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European Carbon Import Tax Effective Against Leakage

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Summary

The European Emissions Trading System (EU ETS) increases costs for energy-intensive companies in the European Union (EU) relative to their competitors outside the EU. This competitive disadvantage can cause companies to lose market share or move production to countries outside the EU. As a result, CO_2 emissions in the EU are decreasing, but they are actually increasing outside the EU. We also call this 'carbon leakage'. To prevent this leakage, companies are compensated for the competitive disadvantage and get a large part of the emission allowances they need for free.

Over the next few years, the EU is introducing a new system: the *Carbon Border Adjustment Mechanism* (CBAM). CBAM will involve an import tax on CO_2 for a number of products. The EU's goal with CBAM is to reduce the risk of carbon leakage through production relocation. The CO_2 import tax will be phased in between 2026 and 2034 for the following product groups: iron & steel, aluminum, cement, fertilizer, electricity and hydrogen. The tax rate will be equal to the ETS price. At the same time, free allowances are phased out in the CBAM sectors. In this study, we estimate the effects of CBAM compared to the old situation, where companies in CBAM sectors received free allowances.

CBAM is more effective than free allowances in reducing carbon leakage. Our modeling analysis shows that leakage under CBAM is about one-third smaller than under ETS with free allowances. CBAM increases import costs by pricing the carbon content of an imported product. In contrast, free allowances offset the increase in a firm's production costs due to the European climate policy. On average, production outside the EU is more polluting than inside the EU. Therefore, the increase in import costs due to CBAM will be larger than the decrease in a company's own production costs due to free allowances. CBAM thus improves the competitive position of European companies in the European market compared to companies outside the EU. Therefore, CBAM is expected to lead to more own production in the EU and fewer relatively more polluting imports from non-EU countries, and thus to smaller carbon leakage due to production relocation.

In the Netherlands, CBAM leads to a stronger increase in the production and export of CBAM products than the EU average, according to the model outcomes. Dutch producers of CBAM goods export relatively much to other EU countries and much less to countries outside the EU. As a result, they also benefit more than average when intra-EU trade increases. A decline in exports to non-EU countries has less of an impact on total exports for the Netherlands.

CBAM increases the production of iron & steel and cement, while the impact on aluminum production is limited. Iron & steel and cement production involves relatively high CO_2 emissions, and there are large differences in emissions between European and non-European producers. The tax on iron & steel and cement imports is therefore relatively high. CBAM therefore has the greatest effect in these sectors. In aluminum production, CO_2 is mainly released during the production of electricity needed in the manufacturing process. The differences in direct emission intensity between EU and non-EU aluminum production are limited. CBAM imposes an import tax only on emissions from the aluminum sector itself. The tax is not on indirect emissions due to electricity use, so the impact for this sector is small. If indirect emissions in the aluminum sector would be part of CBAM, the production of aluminum in the EU would increase more. This is because emissions released from electricity production outside the EU are much higher.

The introduction of CBAM also leads to higher prices and revenues in the European Union. Because of the carbon import tax, the prices of CBAM goods increase by about 4 percent compared to the ETS system with free allowances, according to the model calculations. This price increase does mean that climate damage is better reflected in product prices, as emissions from imported products from non-EU countries are now also priced. For consumers, the effect of the price increase is limited because CBAM goods make up only a limited proportion of all consumer goods. For example, the consumer price index in the Netherlands with CBAM is 0.13 percent higher than with free duties. At the same time, CBAM does generate revenue for the EU, which could be used to reduce other taxes.

If non-EU countries would also introduce a CO_2 price themselves, this leads to strong global CO_2 reductions. CBAM revenues go to the EU member states. Countries that introduce their own CO_2 price are allowed to deduct this from the EU CO_2 import tax in the CBAM system. So in that case, these countries keep the proceeds of that CO_2 price for themselves. Especially for countries that export a lot to the EU and are already considering introducing CO_2 pricing, CBAM can be an extra incentive. To explore what happens if countries adjust their policies in response to CBAM, we ran two additional scenarios. These calculations show that if China, India, the United States and Eastern Europe were to introduce a CO_2 price of 25 euros per ton for the CBAM sectors, global CO_2 reductions would be substantial. However, these countries may also react differently if they perceive CBAM as protectionist. They may then take countermeasures, such as a similar import tax. Such a tax reduces exports from the EU to non-EU countries. In this scenario, the increase in production in Europe due to CBAM will also be smaller.

1 Introduction

The European Union (EU) has one of the highest CO_2 prices in the world. The EU implemented the European Emissions Trading System (EU ETS) in which energy-intensive companies and the power sector must buy allowances for every ton of CO_2 they emit. The number of allowances issued is limited, which puts a cap on total emissions. Emission allowances are tradable and an interaction between supply and demand for allowances creates a price in the market. An agreement was reached in 2023 on a number of adjustments to the EU ETS that accelerates the reduction of allowances in the EU ETS. The announcement of this agreement in 2021 led to an increase in the ETS price from an average of about 25 €/tCO_2 in 2021 to an average of about 85 €/tCO_2 in 2022 and 2023. Since then, the price has fallen again to about 60 €/tCO_2 in February and March 2024. However, the price is expected to go up again as the number of allowances goes to 0 in 2040 under unchanged policies.

A risk of these high CO_2 prices is that production relocates to countries outside the EU, and the CO_2 is emitted elsewhere in the world. Companies in countries outside the EU pay no or a relatively low price for their CO_2 emissions. They can therefore offer their products at a lower price; also to customers within the EU. Especially for sectors in the EU facing international competition, this can lead to loss of market share, or they may choose to move production to a part of the world where emissions are not or less restricted. Global emissions then do not decrease, and may even increase if the production facility outside the EU uses a more polluting technology. The increase in emissions elsewhere in the world as a result of climate policies in Europe is also called the carbon leakage effect. Empirical studies to date have found little evidence of production relocation due to the EU ETS (Verde, 2020; Trinks and Hille, 2023), but these studies examined periods with low CO_2 prices.

Carbon leakage can also occur through price declines in global energy markets. [1] If the demand for fossil fuels in the EU were to decrease because of climate policies, this leads to a lower price worldwide. This lower price may increase fuel consumption, and thus CO_2 emissions, outside the EU. We then speak of 'leakage through the energy market'. The magnitude of this effect depends on the extent to which global fossil fuel supply and demand respond to the price drop.

To prevent production relocation to outside the EU, and thus CO_2 emission relocation, the EU hands out free CO_2 allowances to industry. In practice, most companies in energy-intensive industry receive a large portion of the required allowances for free, while the electricity sector receives no free allowances. The rationale behind this is that the electricity sector is much less prone to leakage than the energy-intensive industry.

The current system of free allowances has some drawbacks. The number of free allowances a company receives is equal to the production multiplied by a benchmark based on the 10% cleanest producing companies in a sector. Companies that receive free allowances have virtually no incentive to reduce production because they will receive fewer allowances in the future. Free allowances are thus an indirect production subsidy. While companies do have an incentive to produce more cleanly because they can also sell the free allowances they receive, research shows that relatively fewer CO_2 emissions are reduced among companies receiving many free allowances (Dechezleprêtre et al., 2023). Moreover, the number of allowances

[1] Pricing CO_2 within the EU can also lead to clean innovations. This knowledge can also be applied outside the EU. This effect goes in the opposite direction; it creates additional CO_2 reductions outside the EU. See, for example, Dröge et al. (2009) and Cosbey et al. (2019) for a more detailed description of different channels of leakage.

decreases over time, so fewer and fewer free allowances can be handed out in the future. Finally, handing out free allowances to energy-intensive industries leads to lower prices of industrial products and therefore provides less incentive to reduce consumption.

Due to the disadvantages of free allowances, the European Commission has decided to introduce the so-called *Carbon Border Adjustment Mechanism* (CBAM) for a number of sectors covered by the EU ETS. [2] The purpose of CBAM is to reduce carbon leakage due to production relocation. In the future, an importer of products covered by CBAM will pay an import tax[3] on CO_2 emissions released during production equal to the ETS price. If a CO_2 price has already been paid in the country of origin when the product is produced, it will be deducted from the import tax. Over a nine-year period, between 2026 and 2034, CBAM will be phased in and free allowances will be phased out. This will avoid double protection for European producers of CBAM products. Export subsidies are not part of CBAM in the current set-up, as this may violate international trade agreements within the World Trade Organization (WTO). Companies that produce in Europe and primarily export outside the EU are therefore still at a competitive disadvantage.

The product groups that will be covered by CBAM are iron and steel, aluminum, cement, fertilizer, electricity and hydrogen. The producers of these products have a high risk of leakage, according to the European Commission, and can be brought under CBAM with relatively limited complexity and administrative burden. Other chemical products and oil products are not yet covered by CBAM because it is more complex to determine the emission intensity for these product groups. For the iron and steel, aluminum and hydrogen product groups, only direct emissions are included for now. This means that the import tax does not take into account emissions that may occur earlier in the production chain, for example from the production of the electricity required. For the cement and fertilizer product groups, however, it was decided to price indirect emissions from required electricity.

In this publication, CPB and PBL examine the effectiveness of CBAM in reducing carbon leakage. We also look at the economic consequences of CBAM. We do so both for the EU as a whole and for the Netherlands in particular. For the analysis we use the newly developed general equilibrium model GREEN-R (Global Recursive Equilibrium model on Energy and Resources).

[2] In the academic literature, import taxes and export subsidies on CO_2 have been mentioned for years as an effective alternative to free allocation of emissions allowances (Monjon en Quirion, 2011; Fischer en Fox, 2012; Böhringer et al., 2022).
[3] Legally, CBAM is not an import tax but a pricing instrument because the importer must purchase certificates, with the price of the certificates equal to the ETS price. Because of readability, we still use the term import tax because from an economic perspective there is no difference between an import tax and a mandatory purchase of allowances.

2 Model and scenarios

For the analysis, we use the GREEN-R model recently developed by CPB and PBL. GREEN-R is a so-called recursive dynamic general equilibrium model that can be used to simulate climate and energy policies. GREEN-R models interactions among sectors, households and government, taking into account the relative importance of a sector to the economy. The model covers all countries in the world, making it possible to map the effects of climate policies in one region on emissions in the rest of the world. Appendix A contains a model description and more information on the region classification and scenarios.

The sectors receiving free allowances and covered by CBAM are shown in table 2.1. In GREEN-R, fertilizer production is not distinguished as a separate sector, but falls within the chemical sector. Because fertilizer is only a limited part of the entire chemical industry, we have chosen not to consider the chemical industry as a CBAM sector in our simulations. Furthermore, we assume that the CBAM tax is equal to the ETS price and is levied on direct CO_2 emissions released from production of imported goods. In the CBAM legislation, unlike other product groups, indirect emissions from electricity use in cement and fertilizer production are also covered by CBAM. We do not include fertilizer in the CBAM scenario. Because of consistency, we decided not to include indirect emissions from cement production in the CBAM scenario either. However, we do consider an additional scenario in which indirect emissions are priced for all product groups.

Table 2.1 – Overview of most important ETS sectors

Sectors	*ETS-FREE-ALLOCATION*	*ETS-CBAM*
Iron & Steel	**Free allocation**	**CBAM**
Other metals (a.o. aluminum)	**Free allocation**	**CBAM**
Minerals (a.o. cement)	**Free allocation**	**CBAM**
Chemical products (a.o. fertilizer)	**Free allocation**	**Free allocation**
Oil products	**Free allocation**	**Free allocation**
Fossil electricity	**-**	**CBAM**

We consider three main scenarios, namely: *ETS-NO-PROTECTION*, *ETS-FREE-ALLOCATION* and *ETS-CBAM*. In *ETS-NO-PROTECTION*, the EU ETS is introduced into the model without any anti-leakage measures. The EU ETS is modeled as an annually declining emissions cap, which leads to an increasing ETS price over time. In this scenario, all allowances are auctioned. We use this scenario to compare the other two scenarios with. In the second scenario *ETS-FREE-ALLOCATION*, free allowances are added to the ETS. This scenario reflects the current situation of the EU ETS. Third, we look at the *ETS-CBAM* scenario where an import tax on CO_2 emissions is added to the ETS.

Finally, we also analyze two scenarios in which countries outside the EU react to the introduction of CBAM. In the *CO_2-PRICE-NON-EU* scenario, we consider a situation in which non-EU countries decide to introduce a CO_2 tax of their own. Specifically, we assume in this scenario that China, India, Eastern Europe including Russia, and North America introduce a CO_2 tax of 25 €/tCO_2 in the three CBAM sectors (iron & steel, other metals and minerals). In the *IMPORT-TAX-NON-EU* scenario, we consider what the consequences are if the same four regions respond to CBAM by introducing their own import taxes on imports from the EU for the three CBAM product groups. We assume that the level of the import tax is exactly the same as the CBAM tax.

3 Effects of CBAM

3.1 Effectiveness of CBAM and free allocation against leakage

We compare the three different EU ETS scenarios with a baseline in which we assume that the EU ETS is never implemented. In this way we can estimate the global CO_2 reduction and leakage due to introduction of the EU ETS. The introduction of the EU ETS leads in all three ETS scenarios to about 675 megaton CO_2 reduction in the EU in 2035 compared to a baseline in which EU ETS is not introduced. The reduction in the EU occurs through substitution from fossil to renewable energy, through energy conservation and through changes in production levels. The production of ETS sectors decreases more than the consumption of their products, due to increased imports from non-EU countries.

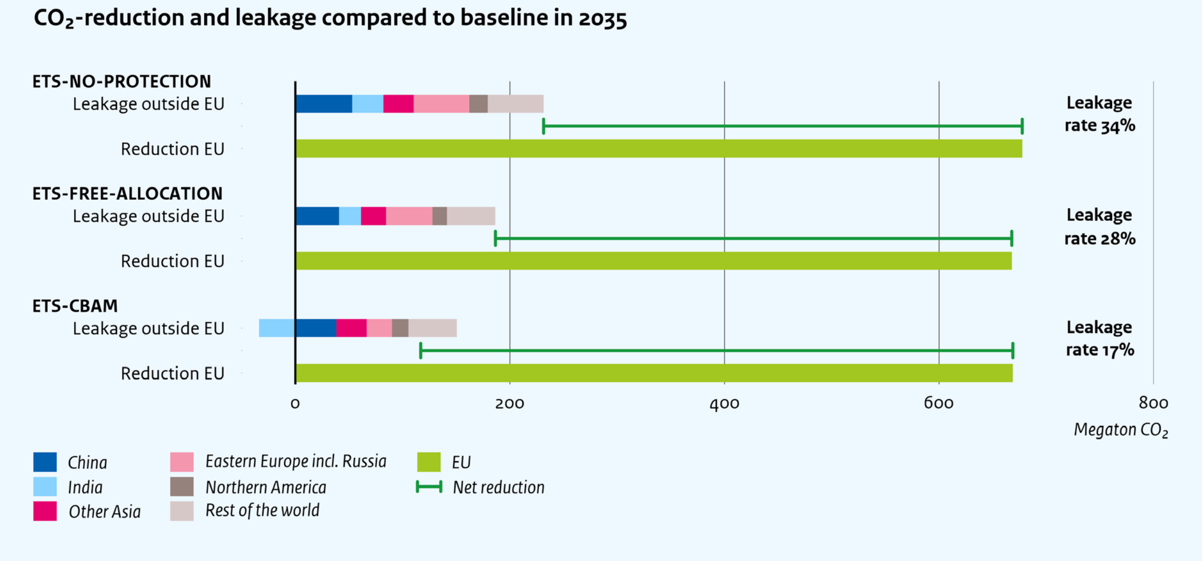
In *ETS-NO-PROTECTION*, over a third of the EU's CO_2 reduction is offset by an increase in emissions outside the EU. Figure 3.1 shows the change in emissions for different regions. In the scenario where the ETS is introduced without measures against leakage, the reduction in the EU of 675 $MtCO_2$ is offset by an increase in emissions outside the EU of 230 $MtCO_2$, mainly in China and Eastern Europe including Russia. This gives a leakage rate of 34%. The increase outside Europe has two causes. First, after the introduction of the ETS, Europe is going to import more energy-intensive products, such as iron, steel and cement. This increases production and emissions outside Europe. In addition, the demand for fossil fuels in Europe is falling, causing the world price to fall. This causes an increase in fossil energy consumption and thus emissions outside Europe.

Introducing free allowances in the model simulation causes a limited decrease in the leakage ratio. Free allocation reduces the leakage rate from 34 percent to 28 percent. Free allowances lower the production costs of ETS companies. This in turn makes their own production more competitive in the global market, lowering imports and raising exports. There is less leakage, because production outside the EU increases less than in *ETS-NO-PROTECTION*.

With CBAM, the leakage rate in the model simulation decreases to 17 percent. CBAM is thus more effective than free allowances. An import tax creates a more level playing field for companies under the EU ETS by pricing the emissions of imported goods. The import tax based on CO_2 emissions causes imported goods to increase in price more than goods produced in the EU. In fact, outside the EU, production in CBAM sectors emits more CO_2 than inside the EU.[4] Because of the higher prices, imports of CBAM goods go down significantly. Within the EU, demand for and thus production of these goods increases as a result. This effect is greater than with free allowances because goods with a higher CO_2 intensity than in the EU are now more heavily priced. CBAM does not fully reduce leakage because CBAM does not apply to all ETS sectors. Moreover, CBAM does not ensure a level playing field for European companies exporting to countries outside the EU, nor does it prevent leakage through international energy markets.[5]

[4] See figure A.4 in the appendix for the emission intensity of production of CBAM-goods in different regions.
[5] Whereas free allocation also lower production costs for companies exporting to countries outside the EU and thus reduce competitive disadvantage, the same is not true of an import tax (Trinomics, 2021). An export subsidy could serve that purpose, but that is not part of the CBAM regulation.

Figure 3.1 - CBAM most effective in reducing leakage



The reduction in carbon leakage calculated by the model is largely in line with the literature. The leakage rate without additional measures is estimated between 10% and 30% by applied general equilibrium models (Böhringer et al., 2012; Branger and Quirion, 2014; Carbone and Rivers, 2017). Our estimate of leakage without protection is slightly at the high end of this range at 34%, but at the lower CO_2 prices that most studies use, there would be less leakage in our model as well (Appendix B). Branger and Quirion (2014) use a meta-analysis and estimate an average leakage reduction of 57% following the introduction of CO_2 border taxes. Several studies in this meta-analysis are not directly comparable to CBAM because often an import tax is combined with an export subsidy. Morsdorf (2022) and Bellora and Fontagné (2023) both do look at the effectiveness of CBAM. They arrive at a leakage reduction of about a half after introducing CBAM, compared to roughly one-third with free allowances.

Anti-leakage measures such as free allowances and CBAM increase the ETS price. In the ETS scenario without measures against carbon leakage, the price reaches 128 €/tCO_2[6] in 2035. In the scenario with free allowances, the price increases by 9% and in the CBAM scenario by 13%. Anti-leakage measures increase EU industry production. This increases the demand for CO_2 allowances from these sectors. Because the total quantity of allowances is fixed, the additional demand causes the ETS price to rise. The result is that sectors without protection (mainly fossil power plants) will have to reduce more CO_2.

3.2 Economic implications of CBAM and free allocation

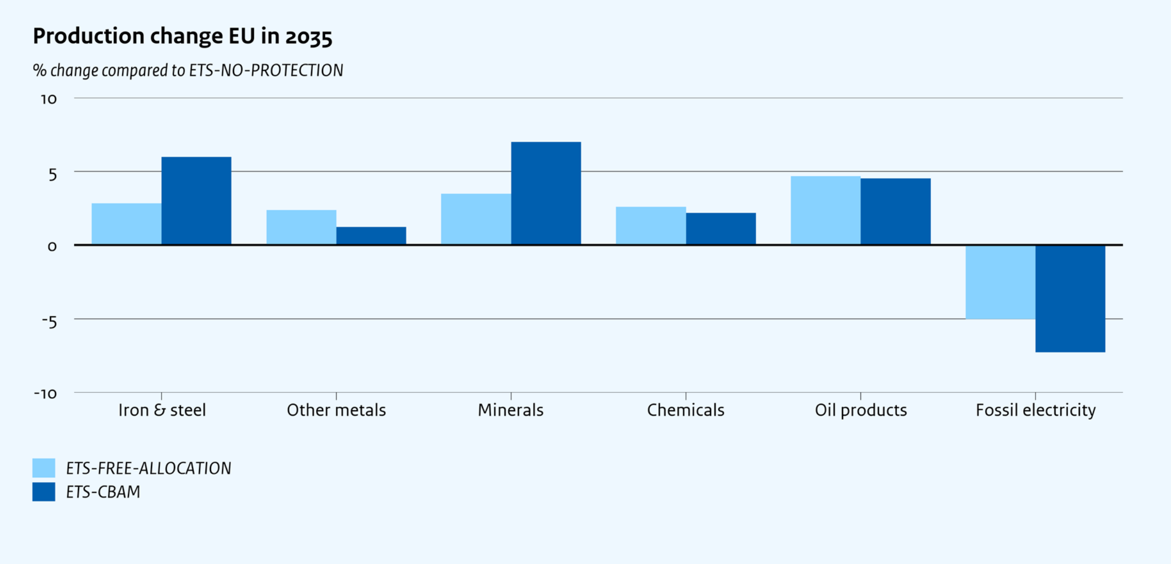
Both anti-leakage measures increase production in the EU sectors subject to the measures. Issuing free allowances has the greatest effect in the oil products and minerals sectors (see figure 3.2). Because the average emissions intensity in the EU is highest in these sectors, these sectors receive the most free allowances per unit of production. For iron and steel and minerals, the introduction of CBAM causes a larger increase in production than free allowances. This is mainly because many foreign producers in these sectors have a high emissions intensity. CBAM then improves competitiveness in the European market vis-à-vis non-EU producers.

[6] All variables in the GTAP-dataset are measured in dollars. We use an exchange rate of 0.91 $/€ to calculate monetary amounts in euros (19-12-2023).

In the other metals sector, CBAM leads only to a limited increase in production because the difference between direct emissions intensity in the EU and outside the EU is limited. In addition, exports to non-EU countries are more important in this sector than in other CBAM sectors. CBAM does not protect exports. The higher ETS price makes electricity from fossil energy more expensive, which will reduce fossil electricity production.

CBAM would be more effective in the other metals sector if it also priced indirect emissions from electricity use. In aluminum production, a price on indirect emissions is not part of CBAM regulations. But emissions from aluminum production occur mainly when generating electricity used for production. Generating electricity outside the EU emits a lot more CO_2 on average than in the EU, so indirect emissions outside the EU are a lot higher. An additional model simulation shows that production in the other metals sector would increase compared to the scenario with free allowances, if indirect emissions did become priced under CBAM. [7] This would also reduce carbon leakage in this sector.

Figure 3.2 – The scenarios *ETS-FREE-ALLOCATION* and *ETS-CBAM* lead to a higher production compared to the ETS-NO-PROTECTION[8]



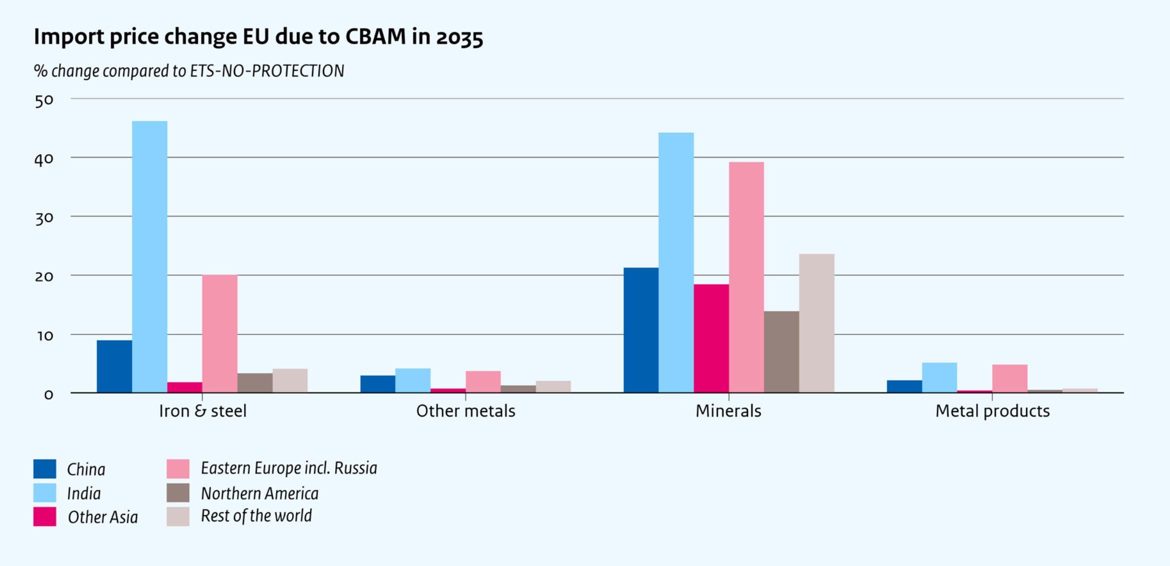
After introduction of CBAM, import prices rise the most for iron & steel and minerals. Import prices rise by tens of percent for iron & steel and minerals (mainly cement) (figure 3.3). For other metals and also metal products, price increases are limited to a few percent. This is because the direct emissions intensity in the production of other metals (mainly aluminum) is limited. For processed metal products, although emissions related to the production of the base metal are priced, base metal costs are only a limited part of the total production costs of metal products. In addition to base metals, capital, labor and other intermediate goods are needed for production, so the price increase due to CBAM is limited.

The increase in import prices varies widely among countries of origin, with imports from India having the highest price increase. This is because emission intensities vary widely between countries. [9] India has the highest emissions intensity for iron & steel and mineral production. As a result, price increases for imports

[7] Table B.4 in the appendix shows the leakage rate and production change in a scenario in which indirect emissions are part of CBAM for all product groups.
[8] We compare *ETS-FREE-ALLOCATION* and *ETS-CBAM* with the *ETS-NO-PROTECTION* scenario because we are specifically interested in the effectiveness of the anti-leakage measures. Thus, a 5% increase in production in the *ETS-CBAM* scenario means that the introduction of CBAM increases production by 5% compared to the scenario with ETS without CBAM. However, production in the *ETS-CBAM* scenario may still be lower than production in the baseline without ETS.
[9] See figure A.4 in the appendix for the emission intensity of production of CBAM-goods in different regions.

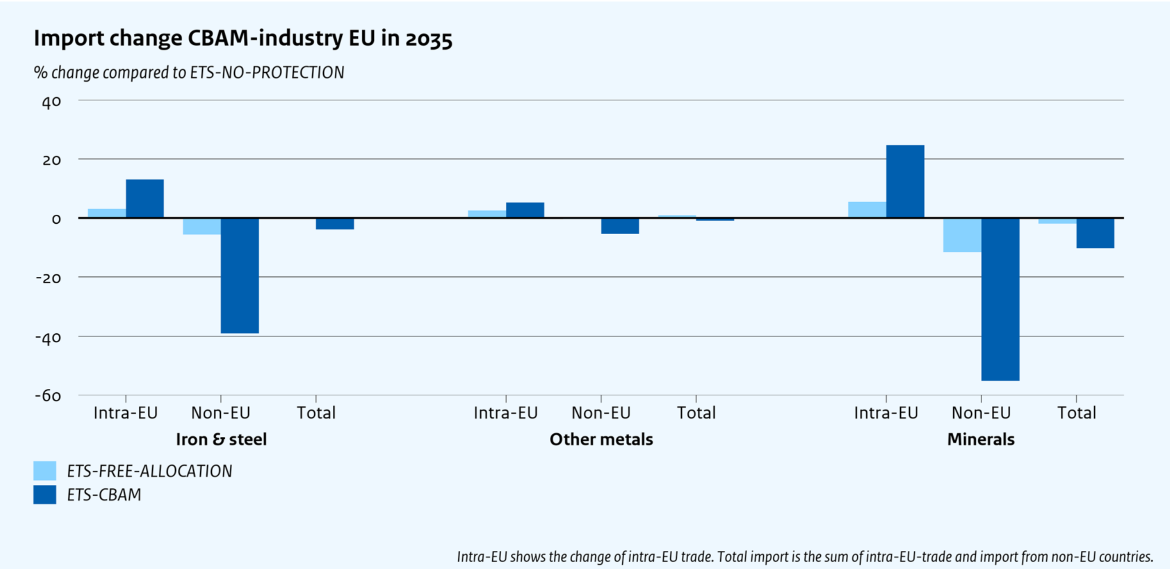
from India exceed 40% in these sectors. Prices of imports from North America rise the least compared to other regions.

Figure 3.3 – Import prices increase due to CBAM



The decrease in imports from outside the EU due to CBAM is largely offset by an increase in trade between EU countries. Issuing free allowances and CBAM have qualitatively the same effect. Free allowances make production in the EU cheaper, which leads to an increase in imports from EU countries and a decrease in imports from non-EU countries (see also figure 3.4). In the ETS-CBAM scenario, the same shift takes place, but the effects are larger. Due to large import price increases, imports from non-EU countries to EU countries fall on average by 40% and 55% for iron & steel and minerals, respectively. This decrease will be absorbed by increased production within the EU. Mutual trade between EU countries will also increase. The effect on total imports is limited because the share of imports from outside the EU is relatively small anyway.[10]

Figure 3.4 – Trade between EU-countries increases at the expense of import from non-EU countries

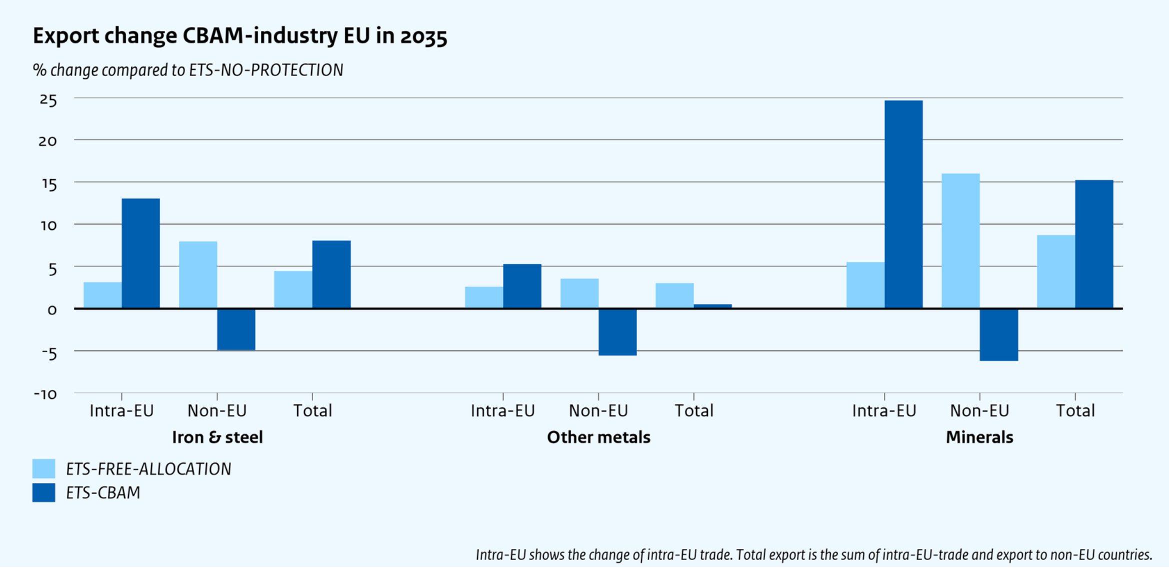


[10] See figure A.5 in the appendix for an overview of the main trading partners of the Netherlands and the EU in CBAM goods.

Issuing free allowances increases both intra-EU trade and exports to non-EU countries. With free allowances, EU companies have lower production costs, which also allows them to charge lower prices for their products. The lower prices lead to an increased demand for products (inside and outside the EU) and thus an increase in production and an increase in exports (see also figure 3.5). Exports to countries outside the EU do rise faster than intra-EU trade, because other EU producers also receive free allowances. Relative to non-EU countries, the competitive position of European companies actually improves.

CBAM, on the other hand, leads to fewer exports to non-EU countries. CBAM is only an import tax and therefore does not provide direct protection for exporting companies. Exports from EU countries to non-EU countries decrease compared to *ETS-FREE-ALLOCATION* because CBAM sectors will no longer receive free allowances after CBAM is introduced. Thus, for European companies primarily focused on the international market outside Europe, CBAM offers no competitive protection. As import prices from some non-EU countries rise sharply, CBAM does create a demand shift to goods produced within the EU. This leads to an increase in intra-EU trade for CBAM sectors. This effect dominates, increasing total exports in CBAM sectors compared to the ETS scenario without protection. For other metals, the increase in trade does not apply because exports to countries outside the EU are relatively important in this sector.

Figure 3.5 – Export to the rest of the world increases with free allocation, but decreases with CBAM



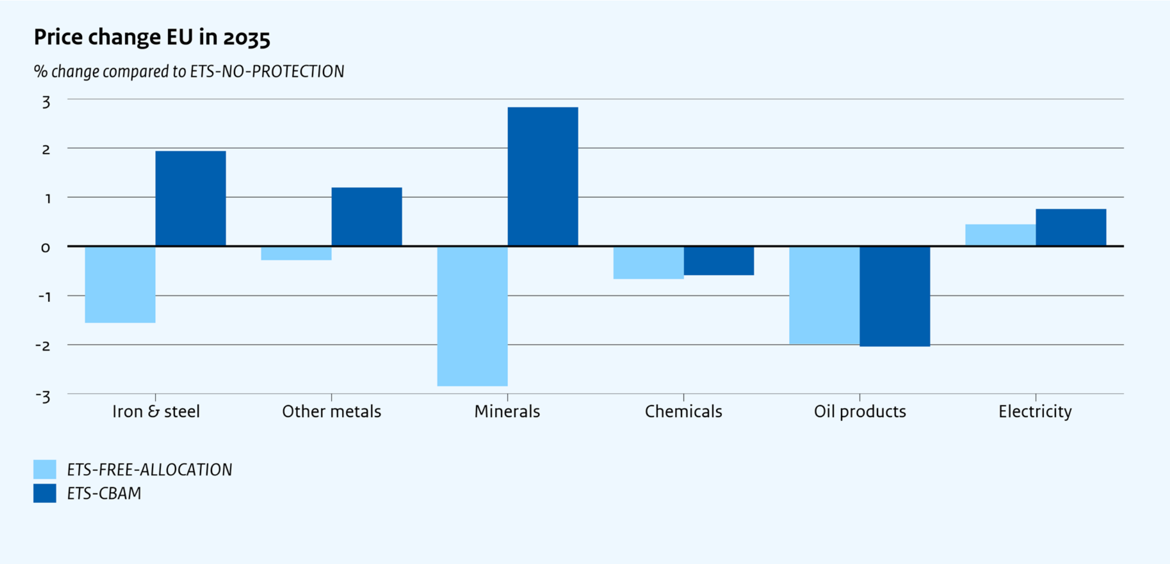
Free allowances lower the prices of goods, while CBAM actually raises prices. We assume that changes in production costs are fully passed through into prices. Free allowances then lower production costs, causing prices to fall in all sectors receiving free allowances (figure 3.6). The electricity price does rise because the ETS price rises because of free allowances. And the electricity sector does not receive free allowances. A consequence of CBAM is that the prices of CBAM goods in the EU rise. The removal of free allowances makes production of these goods within the EU more expensive. And the import tax makes imports from outside the EU more expensive. This will increase production costs for companies using CBAM products as inputs, which may worsen their competitive position in the global market (Trinomics 2021; Rübbelke et al. 2022). In general, however, this effect appears to be limited because the share of CBAM products is limited in total production costs. Chemicals and refineries are not covered by CBAM. They still receive free allowances, which reduces the price for these product groups in both scenarios.

Higher prices also mean that because of CBAM, the external costs of climate change are better reflected in the price of goods. This gives consumers and companies a greater incentive to reduce consumption of CO_2-intensive goods. This applies to goods imported from outside the EU, as import costs increase because of

CBAM. But even for goods produced in the EU, climate costs are better reflected in the product price, because companies no longer receive subsidies in the form of free allowances due to CBAM.

Finally, CBAM provides additional revenue, whereas issuing free allowances actually deprives the government of revenue. Currently, 57% of allowances in the EU ETS are auctioned. This means that the revenue from the EU ETS could be considerably higher if more allowances were auctioned. CBAM, on the other hand, is generating additional revenue itself. Consumers see prices rise, especially of CBAM products, but governments in the EU could use this extra revenue to reduce other taxes.

Figure 3.6 - CBAM leads to price increases in CBAM-goods



3.3 Differences between the Netherlands and the EU

After the introduction of CBAM, the Netherlands' total exports of CBAM goods, at 12%, are rising much more than the EU average of 6%. This increase is entirely caused by an increase in exports to EU countries (see figure 3.7). Exports to non-EU countries fall slightly due to the introduction of CBAM, but Dutch producers of CBAM goods export relatively much to other EU countries and much less to countries outside the EU. As a result, they also benefit more than average when intra-EU trade increases. A decline in exports to non-EU countries therefore also has a smaller impact on total exports for the Netherlands. Due to sharply increased exports to EU countries, output in the CBAM sectors also increases more than the EU average (figure 3.8). [11] In the *ETS-FREE-ALLOCATION* scenario, the outcomes for the Netherlands are similar to the rest of the EU (figure 3.7 and figure 3.8).

At the macro level, the effects of free allowances and CBAM are limited for the Netherlands because services make up a large part of GDP and the consumption mix. The consumer price index in the Netherlands increases by 0.15% and 0.02% in the *ETS-CBAM* scenario and the *ETS-FREE-ALLOCATION* scenario, respectively. Prices rise more sharply in the CBAM scenario due to the import tax. GDP rises slightly in both protection scenarios (0.15% in *ETS-FREE-ALLOCATION* and 0.18% in *ETS-CBAM*), because production in industry increases. No major effects occur in the labor market either, in line with Jansema-Hoekstra et al. (2018).

[11] See table B.1 in the appendix for an overview of the production increase of CBAM-goods in different EU countries. We calculate the production change compared to *ETS-NO-PROTECTION*, in which the production of industrial goods decreases because of the ETS. An increase compared to this scenario therefore means that production decreases less because of ETS.

Figure 3.7 – The Netherlands will trade more with other EU-countries and less with the rest of the world

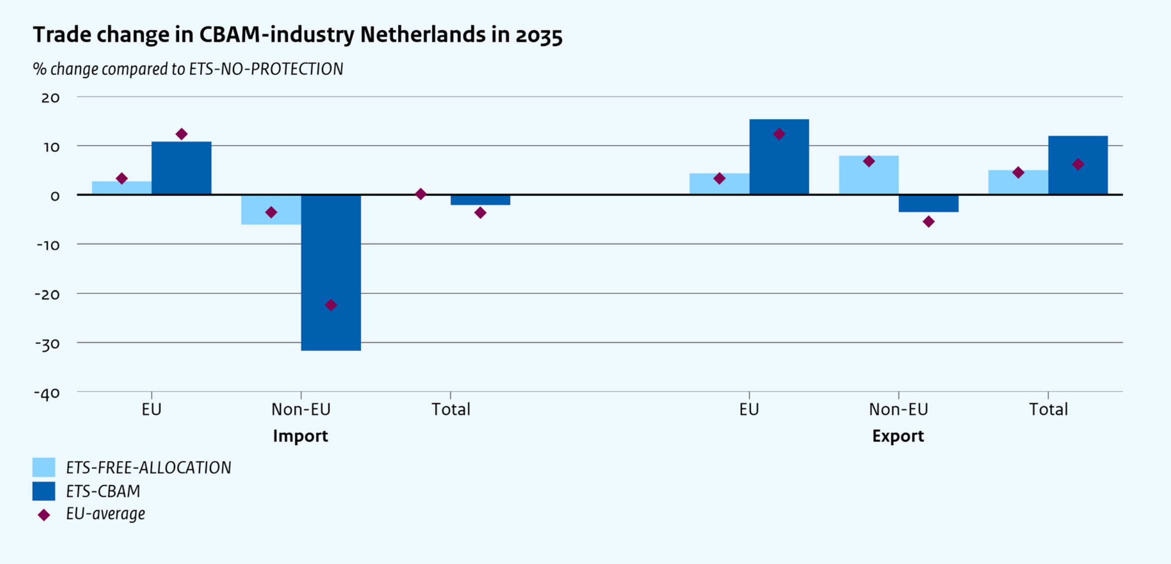
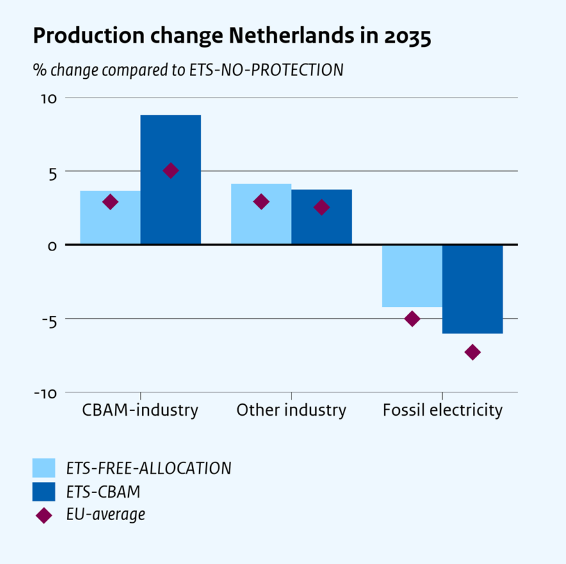


Figure 3.8 – Dutch production in CBAM-sectors increases relatively strong



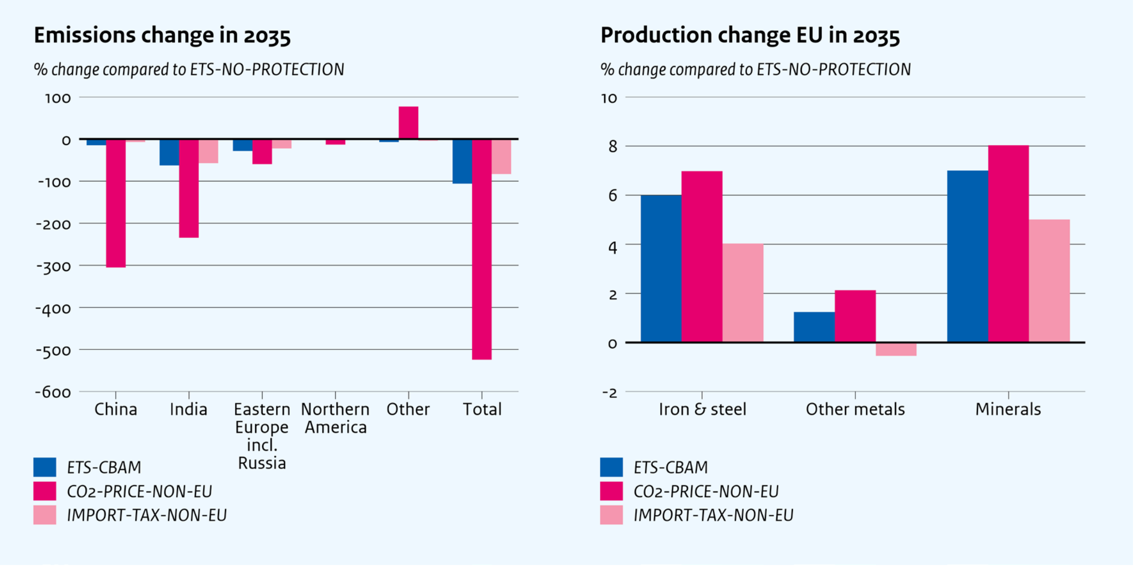
3.4 Scenarios in which foreign regions react

An import tax like CBAM can be an additional reason for non-EU countries to also introduce CO_2 pricing. Especially for countries that export a lot to the EU and are already considering introducing CO_2 pricing, CBAM can be an extra incentive. Countries that introduce a CO_2 tax themselves may deduct this tax from the CBAM import tax. They then keep the revenue from their own tax, while the CBAM revenue goes to the EU. Thus, Böhringer et al. (2016) conclude, based on game theory, that an import tax on CO_2 may encourage other countries to adopt more climate policies. Pauw et al. (2022) find that several EU trading partners have announced or are discussing changes to their climate policies.

Global CO_2 emissions fall sharply if China and India introduce a carbon tax. With a CO_2 price of 25 euros per ton of CO_2 in the CBAM sectors, emissions in China and India go down by hundreds of megatons if they introduce a carbon tax (see figure 3.9, CO_2-PRICE-NON-EU). By comparison, the reduction in emissions due to the EU ETS is equal to 675 megatons of CO_2 in our simulations compared to the baseline without the ETS. Emissions in Eastern Europe including Russia, and North America also go down slightly if these countries introduce a carbon tax, but the reduction is much smaller compared to China and India. Because of leakage effects, emissions in the rest of the world go up if China and India introduce a carbon tax. Net, this scenario still yields an additional 400 megaton CO_2 reduction in non-EU countries, compared to *ETS-CBAM*.

If non-EU countries respond by introducing their own import taxes, the effect on global emissions is limited. However, production in European industry would go down. An import tax by non-EU countries on EU products will cause these countries to import less from the EU. They will produce more locally, as EU products become relatively more expensive. This causes an increase in emissions in these countries and globally, because CO_2 emissions from production in CBAM sectors outside the EU are generally higher than within the EU (see figure 3.9, *IMPORT-TAX-NON-EU*). However, the increase in emissions is limited, so global emissions in this scenario are still lower than in the *ETS-FREE-ALLOCATION* scenario. EU manufacturing output does fall due to declining exports to countries outside the EU. The decline is greatest in the other metals sector, as this sector exports the most to countries outside the EU.

Figure 3.9 – Change in emissions and EU production if non-EU countries react to CBAM



4 Discussion

Introduction of CBAM is more effective in reducing carbon leakage than issuing free allowances. This finding of our analysis seems robust. With other assumptions, model results will be different. For example, there is considerable uncertainty about the cost of emission reduction technologies, such as carbon capture and storage (CCS) and the production of green hydrogen and renewable fuels for aviation and shipping. However, the relative differences between the scenarios are unlikely to change significantly due to such uncertainties. The higher the cost of emission reduction, the higher the ETS price and also the greater the carbon leakage. The reverse is true for a lower ETS price. In all cases, CBAM will reduce leakage relative to free allowances to a similar extent (see Appendix B, Table B.2). More generally, the effects of CBAM will be larger with a higher ETS price and smaller with a lower ETS price (see also Table B.3).

If other countries will implement additional climate policies, less carbon leakage will take place, reducing the impact of CBAM. In our baseline, we include only the climate policies set out in current legislation. These policies are often insufficient to meet the Paris Climate Agreement. If non-EU countries take more stringent measures, their emissions intensity will be lower by 2035. This reduces carbon leakage, especially if the additional climate policies of non-EU countries include an absolute emissions cap. CBAM is then less effective, but also less needed.

Additional national and European climate policies in Europe can change model results for specific member states. In addition to the EU ETS, there are other policies within Europe aimed at greenhouse gas reduction. For example, several countries, including the Netherlands, will end the use of coal for electricity production. There will also be a second emissions trading system (ETS2) from 2027 that will impose an emissions cap on a large portion of emissions not covered by the EU ETS. Furthermore, several member states provide subsidies to industry for investments in emission reduction, such as in the Netherlands through the SDE++ scheme and customized agreements. Also, some member states compensate companies that use a lot of electricity for an increase in the price of electricity because of the ETS. The Netherlands had such a scheme, but recently abolished it. In our analysis, we do not include member state-specific policy measures. These are not expected to substantially change the overall picture for Europe, but might change the distribution of effects across member states. We also exclude ETS2. This emissions cap would limit the possibility of intra-EU leakage from ETS sectors to non-ETS sectors, but in the model results there is hardly any such shift.

Because of insufficient detail in the underlying data, some product groups in the model analysis do not match well with the CBAM product groups. The most detailed sector level in the dataset used often includes multiple product groups. As a result, the minerals sector in the model includes not only cement production, but also the production of glass and bricks, for example. The other metals sector includes production of other metals, such as copper and zinc, in addition to aluminum production. The product mix within these aggregate sectors differs between countries, meaning that trade flows and emission intensities of the aggregate sectors in the model will differ from the actual trade flows and emission intensities of aluminum and cement. Because cement and aluminum do generally represent a significant share of the minerals and other metals sectors, the model results do give a good idea of the potential impacts for the CBAM product groups.

In the Netherlands, the composition of the minerals and other metals sectors differs significantly from the European average because little cement and no aluminum is produced in the Netherlands anymore. The model results therefore do not give an accurate picture of the effects of introducing CBAM for these sectors in the Netherlands. We therefore only show results for the Netherlands for all CBAM sectors combined. Moreover, the focus of our analysis is on the effects of changes in production costs due to climate policies and we have not taken into account various factors that may make it difficult to expand production in the Netherlands, such as a tight labor market or local environmental and nitrogen regulations.

The results are based on industry averages. The results for individual companies will differ from the averages. Companies within a sector differ from each other, both in their emission intensity and their trading relationships. Therefore, for individual companies, effects of CBAM may be quite different from those for the sector as a whole. For example, CBAM will have much less impact on the output of a European company that primarily exports to countries outside the EU than on the output of a company that is primarily oriented to the European market. Furthermore, in the model analysis we use the average emissions intensity in a country to determine the level of the import tax. If individual firms can demonstrate that they produce cleaner, they qualify for lower tariffs. Thus, a shift could occur in countries outside Europe. Especially companies with low emission intensity then export their products to Europe, so the effect of CBAM on carbon leakage will be smaller.

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Appendix A - Description GREEN-R

Firms

Firms maximize production given a production function. The production function is built up using multiple layers of Constant Elasticity of Substitution (CES). Below is an example of a CES production function with only capital and labor:

$Q = A\left(\alpha K^{1-\frac{1}{\sigma}} + (1-\alpha)L^{1-\frac{1}{\sigma}}\right)^{1/_{1-1/\sigma}}$. Here Q is the total production, K is the amount of capital and L is the amount of labor that is used in production. σ in this example is the substitution elasticity between capital and labor. This elasticity controls how easy it is to substitute capital for labor and vice versa. The share parameter α determines the shares of capital and labor, while the scale parameter A scales the total production.

Each sector in GREEN-R produces one product. The share parameters α and scale parameters A are calibrated for each sector based on global input-output data for 2017 from GTAP11 (Aguiar et al. 2023). The substitution elasticities are based on literature. We assume that all sectors have the same production structure and substitution elasticities. The final production function does vary widely across sectors because the share and scale parameters are different for each sector. Furthermore, perfect competition is assumed, so firms do not make a profit. Total output is then equal to the sum of production costs including taxes.

Figures A.1 and A.2 show the structure of production. Figure A.1 shows how capital and labor are combined with an elasticity of 0.8 and then energy is added with an elasticity of 0.5. The elasticity between capital-labor and energy determines how easy it is to save energy. If energy becomes more expensive because of climate policies, then companies will invest in energy-efficient machinery and smart systems for optimal energy use (capital). Capital-labor-energy is then combined with intermediates. Only limited substitution is possible between intermediates because production processes often have limited possibilities to change raw materials. Finally, a sector-specific production factor is added. This production factor is only relevant for agriculture (land) and fossil fuel extraction (natural resources). Sectors with a sector-specific production factor can only scale up production to a limited extent when demand increases because the amount of land and natural resources is limited.

Figure A.2 shows how GREEN-R models the use of energy in production functions. As mentioned earlier, companies can reduce emissions by saving energy. But companies can also substitute between energy sources. We distinguish between oil, gas, coal and electricity. And within electricity production, we distinguish five generation technologies: Nuclear & Hydro, Coal, Gas, Wind & Solar and other. With a carbon tax, fossil fuels will become more expensive. The price increase will be highest for coal, because coal contains relatively the most CO_2. Companies will switch from fossil fuels to electricity in response to a price increase. Within fossil fuels, oil and gas will be more attractive than coal. And within generation technologies, renewable generation will take market share away from fossil generation.

Figure A.1 – Production function

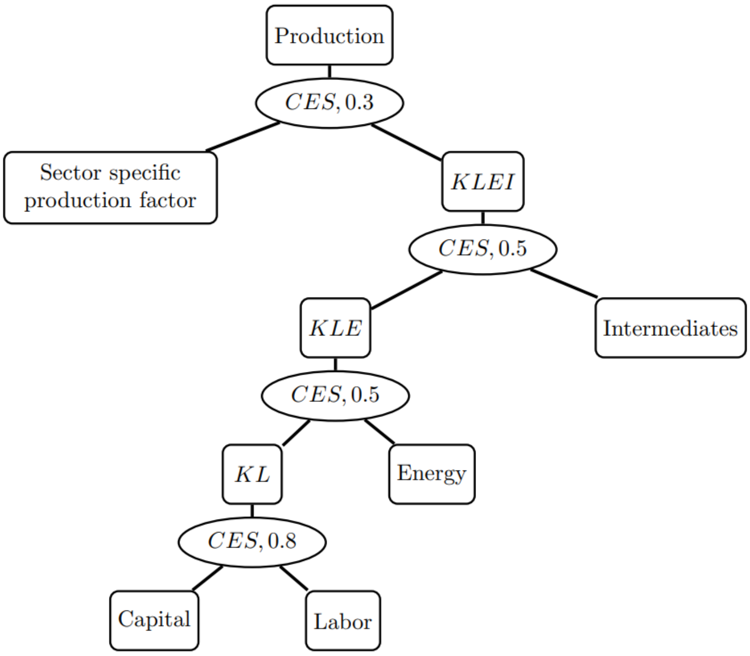

Figure A.2 – Energy in production function

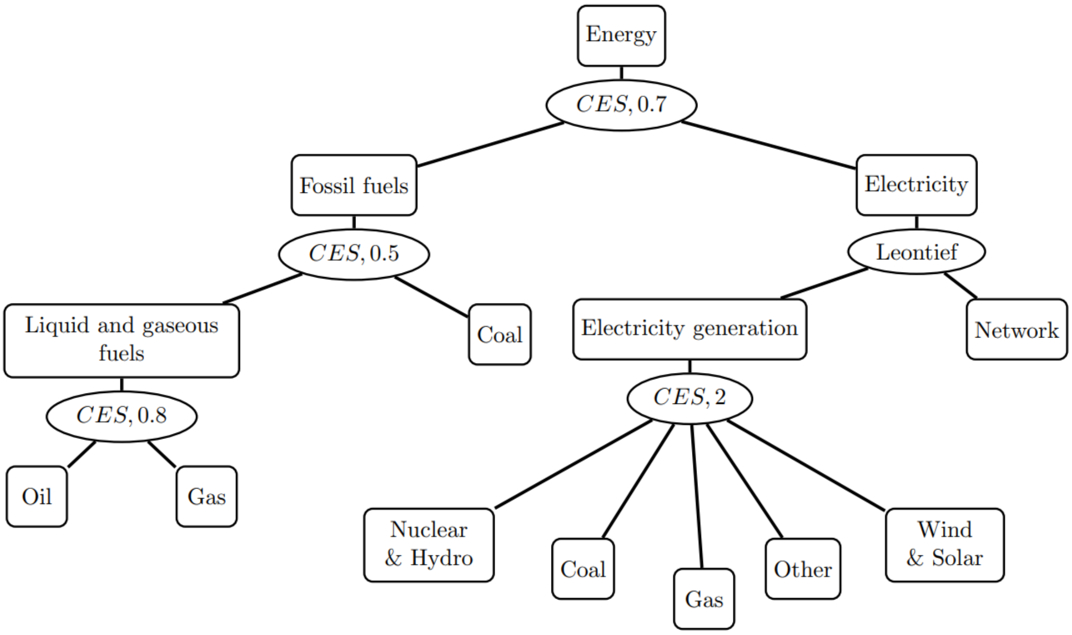

Table A.1 summarizes the sectors we distinguish in GREEN-R. We chose as much detail as possible in industrial sectors relevant to CBAM. Other sectors that are less relevant to this study are a lot more aggregated, for example the services sector.

Tabel A.1 – Overview of sectors

Industrial sectors	Electricity	Other sectors
Chemical products	Electricity Coal	Agriculture, Forestry & Fishing
Iron & steel	Electricity Gas	Coal extraction
Other metals	Electricity Wind & Solar	Gas extraction
Metal products	Electricity Nuclear & Hydro	Oil extraction
Minerals	Electricity Other	Services
Oil products	Electricity Transmission & Distribution	Transport
Paper & paper products		
Other industry		

Government

The government receives all taxes that are paid. The model includes different types of taxes, such as income tax, VAT, taxes on capital and labor, imports and exports, and also a tax on CO_2 emissions. Part of the tax revenue is transferred to households (we assume the share of these transfers in total tax revenue to be constant over time). The remaining tax revenue is used by the government for the consumption of goods and services. We assume that the government has a Cobb-Douglas utility function, which keeps the relative budget per product group constant. This best matches the fixed budgets that governments often use.

Households

In GREEN-R, there is one representative household per region. Households own the factors of production (labor, capital, land and natural resources) and receive income from firms that use these factors. Over this income, they pay taxes to the government. On the other hand, households also receive a transfer from the government. Of the disposable income (after paying taxes), a fixed portion is saved and the remainder is consumed.

The utility function of households is a CES function with substitution elasticity of 0.4. For energy, this means that the own-price elasticity is about -0.4.[12] We assume that households have the same substitution possibilities as firms within the energy products category. This means that the utility function of households consists of one layer for all goods and energy. And the utility function for energy has the same structure as in figure A.2.

Investment

Household savings are invested in investment goods. Investments consist of different goods (think buildings and machinery) and are distributed among these goods based on a Cobb-Douglas utility function. Thus, this means that the relative budgets for each investment category remain the same. Investments are added to the capital stock each year. Because a portion of the capital stock is also depreciated each year, the net increase depends on the difference between depreciation and investment.

[12] The own-price elasticity of energy is equal to $-\sigma * (1 - s_E)$, where σ is the CES substitution elasticity and s_E is the share of energy in total household expenditure. This gives a price elasticity of about -0.4 because the share of energy is relatively small.

International

We distinguish eleven regions within Europe and another ten regions outside Europe. The largest economies within Europe plus Belgium are included as separate countries because they are important trading partners of the Netherlands. The remaining countries are combined into four regions within the EU. Outside the EU, China, India and Turkey are included as individual countries because they are also important trading partners of the Netherlands. Other regions are aggregated to keep the analysis manageable.

The European Union in the model also includes Iceland and Norway because, as EEA members, these countries are also part of the EU ETS. We also decided to include Britain in the EU ETS. Because of Brexit, Britain left the EU ETS and introduced its own ETS. While the price of the own ETS in 2023 is somewhat lower than the price in the EU ETS, an additional check where Britain is not part of the ETS did not give substantially different results.

Table A.2 – Overview of region classification

Region	Countries	EU ETS & CBAM
Belgium	Belgium	X
France	France	X
Germany	Germany	X
Italy	Italy	X
Netherlands	Netherlands	X
Spain	Spain	X
United Kingdom	United Kingdom	X
Central and Eastern-Europe	Bulgaria, Croatia, Czech Republic, Hungary, Poland, Romania, Slovakia, Slovenia	X
Northern-Europe	Denmark, Estonia, Finland, Latvia, Lithuania, Norway and Sweden	X
Other Western-Europe	Austria, Ireland & Luxembourg	X
Other Southern-Europe	Cyprus, Greece, Malta and Portugal	X
Central- en Southern-America	Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Haiti, Jamaica, Guatemala, Honduras, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Trinidad and Tobago, Uruguay, Venezuela	
China	China and Hong Kong	
India	India	
Eastern-Asia	Japan, South-Korea and Taiwan	
Eastern-Europe	Albania, Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russia, Serbia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan	
Northern-America	Canada, Mexico and USA	
Turkey	Turkey	
Switzerland	Switzerland	
South-East-Asia	Brunei, Cambodia, Philippines, Indonesia, Laos, Malaysia, Myanmar, Singapore, Thailand, Vietnam	
Rest of the world	Alle other countries	

The total demand for a product in a region is equal to the sum of demand from firms, households, government and investment demand in that region. For this total demand, the model determines how it is divided between domestically produced goods and imported goods. You could interpret this as if one central intermediary in the model buys the products, both domestically produced and imported. And this middle party then delivers these products to domestic customers.

Products are region-specific and not perfectly substitutable. For example, Dutch companies and consumers may prefer the product variant produced in Germany over the one from France for a given product. So-called Armington elasticities determine how easy it is to substitute between producers from different regions. Armington elasticities differ between product groups. Some product groups are more homogeneous, which makes substitution between regions easier. We adopt the Armington elasticities from GTAP11. We use a CES function with two layers to model region choice. Here, as in GTAP11, we assume that it is easier to substitute between two foreign suppliers than between domestic production and imports (Hertel and van der Mensbrugghe, 2024). Figure A.3 shows the CES structure and Table A.3 shows the Armington elasticities for industrial sectors. These elasticities play an important role in determining changes in international trade flows following the introduction of an import tax such as CBAM.

Figure A.3 – Armington-structure

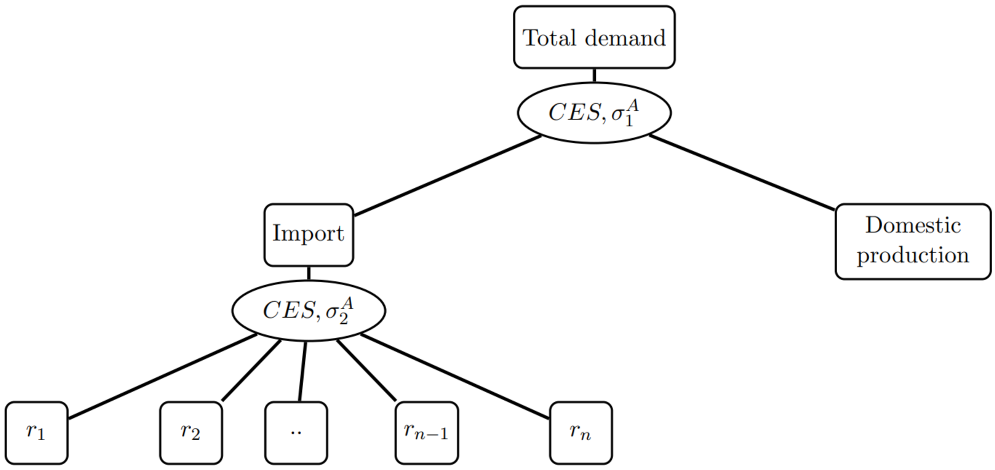

Table A.3 - Armington elasticities for industrial sectors

Industrial sectors	σ_1^A – Substitution between import and domestic production	σ_2^A – Substitution between import from different regions
Chemical products	3.3	6.6
Iron & steel	3.0	5.9
Other metals	4.2	8.4
Metal products	3.8	7.5
Minerals	2.9	5.8
Oil products	2.1	4.2
Paper and paper products	3.0	5.9
Other industry	3.4	6.7

Data

GREEN-R is based on the GTAP11 dataset with a base year of 2017. GTAP is a comprehensive dataset with data on intermediate supplies and final use of goods and services, capital and labor inputs, international trade flows, tax revenues, energy use and greenhouse gas emissions for 160 regions and 65 sectors. Production functions of firms and utility functions of households are calibrated in the model such that the initial situation of the GTAP data in 2017 is the optimal outcome of the model.

Below we show the CO_2 intensity and trade flows for the Netherlands and the EU based on the GTAP dataset. CO_2 intensity is defined as the amount of emissions per unit of production, where we distinguish between the emissions that occur directly in production and the indirect emissions that occur in the generation of the electricity used in production (indirect, also called scope 2). The CO_2 intensity of production ultimately determines the amount of the import tax. Import prices of CBAM goods increase the most for imports from countries with a high CO_2 intensity. Furthermore, initial trade flows are important for the impact of CBAM. This is because most trade takes place within the EU and CBAM only impacts trade with countries outside the EU.

Figure A.4 – CO_2-intensity of production of CBAM-goods in different regions

Both the direct and indirect CO_2 intensity of CBAM sectors in regions not covered by the EU ETS are higher than in countries covered by the EU ETS. This is mainly caused by higher use of coal in these regions. Figure A.4 shows the CO_2 intensity of the iron and steel, other metals and minerals sectors in different regions. The figure also shows emissions from the production of electricity used in these sectors. These indirect emissions are particularly relevant in the other metals sector because aluminum production is very electricity-intensive. Overall, the CO_2 intensity of other metals is significantly lower than in the other two sectors because less CO_2 is released in production. The differences in CO_2 intensity as found in the GTAP data are broadly consistent with differences shown by the World Bank (World Bank,2023). [13]

Figure A.5 – Import from EU-countries and non-EU countries for the Netherlands and the EU

Figure A.5 shows the Netherlands and EU imports of goods covered by CBAM. Most of the Dutch imports of CBAM goods come from other EU countries, to which the import tax does not apply because they are already covered by the EU ETS. Of the remaining imports in 2017, most came from the Eastern Europe region, dominated by Ukraine and Russia (mainly metals) and China and North America (mainly minerals). The distribution of EU imports by region of origin shows considerable similarity to Dutch imports from non-EU countries. Biggest exception is the large share of imports from North America of other metals for the EU as a whole, while for the Netherlands the share from Eastern Europe stands out.[14] Despite the limited trade volume

[13] The minerals sector in the GTAP database includes more activities than just cement production. Because these activities are less CO_2 intensive, the CO_2 intensity of the minerals sector is also much lower than that for the cement sector in the World Bank comparison. Due to differences in the composition of the minerals sector in different countries, the differences between the EU and other regions in the GTAP data are actually a factor 2 to 4 larger than in the World Bank data. This also explains the low CO_2 intensity of this sector in the Netherlands compared to the EU average. This is because not much cement is produced in the Netherlands. This may result in the GREEN-R model overestimating the effects of introducing CBAM for the minerals sector.

[14] After the war in Ukraine, the trade relationship between Europe and Russia changed considerably. We have not corrected for this.

between the EU and India in CBAM goods sectors, the high CO_2 intensity of the relevant sectors makes India sensitive to the introduction of CBAM (see figure A.4).

Baseline and scenarios

The model is calibrated on the GTAP dataset in the base year 2017. For the development toward the future (2017-2035), we construct a baseline using projections from different sources. The development of labor supply is based on projections from the UN population database. Furthermore, we reproduce OECD GDP projections in the model for each region by adjusting labor productivity. Finally, we use the energy scenarios from the IEA's World Energy Outlook 2023 with current policies to determine energy efficiency. We ensure that global prices for oil, coal and gas match realizations (through 2022) and future price trends assumed in the World Energy Outlook. Furthermore, we match oil, coal and gas use and generation shares of different types of electricity by region. Thus, the higher energy prices following Russia's invasion of Ukraine are included in the baseline.

To identify the effects of the EU ETS with or without anti-leakage measures, we first create a baseline without the EU ETS. All effects of the policy scenarios can then be plotted against this baseline path. We do this including the ETS price projections while calibrating the energy use in the model to the World Energy Outlook. We then use the model to determine a baseline without ETS by setting the ETS price to zero. Thus, we construct a baseline without the EU ETS as the benchmark scenario. Other climate policies that have already been implemented are implicitly included via the energy demand in the baseline.

In the first of the three scenarios, called *ETS-NO-PROTECTION*, the EU ETS is introduced into the model without anti-leakage measures. The EU ETS is modeled as an annual emissions cap for the ETS sectors in the EU, where everyone will pay the same price for emitting CO_2. In this scenario, all allowances are auctioned. The emissions cap decreases annually, causing the ETS price to increase over time. The revenue from auctioning allowances is passed back to households. This keeps the total tax burden the same under the different scenarios.

In the second scenario, *ETS-FREE-ALLOCATION*, part of the allowances in the EU ETS is allocated for free. This scenario reflects the current situation of the EU ETS, with energy-intensive industry receiving a large part of their allowances for free. We use the following method to determine the number of free allowances per sector. First, we determine the actual ratio between verified emissions and free allowances from ETS data. [15] Then we multiply this ratio by the sector emissions from GTAP to determine a benchmark (the number of free allowances per unit of production) per sector. Over time, we adjust the benchmarks so that 57% of allowances are auctioned each year.

Third, we consider the *ETS-CBAM* scenario in which an import tax on CO_2 emissions is added to the ETS. The amount of the tax is equal to direct CO_2 emissions released from production of imported goods multiplied by the ETS price. CBAM applies in this scenario to the iron & steel, other metals (including aluminum), minerals (including cement) and electricity sectors. The CBAM legislation taxes indirect emissions from electricity use only for cement and fertilizer. We do not include fertilizer (part of chemistry) in the CBAM scenario. Because of consistency, we decided not to include a tax on indirect emissions in cement in this scenario as well. Indirect emissions are also limited in this sector compared to direct emissions (figure A.4). We do consider an extra scenario where indirect emissions are covered by CBAM for all product groups (appendix B). The import tax is phased in linearly between 2026 and 2034, while free allowances are phased out linearly over the same period.

[15] We use data from the European Emission Authority: European Union Emissions Trading System (EU-ETS) data from EUTL (europa.eu).

Appendix B – Additional results

Table B.1 – Production change CBAM-industry in 2035 compared to *ETS-NO-PROTECTION* for different EU-countries

	ETS-FREE-ALLOCATION	ETS-CBAM
France	2.1%	6.3%
Germany	3.1%	5.6%
Italy	3.1%	5.8%
Netherlands	3.7%	8.8%
Spain	3.0%	4.8%
United Kingdom	3.5%	1.3%
EU-total	**2.9%**	**5.0%**

Table B.2 – Leakage rate in 2035 with lower and higher ETS-price

	ETS	ETS-FREE-ALLOCATION	ETS-CBAM
Halving of ETS price	30.7%	25.1%	16.1%
Standard ETS price	34.2%	27.9%	17.5%
Doubling of ETS price	39.5%	32.5%	20.4%

Table B.2 – Production change in 2035 compared to *ETS-NO-PROTECTION* with lower and higher ETS price

		ETS-FREE-ALLOCATION	ETS-CBAM
Halving of ETS price	Iron & steel	1.8%	3.6%
	Other metals	1.5%	0.6%
	Minerals	2.3%	3.8%
	Chemicals	1.7%	1.5%
	Oil products	3.0%	3.0%
	Fossil electricity	-2.4%	-3.2%
Standard ETS price	Iron & steel	2.8%	6.0%
	Other metals	2.4%	1.2%
	Minerals	3.5%	7.0%
	Chemicals	2.6%	2.2%
	Oil products	4.7%	4.5%
	Fossil electricity	-5.0%	-7.3%
Doubling of ETS price	Iron & steel	4.4%	9.2%
	Other metals	3.5%	2.6%
	Minerals	5.0%	12.9%
	Chemicals	3.9%	2.9%
	Oil products	7.1%	6.4%
	Fossil electricity	-9.9%	-16.2%

Table B.4 – Leakage rate and production change EU compared to *ETS-NO-PROTECTION* in 2035 when indirect emissions due to electricity use (scope 2) are part of CBAM

		ETS-CBAM	ETS-CBAM-SCOPE2
Leakage rate		17.5%	15.9%
Production change	Iron & steel	6.0%	7.3%
	Other metals	1.2%	4.0%
	Minerals	7.0%	7.3%
	Chemicals	2.2%	2.1%
	Oil products	4.5%	4.5%
	Fossil electricity	-7.3%	-7.7%