the plot represents a $A_{i,j} > 5\%$ value. The diagonal Milky Way of crosses represents the country submatrices' dependence. Off-diagonal elements represent the central trade exchange between partners. First, we notice that the bulk of substantial trading is located within countries. Second, many countries dominate the global supply chain, namely China, Germany, Russia, the USA, Ireland, and the aggregated regions of the rest of the world. This is notably the case for the aggregate of African and Middle Eastern countries, which are underrepresented in the list of countries.

³⁷Notice that $\sum_{i=1}^n a_{i,j} < 1 \forall j$ is generally accepted in open models since a part of primary inputs use is coming from the payment sector (e.g., labor, capital, etc.).

Figure 11: Sparsity pattern of the A matrix



Source: Exiobase 2022 & Author's calculations.

A.1 Matrix representation in the MRIO model

$$\begin{aligned}
 Z &= \begin{bmatrix} \begin{pmatrix} z_{11}^{11} & \cdots & z_{1n}^{11} \\ \vdots & \ddots & \vdots \\ z_{n1}^{11} & \cdots & z_{nn}^{11} \end{pmatrix} & \cdots & \begin{pmatrix} z_{11}^{1m} & \cdots & z_{1n}^{1m} \\ \vdots & \ddots & \vdots \\ z_{n1}^{1m} & \cdots & z_{nn}^{1m} \end{pmatrix} \\ \vdots & & \vdots \\ \begin{pmatrix} z_{11}^{m1} & \cdots & z_{1n}^{m1} \\ \vdots & \ddots & \vdots \\ z_{n1}^{m1} & \cdots & z_{nn}^{m1} \end{pmatrix} & \cdots & \begin{pmatrix} z_{11}^{mm} & \cdots & z_{1n}^{mm} \\ \vdots & \ddots & \vdots \\ z_{n1}^{mm} & \cdots & z_{nn}^{mm} \end{pmatrix} \end{bmatrix} \\
 A &= \begin{bmatrix} \begin{pmatrix} a_{11}^{11} & \cdots & a_{1n}^{11} \\ \vdots & \ddots & \vdots \\ a_{n1}^{11} & \cdots & a_{nn}^{11} \end{pmatrix} & \cdots & \begin{pmatrix} a_{11}^{1m} & \cdots & a_{1n}^{1m} \\ \vdots & \ddots & \vdots \\ a_{n1}^{1m} & \cdots & a_{nn}^{1m} \end{pmatrix} \\ \vdots & & \vdots \\ \begin{pmatrix} a_{11}^{m1} & \cdots & a_{1n}^{m1} \\ \vdots & \ddots & \vdots \\ a_{n1}^{m1} & \cdots & a_{nn}^{m1} \end{pmatrix} & \cdots & \begin{pmatrix} a_{11}^{mm} & \cdots & a_{1n}^{mm} \\ \vdots & \ddots & \vdots \\ a_{n1}^{mm} & \cdots & a_{nn}^{mm} \end{pmatrix} \end{bmatrix}, \quad X = \begin{bmatrix} \begin{pmatrix} x_1^1 \\ \vdots \\ x_n^1 \end{pmatrix} \\ \vdots \\ \begin{pmatrix} x_1^m \\ \vdots \\ x_n^m \end{pmatrix} \end{bmatrix}. \\
 Y &= \begin{bmatrix} \begin{pmatrix} Y_1^{1,s} \\ \vdots \\ Y_n^{1,s} \end{pmatrix} & \cdots & \begin{pmatrix} Y_1^{1,m} \\ \vdots \\ Y_n^{1,m} \end{pmatrix} \\ \vdots & & \vdots \\ \begin{pmatrix} Y_1^{m,s} \\ \vdots \\ Y_n^{m,s} \end{pmatrix} & \cdots & \begin{pmatrix} Y_1^{m,m} \\ \vdots \\ Y_n^{m,m} \end{pmatrix} \end{bmatrix}, \quad y = \begin{bmatrix} \sum_{s=1}^m Y_1^{1s} \\ \vdots \\ \sum_{s=1}^m Y_n^{1s} \\ \vdots \\ \sum_{s=1}^m Y_1^{ms} \\ \vdots \\ \sum_{s=1}^m Y_n^{ms} \end{bmatrix} \\
 (I - A)^{-1} &= \begin{bmatrix} I - A^{11} & -A^{12} & \cdots & -A^{1m} \\ -A^{21} & I - A^{22} & \cdots & -A^{2m} \\ \vdots & \vdots & \ddots & \vdots \\ -A^{m1} & -A^{m2} & \cdots & I - A^{mm} \end{bmatrix}^{-1}
 \end{aligned}$$

A.2 The supply chain as a graph network

A directed and weighted network is defined as a triple $G = (V, E, a)$, where V represents a set of n nodes, E is the set of ordered pairs of elements in V (directed edges), and a is a non-negative real weight assigned to each edge. Two nodes are considered adjacent if there exists at least one edge (i, j) from node i to node j .

The graph can be represented by its $n \times n$ adjacency matrix $A = (a_{i,j})$, where element (i, j) represents the weight $a_{i,j}$ of the edge from node i to j . Missing edges correspond to zero weights in the adjacency matrix such that $a_{i,j} > 0$ if $(i, j) \in E$ and $a_{i,j} = 0$ otherwise.

To understand node dependencies, it is generally assumed to concentrate on neighborhood $\mathcal{N}_i$, which is the neighbors of node i to which it is linked $\mathcal{N}_i = \{j : a_{i,j} > 0\}$. Then, we can define the degree, $\mathbf{k}_i$ of node i as the cardinality of its neighborhood:

$$\mathbf{k}_i = \#\mathcal{N}_i$$

For a directed weighted network, it is more common to consider the weighted degree of a node. We define the out-degree $\mathbf{k}_i^{\text{out}}$, and the in-degree $\mathbf{k}_i^{\text{in}}$ as follows:

$$\mathbf{k}_i^{\text{out}} = \sum_j^n a_{i,j}$$

$$\mathbf{k}_i^{\text{in}} = \sum_j^n a_{j,i}$$

The out-degree of a node is the weighted sum of its outgoing edges, while the in-degree is the weighted sum of edges entering node i . In the downstream analysis of the CBAM-product network, the in-degree reflects a node's relative importance, whereas in the upstream analysis, importance is captured by the out-degree.

The widely used eigenvector centrality measures a node's importance based on the principle that a node is considered important if connected to other important nodes. It is mathematically defined as:

$$\lambda c_i = \sum_{j \neq i} a_{j,i} c_j$$

where λ is a positive scalar. In this case, the centrality of each node i is proportional to the sum of the centrality of its neighbors. While eigenvector centrality is commonly used as a standard centrality measure, it is not optimal for directed networks that are not strongly connected. Therefore, we employ the Katz-Bonacich centrality measure, which assigns each node a baseline centrality β :

$$c_i = \frac{1}{\lambda} \sum_{j \neq i} a_{j,i} c_j + \beta$$

In matrix form, we define the vector of Katz-Bonacich centrality measure as:

$$\mathbf{KB} = \beta \left(I - \frac{1}{\lambda} A^\top \right) \mathbf{1}$$

where $\beta = 0.75$ in our computations. For the downstream analysis, we keep nodes with $\mathbf{k}_i^{\text{out}} > 0.005$, and $\mathbf{KB}_i > 1.005$.

B Additional results

B.1 Tables

Table 14: Regions in the input-output tables

Code	ISO	Name	Region	Sub-region	EU+
ZA	ZAF	South Africa	Africa	Sub-Saharan Africa	
BR	BRA	Brazil	Americas	Latin America	
CA	CAN	Canada	Americas	Northern America	
MX	MEX	Mexico	Americas	Latin America	
US	USA	United States	Americas	Northern America	
CN	CHN	China	Asia	Eastern Asia	
CY	CYP	Cyprus	Asia	Western Asia	
ID	IDN	Indonesia	Asia	South-eastern Asia	
IN	IND	India	Asia	Southern Asia	
JP	JPN	Japan	Asia	Eastern Asia	
KR	KOR	South Korea	Asia	Eastern Asia	
TR	TUR	Turkey	Asia	Western Asia	
TW	TWN	Taiwan	Asia	South-eastern Asia	
AT	AUT	Austria	Europe	Western Europe	✓
BE	BEL	Belgium	Europe	Western Europe	✓
BG	BGR	Bulgaria	Europe	Eastern Europe	✓
CH	CHE	Switzerland	Europe	Western Europe	
CZ	CZE	Czech Republic	Europe	Eastern Europe	✓
DE	DEU	Germany	Europe	Western Europe	✓
DK	DNK	Denmark	Europe	Northern Europe	✓
ES	ESP	Spain	Europe	Southern Europe	✓
EE	EST	Estonia	Europe	Northern Europe	✓
FI	FIN	Finland	Europe	Northern Europe	✓
FR	FRA	France	Europe	Western Europe	✓
GB	GBR	Great Britain	Europe	Northern Europe	
GR	GRC	Greece	Europe	Southern Europe	✓
HR	HRV	Croatia	Europe	Southern Europe	✓
HU	HUN	Hungary	Europe	Eastern Europe	✓
IE	IRL	Ireland	Europe	Northern Europe	✓
IT	ITA	Italy	Europe	Southern Europe	✓
LT	LTU	Lithuania	Europe	Northern Europe	✓
LU	LUX	Luxembourg	Europe	Southern Europe	✓
LV	LVA	Latvia	Europe	Northern Europe	✓
MT	MLT	Malta	Europe	Southern Europe	✓
NL	NLD	Netherlands	Europe	Western Europe	✓
NO	NOR	Norway	Europe	Northern Europe	✓
PL	POL	Poland	Europe	Eastern Europe	✓
PT	PRT	Portugal	Europe	Southern Europe	✓
RO	ROU	Romania	Europe	Eastern Europe	✓
RU	RUS	Russia	Europe	Eastern Europe	
SK	SVK	Slovakia	Europe	Eastern Europe	✓
SI	SVN	Slovenia	Europe	Southern Europe	✓
SE	SWE	Sweden	Europe	Northern Europe	✓
AU	AUS	Australia	Oceania	Oceania	
WA	WAF	World (Africa)	Africa		
WE	WEU	World (Europe)	Europe		
WF	WEX	World (Rest of the world)	World		
WL	WLA	World (Latin America)	Americas		
WM	WME	World (Middle East)	Middle-East		

Source: Exiobase 2022.

Table 15: Sectoral coverage (in % of nationwide emissions) and carbon prices (in €/tCO₂e) of implemented carbon pricing program (2022)

	Carbon pricing program	Energy	Industry	Buildings	Mining	Transport	Aviation	Coverage	κ
Carbon Tax	Argentina	●	●	○	●	●	○	20%	4.7
	Canada federal fuel charge	●	●	●	●	●	●	30%	38.0
	Chile	●	●	○	●	○	○	29%	4.7
	Colombia	●	●	●	●	●	●	23%	4.7
	Iceland	●	●	●	○	●	○	55%	32.5
	Japan	●	●	●	●	●	○	75%	2.3
	Liechtenstein	●	●	●	○	●	○	81%	123.4
	Mexico	●	●	●	●	●	●	44%	3.5
	Singapore	●	●	○	●	○	○	80%	3.5
	South Africa	●	●	●	●	●	●	80%	9.3
	Switzerland	●	●	●	○	○	○	33%	123.4
	Great Britain CPS	●	○	○	○	○	○	24%	22.5
	Ukraine	●	●	●	○	○	○	71%	0.9
	Uruguay	●	●	○	○	●	○	11%	130.4
ETS	Canada federal OBPS	●	●	○	○	○	○	1%	38.0
	China national	●	○	○	○	○	○	31%	8.7
	EU ETS	●	●	○	●	○	●	38%	82.2
	Indonesia	●	○	○	○	○	○	26%	0.6
	Kazakhstan	●	●	○	●	○	○	46%	1.0
	Mexico pilot	●	●	○	●	○	○	40%	0.0
	Montenegro	●	○	○	○	○	○		24.0
	New Zealand	●	●	●	●	●	●	49%	50.0
	South Korea	●	●	●	●	○	●	74%	17.8
	Switzerland ETS	●	●	○	●	○	○	11%	61.0
	United Kingdom ETS	●	●	○	●	○	●	28%	94.0

● Full coverage, ● Partial coverage, ○ No coverage.

Source: [Dao et al. \(2024\)](#) & Author's calculations.

Table 16: Estimation of elasticity $\hat{\xi}_j$, mean $\bar{\theta}_j$, and standard deviation $\sigma(\theta_j)$ of markups (1)

Product	$\hat{\xi}_j$	$\bar{\theta}_j$	$\sigma(\theta_j)$
Other Bituminous Coal	0.522	2.855	0.557
Real estate services	0.854	2.475	1.007
Gas Works Gas	0.544	2.386	0.691
Crude oil extraction	0.791	2.369	1.370
Wholesale trade and commission trade services	0.718	2.355	0.476
Oxygen Steel Furnace Gas	0.483	2.337	0.522
Paper waste for treatment: incineration	0.711	2.281	0.492
Oil seeds	0.703	2.263	2.036
Copper ores and concentrates	0.698	2.243	1.246
Lignite/Brown Coal	0.739	2.191	0.683
Renting services of machinery and equipment	0.737	2.152	0.380
Precious metal ores and concentrates	0.505	2.147	0.682
Coking Coal	0.573	2.097	0.633
Lead, zinc, and tin ores and concentrates	0.567	2.064	0.605
Financial intermediation services	0.718	2.056	0.555
Electricity by Geothermal	0.491	2.035	0.306
Coke oven gas	0.534	2.005	0.580
Natural Gas Liquids	0.606	1.993	0.693
Iron ores	0.513	1.976	0.499
Sub-Bituminous Coal	0.421	1.967	0.437
Aviation Gasoline	0.473	1.966	0.811
Gasoline Type Jet Fuel	0.513	1.962	0.269
Blast Furnace Gas	0.601	1.945	0.666
Sale, maintenance, repair of motor vehicles	0.695	1.943	0.785
Services auxiliary to financial intermediation	0.862	1.934	0.764
Products of Vegetable oils and fats	0.700	1.914	0.787
Biogasification and land application	0.612	1.911	0.451
Intert/metal waste for treatment	0.755	1.906	0.496
Incineration	0.736	1.898	0.455
Retail trade services of motor fuel	0.711	1.888	0.677
Glass and glass products	0.860	1.844	0.557
Paper and wood waste for treatment	0.309	1.817	0.211
Hotel and restaurant services	0.878	1.813	1.148
Sand and clay	0.847	1.813	0.383
Other Hydrocarbons	0.658	1.794	4.956
Other land transportation services	0.618	1.793	0.261
Fertiliser	0.732	1.792	0.455
Paper for treatment	0.732	1.780	0.364
Retail trade services	0.616	1.773	0.417
Nickel ores and concentrates	0.444	1.769	0.284
Natural gas extraction	0.784	1.735	1.150
Crops	0.584	1.672	0.795
Supporting and auxiliary transport services	0.720	1.641	0.404
Composting and land application	0.760	1.613	0.421
Transmission services of electricity	0.769	1.611	0.441
Oil/hazardous waste for treatment	0.739	1.607	0.349
Tobacco products	0.727	1.605	0.403
Motor Gasoline	0.631	1.601	0.235

Continued on next page

Table 16: Estimation of elasticity $\hat{\xi}_j$, mean $\bar{\theta}_j$, and standard deviation $\sigma(\theta_j)$ of markups (2)

<i>Continued from previous page</i>			
Product	$\hat{\xi}_j$	$\bar{\theta}_j$	$\sigma(\theta_j)$
Metal products	0.717	1.600	0.293
Electrical machinery	0.687	1.591	0.309
Biogas	0.529	1.572	0.317
Distribution services of gaseous fuels	0.824	1.571	0.508
Cement	0.854	1.555	0.163
Iron and steel	0.869	1.548	0.334
Furniture; other manufactured goods	0.636	1.541	0.318
Plastics	0.689	1.512	0.247
Post and telecommunication services	0.579	1.502	0.354
Electricity by coal	0.817	1.450	0.468
Wood and products of wood	0.760	1.448	0.200
Distribution and trade services of electricity	0.633	1.443	0.333
Aluminium	0.852	1.429	0.359
Chemical and fertilizer minerals	0.737	1.415	0.270
Rubber and plastic products	0.696	1.413	0.177
Heavy Fuel Oil	0.810	1.406	0.257
Precious metals	0.820	1.398	0.417
Machinery and equipment	0.638	1.398	0.279
Nuclear fuel	0.636	1.377	0.459
Beverages	0.601	1.362	0.169
Kerosene	0.672	1.362	0.506
Electricity by gas	0.697	1.357	0.296
Petroleum Coke	0.617	1.349	0.260
Non-specified Petroleum Products	0.698	1.323	0.316
Chemicals	0.780	1.322	0.283
Liquefied Petroleum Gases	0.690	1.313	0.338
Air transport services	0.634	1.302	0.317
Paper and paper products	0.757	1.289	0.235
Steam and hot water supply services	0.689	1.287	0.251
Refinery Feedstocks	0.761	1.283	0.355
Refinery Gas	0.585	1.279	0.217
Other Liquid Biofuels	0.657	1.270	0.249
Naphtha	0.793	1.261	0.348
Gas/Diesel Oil	0.722	1.231	0.183
Textiles	0.665	1.227	0.266
Biodiesels	0.629	1.225	0.199
Biogasoline	0.587	1.212	0.300
Kerosene Type Jet Fuel	0.707	1.210	0.191
Lead, zinc and tin	0.783	1.186	0.207
Food products	0.599	1.169	0.122
Meat products	0.543	1.132	0.626
Coke Oven Coke	0.695	1.119	0.220
Construction work	0.564	1.109	0.128
Public administration and defence services	0.573	1.096	0.131
Recreational, cultural and sporting services	0.552	1.068	0.100
Products of meat poultry	0.543	1.064	0.182
Other services	0.528	1.039	0.251
Education services	0.580	1.020	0.071
Health and social work services	0.558	1.011	0.093

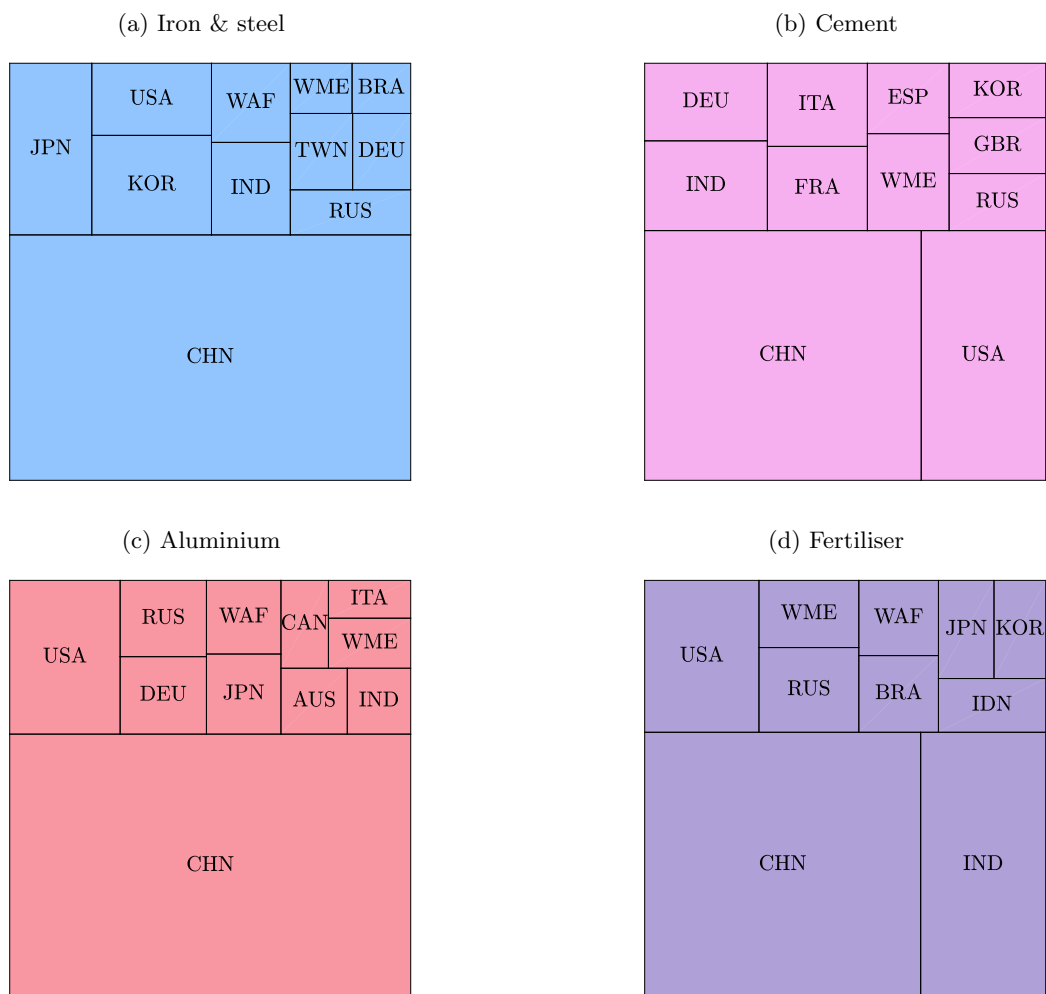
Table 17: Direct and total carbon intensities (in kgCO₂e/€) of CBAM products in Europe

Region	Aluminium		Cement		Fertiliser		Iron & steel	
	CI_{direct}	CI_{total}^{up}	CI_{direct}	CI_{total}^{up}	CI_{direct}	CI_{total}^{up}	CI_{direct}	CI_{total}^{up}
Austria	0.24	0.59	0.52	0.79	0.47	0.70	0.29	0.62
Belgium	0.02	0.54	1.07	1.49	0.40	0.64	0.37	0.91
Bulgaria	0.19	1.57	1.96	2.70	0.38	1.03	5.21	5.71
Cyprus	0.10	0.49	1.87	2.69	0.22	0.53	0.08	0.31
Czech Republic	0.06	0.64	1.97	3.19	0.31	1.03	0.73	1.48
Germany	0.08	0.67	0.95	1.28	0.86	1.02	0.27	0.74
Denmark	0.06	0.35	0.99	1.24	0.05	0.27	0.06	0.32
Estonia	0.01	0.69	0.67	1.45	0.06	0.51	0.01	0.40
Spain	0.24	0.87	0.85	2.03	1.04	1.39	0.11	0.72
Finland	0.01	0.47	0.49	0.73	1.24	1.64	0.08	0.40
France	0.04	0.38	0.63	0.90	0.50	0.62	0.30	0.55
Greece	0.20	1.05	2.52	3.47	0.26	0.61	0.03	0.59
Croatia	0.02	0.31	1.69	1.98	0.35	0.54	0.05	0.33
Hungary	0.05	0.69	0.86	1.40	2.00	3.59	0.23	1.11
Ireland	0.42	0.81	0.40	0.64	0.01	0.12	0.04	0.18
Italy	0.07	0.53	0.47	0.87	0.04	2.42	0.17	0.73
Lithuania	0.01	0.46	1.42	2.12	0.26	0.37	0.06	0.91
Luxembourg	0.00	0.51	7.22	8.09	0.05	0.28	0.10	0.58
Latvia	0.16	0.38	1.54	2.09	0.07	0.34	0.07	0.23
Malta	17.81	18.08	0.00	0.00	5.29	5.68	0.71	1.22
Netherlands	0.25	1.03	0.92	1.28	1.10	1.69	2.01	2.39
Poland	0.21	0.89	1.50	2.28	0.31	0.82	0.48	1.21
Portugal	19.02	19.58	3.03	3.91	0.27	0.63	0.21	0.75
Romania	0.09	0.51	1.10	1.77	0.46	1.00	0.60	1.09
Sweden	0.16	0.57	0.71	0.95	2.07	2.27	0.33	0.69
Slovenia	0.13	0.48	0.64	1.11	0.06	0.28	0.11	0.44
Slovakia	0.04	0.51	1.40	2.22	2.42	2.70	2.49	2.91
Norway	0.24	0.70	1.80	2.03	0.59	0.87	0.54	0.96
Average	1.43	1.94	1.40	1.95	0.76	1.20	0.56	1.02
Median	0.09	0.58	1.03	1.63	0.37	0.76	0.22	0.72

Source: Exiobase 2022 & Author's calculations.

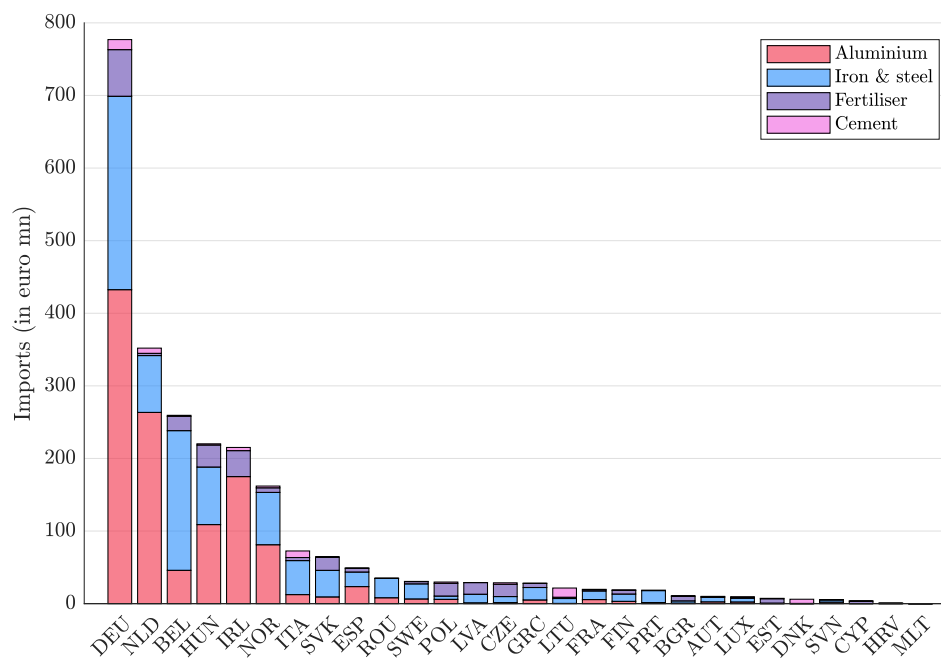
B.2 Figures

Figure 12: Largest global producers of CBAM-covered products in 2022



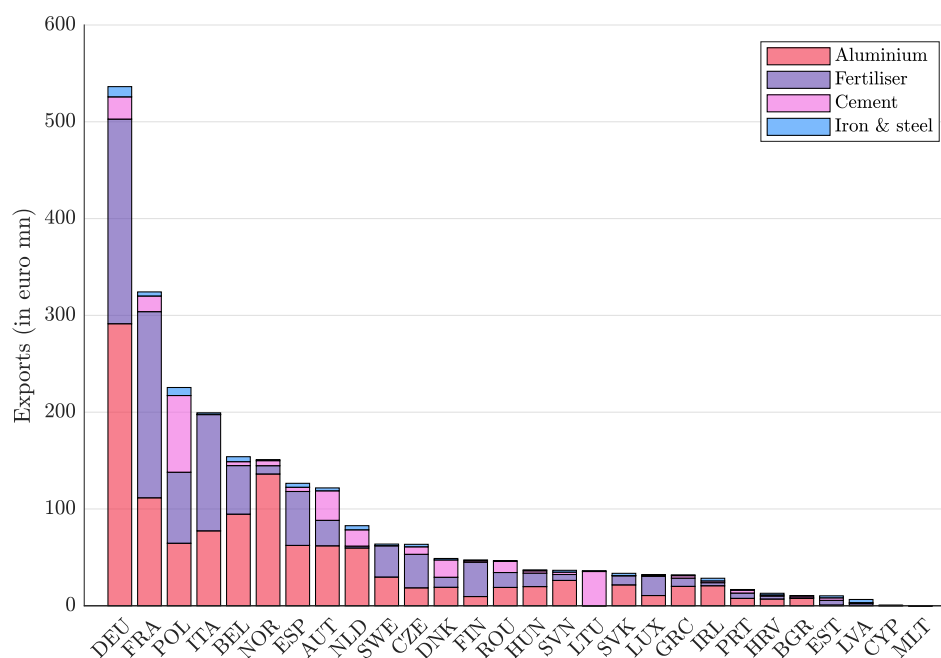
Source: Exiobase 2022 & Author's calculations.

Figure 13: European imports of CBAM products within the EU (in € mn)



Source: Exiobase 2022 & Author's calculations.

Figure 14: European exports of CBAM products within the EU (in € mn)



Source: Exiobase 2022 & Author's calculations.

Figure 15: Main sectors' contribution to PPI and CPI variations

