

Mörsdorf, George

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A simple fix for carbon leakage? Assessing the environmental effectiveness of the EU carbon border adjustment

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George Mörsdorf

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Poschingerstr. 5, 81679 Munich, Germany

Telephone +49(0)89 9224 0, Telefax +49(0)89 985369, email ifo@ifo.de

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A Simple Fix for Carbon Leakage? Assessing the Environmental Effectiveness of the EU Carbon Border Adjustment*

Abstract

As part of its ambitious European Green Deal package, at the heart of which stands the commitment to become carbon-neutral by 2050, the European Commission announced that it would propose a “carbon border adjustment mechanism” to address the risk of carbon leakage. This study models the measure in a Computable General Equilibrium framework and analyses how effective it would be in reducing the incidence of carbon leakage. The analysis suggests that even a sectorally limited EU carbon border adjustment would reduce the carbon leakage rate by up to two thirds, making it more effective than the current system of free allocation. Besides environmental benefits, it would also offset competitiveness losses of European energy-intensive industries incurred by a higher EU carbon price and generate additional income for public budgets. At the same time, the analysis shows that around a third of the overall incidence of carbon leakage is driven not by competitiveness but by energy price effects, making it impossible to offset by border measures.

JEL Code: Q58, Q54, C68

Keywords: Carbon border adjustment, carbon leakage, Computable General Equilibrium, EU climate policy, energy-intensive industries

George Mörsdorf**
University of Munich
Department of Economics
Geschwister-Scholl-Platz 1
80539 Munich, Germany,
European Commission
george.moersdorf@outlook.de

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** The author is currently employed at the European Commission but the research presented here was done independently of his placement there. All views and opinions expressed here are those of the author and do not necessarily represent the views and opinions of the European Commission.

1. Introduction

Carbon leakage – the phenomenon that part of the greenhouse gas emissions abated domestically may resurface outside the boundaries of the regulated jurisdiction – has long been a topic of discussion among policymakers and academics. This is because it not only implies that unilateral measures are less effective than they appear at first sight, but also that there are benefits to being a “climate laggard” and to undercutting the environmental regulations of others in order to attract economic activity. This, in turn, could undermine the virtuous dynamic and goodwill that the Paris Agreement, which relies on voluntary contributions and peer pressure to move towards carbon neutrality, is built on.

While few instances of carbon leakage have been identified so far ([Fallmann et al., 2015](#), [Dechezleprêtre and Sato, 2017](#)), economic modelling suggests that between 10 and 25% of emission reductions achieved through economy-wide carbon pricing could be offset by carbon leakage phenomena, if no countervailing measures – such as sectoral exemptions, output-based rebates or carbon border adjustments – are taken ([Böhringer et al., 2012](#), [Branger and Quirion, 2014](#), [Carbone and Rivers, 2017](#)).

There are two main channels through which carbon leakage could take place: The first, and most intuitive, is when the production of energy-intensive goods (such as steel, cement or chemicals) moves to less regulated countries (either through outright relocation or gradual shifts in investment), incentivised by differences in production costs and a lower regulatory burden; this is called the “competitiveness channel”. The second channel is more indirect but similarly important: Domestic restrictions on the use of fossil fuels could depress their prices internationally and thereby incentivise greater use in other, less regulated countries and sectors; this is called the “energy markets channel” ([Görlach and Zelljadt, 2018](#), [Cosbey et al., 2019](#)).

Technology spillovers are often posited as a third, and countervailing channel of carbon leakage: Ambitious climate regulation in technologically advanced jurisdictions could spark innovation in clean energy technologies and thereby reduce emissions globally, thus giving rise to negative carbon leakage. The “technology spillovers channel” is indeed a real and relevant force (Gerlagh and Kuik, 2014, Dechezleprêtre and Sato, 2017), but due to its idiosyncratic nature and the difficulties of integrating technology and spillovers into the modelling, this channel is not taken into account in the remainder of this study.

In the European Union, where the world’s biggest emissions trading system (ETS) has been in place since 2005, concerns about carbon leakage and about the economic viability of energy-intensive industries led to the introduction of a system of “free allocation”: economic sectors deemed to be at risk of carbon leakage (based on their exposure to international trade and their carbon intensity) receive most of their emission allowances for free, with allocation levels based on product-specific benchmarks and historical output levels.¹

The free allocation system, which amounts to a lump-sum, in-kind subsidy for economic operators in certain sectors, should in theory not affect incentives to produce output or reduce emissions, but rather provide an approximate compensation (for the best-in-class installations) of the losses incurred through the ETS. However, it is unclear whether economic operators correctly perceive the opportunity cost of emissions allowances, or whether they view free allocation as an effective ETS exemption or a per-unit subsidy on the covered goods (Fallmann et al., 2015). Modelling studies (including this one) generally treat free allocation as the former,

¹ The legal basis is Article 10a of Directive 2003/87/EC; the “Benchmarking Decision” (Commission Delegated Regulation (EU) 2019/331) specifies the details for free allocation: Historical output levels refer to a 5-year period preceding the start of the respective trading period, with exceptions applying to new entrants, installations with significant capacity adjustments and closures. Ex-ante benchmarks for different products are set at a level corresponding to a best-in-class performance in terms of emissions per unit of output.

as an “output-based rebate”, which helps circumvent the complexities of modelling production capacities separately from output.

Whatever the exact channel of effect, the free allocation system appears to have prevented the incidence of carbon leakage so far ([Fallmann et al., 2015](#), [Naegele and Zaklan, 2019](#)). It has therefore been extended into the fourth ETS trading phase (2021-2030), with a stronger focus on targeting support to those sectors most exposed to a risk of carbon leakage.² At the same time, there are critics who argue that the free allocation system undermines the “polluter pays principle” since the energy-intensive industries, which are responsible for a large share of emissions in industry, are effectively shielded from the costs; they also criticise that the system reduces incentives for industry to invest into deep decarbonisation, and call for a more fundamental reform of the system (e.g. [Carbon Market Watch, 2019](#)).

Today, in the wake of significantly reinforced commitments to climate neutrality by 2050 and to a 55% reduction (below 1990 emission levels) by 2030, a new instrument to tackle carbon leakage is under discussion in the EU: A carbon border adjustment, which would oblige importers of carbon-intensive goods to pay (through customs duties or through inclusion into the ETS) a price on the greenhouse gas emissions embodied in these goods. Also under discussion, though more among academics than among policymakers, is a “symmetrical” carbon border adjustment, which would grant compensation for ETS costs to domestic producers that export their goods ([Cosbey et al., 2019](#), [Ismer et al., 2020](#)).³

The theoretical benefits of the measure are clear: A comprehensive carbon border adjustment would ensure that all goods sold on the European market face the same price on carbon emissions incurred in their production, which increases efficiency and ensures a level playing

² Directive 2003/87/EC, as amended by Directive (EU) 2018/410.

³ Equivalent (in terms of the incentive structure) to a symmetrical adjustment would be the combination of the existing free allocation system with a domestic consumption tax on carbon-intensive goods. This is one of the options discussed by [Ismer et al., 2020](#).

field for different producers. In fact, in a simple, multi-country theoretical model where other countries' carbon prices are taken as given, it can be demonstrated that the combination of domestic carbon pricing with a symmetrical carbon border adjustment emerges as the “second-best” economic solution ([Markusen, 1975](#), [Hoel, 1996](#)).

With all producers facing higher production costs, domestic producers would be able to pass on to consumers the additional costs of either buying emissions allowances or investing into cleaner production methods, without fear of being pushed out of the market by foreign competitors not subjected to the same cost and regulations. If producing abroad no longer allows companies to evade costs, there would also be less of an incentive to relocate production and thus less carbon leakage. Finally, a carbon border adjustment could even incentivise adoption of more ambitious climate policies in other regions of the world (cf. [Lessmann et al., 2009](#), [Böhringer et al., 2016](#)).

On the other hand, there are legal and political aspects to keep in mind: WTO rules impose certain limitations on the design of the instrument (cf. [Mehling et al., 2019](#) for a detailed discussion), and international trade tensions make legal disputes and political conflict surrounding its introduction likely. Some authors warn that too much political capital would have to be spent on the initiative, thereby distracting from more effective domestic measures ([Zachmann and McWilliams, 2020](#)). Also administrative aspects, e.g. how to assess the carbon content of complex goods or how to deal with non-cooperative producers from foreign countries, pose some problems that would have to be solved before a carbon border adjustment can be introduced (cf. [Cosbey et al., 2019](#), [Zachmann and McWilliams, 2020](#)).

While these are all relevant arguments to keep in mind and which merit further study, this study focuses on the questions that can be answered quantitatively based on economic modelling: How effective would an EU carbon border adjustment be in reducing the incidence of carbon

leakage? How much more effective would it be than the free allocation system currently in place? What would the budgetary impacts be and how would the energy-intensive industries be affected?

2. Methodology and Data

Like much of the modelling literature in the field, this study follows the computable general equilibrium (CGE) approach. CGE models are macroeconomic models that represent the economy as a set of interconnected goods and factor markets, based on linearised behavioural equations and market clearing conditions. They exist in many varieties and have been used, for instance, to model gains from free trade agreements, effects of economic growth on factor markets or the effectiveness of environmental policies (cf. for an overview [Hertel, 1997](#), [Dixon and Jorgenson, 2012](#)).

This study builds on the GTAP-E model (as documented in [Burniaux and Truong, 2002](#), [McDougall and Golub, 2009](#)), a multi-sectoral, multi-regional CGE model that calculates greenhouse gas emissions on the basis of fossil fuel consumption and that allows for the setting of carbon prices. Two additions were made to the basic model: First, process emissions – those 10% of global greenhouse gas emissions that are connected not to the combustion of fossil fuels but to chemical processes that take place e.g. in the production of cement or steel – were integrated into the model by introducing an output tax proportional to a product’s carbon content and the domestic carbon price. This is an important addition since process emissions play an important role in driving carbon leakage: [Bednar-Friedl et al. \(2012\)](#) show that the neglect of process emissions leads to an underestimation of the carbon leakage rate by approximately one third. Second, a carbon border adjustment was incorporated into the model by introducing sector-specific tariffs and export subsidies on carbon-intensive goods, set in proportion to regional carbon intensities and to the respective carbon price difference between regions. Appendix A shows the main equations that were added to the standard GTAP-E model.

The model is calibrated on the GTAP10 database (documented in [Aguilar et al., 2019](#)), which reports economic data and greenhouse gas emissions for the base year 2014 – the latest data

available at the time of writing. Data from the UNFCCC on process emissions, which GTAP10 does not include, is extrapolated to the base year and added to the database, based on the methodology described by [Bednar-Friedl et al. \(2012\)](#) and outlined in appendix B.

Table 1 shows the sectoral and regional aggregation used in the simulations. The aggregation chosen here is broadly in line with the previous carbon leakage literature (cf. e.g. [Böhringer et al., 2012](#)). It focuses on those sectors that are known to be most relevant to the phenomenon of carbon leakage – the energy goods sectors, the energy-intensive industries (metals, minerals and chemicals), and the transport sector – while others are subsumed into the “all other goods” category. Countries are grouped into macro-regions based on geographical and political proximity and economic structure.

Sectors	Regions
<i>Energy goods</i>	<i>Annex 1</i>
Electricity	Europe (EU-27, UK, EFTA)
Refined oil and coal products	North America (USA, Canada)
Natural gas	Japan/Oceania (Japan, Australia, New Zealand)
Crude oil	Russia (incl. Ukraine, Belarus, Kazakhstan)
Coal	
<i>Non-energy goods</i>	<i>Non-Annex 1</i>
Metals (Iron and steel, non-ferrous metals)	China (incl. South Korea, Taiwan, Hong Kong, Singapore ⁴)
Minerals (Cement, other non-metallic minerals)	South and South-East Asia
Chemicals	Latin America
Transport	Sub-Saharan Africa
All other goods	Energy-exporting countries ⁵
	Rest of Eurasia (mainly Western Balkans, Central Asia)

Table 1: Sectoral and regional disaggregation used in this thesis

The region “Europe” comprises mainly the 27 EU member states but also the EFTA member states (Norway, Iceland, Liechtenstein and Switzerland) and the UK. These all participate either in the EU ETS itself or in a separate ETS linked to or closely modelled after the EU ETS, and

⁴ These countries, while closer to industrialised countries in their industrial structure today, are not part of the Annex 1 of the Kyoto Protocol for historical reasons and therefore grouped with China here.

⁵ Included are Indonesia, Malaysia, Bolivia, Ecuador, Venezuela, Iran, Kuwait, Oman, Qatar, Saudi Arabia, UAE, Egypt, Nigeria.

policies are by and large aligned also in non-ETS sectors⁶ – though of course it is not certain whether this will remain the case, particularly as regards the UK. Coherence of climate policies within other regions is more questionable but this does not affect the results of this study, which assumes that only Europe pursues an active climate policy while other world regions do not change their policies.

Once the model has been calibrated to the initial state of the global economy, it is possible to perform counterfactual simulations. First, as a reference scenario, the effect of an increase in the European carbon price by 50 USD/tCO₂-eq. is simulated in the absence of any anti-leakage instruments. This price hike serves as a simplified representation of the complex set of policies that would be put into place in practice to achieve the targeted emission reductions, and it is set at an order of magnitude that analysts expect could take place within the European emissions trading system over the next 10 years in response to the increase in climate targets in the EU ([Carbon Tracker, 2018](#), [Carbon Pulse, 2020](#), [Argus, 2020](#), [Reuters, 2020](#)). Then, different anti-leakage measures (carbon border adjustment and free allocation, each with varying degrees of coverage) are added and their impacts compared to the reference scenario. These scenarios will be further specified in the next chapter.

⁶ Norway, Iceland and Liechtenstein participate directly in the EU ETS; Switzerland has an own ETS linked with the EU ETS; a separate UK ETS entered into force on 1.1.2021 but with very similar provisions to the EU ETS and discussions ongoing about how to link the two in the future.

3. Results and Discussion

3.1 Carbon leakage rates

Figure 1 shows the impacts of the increase in the European carbon price for the reference scenario, assuming that other regions do not change their climate policies. According to the model, this would bring about an emission reduction by 493 MtCO₂-eq., i.e. 13.31% of total European emissions.

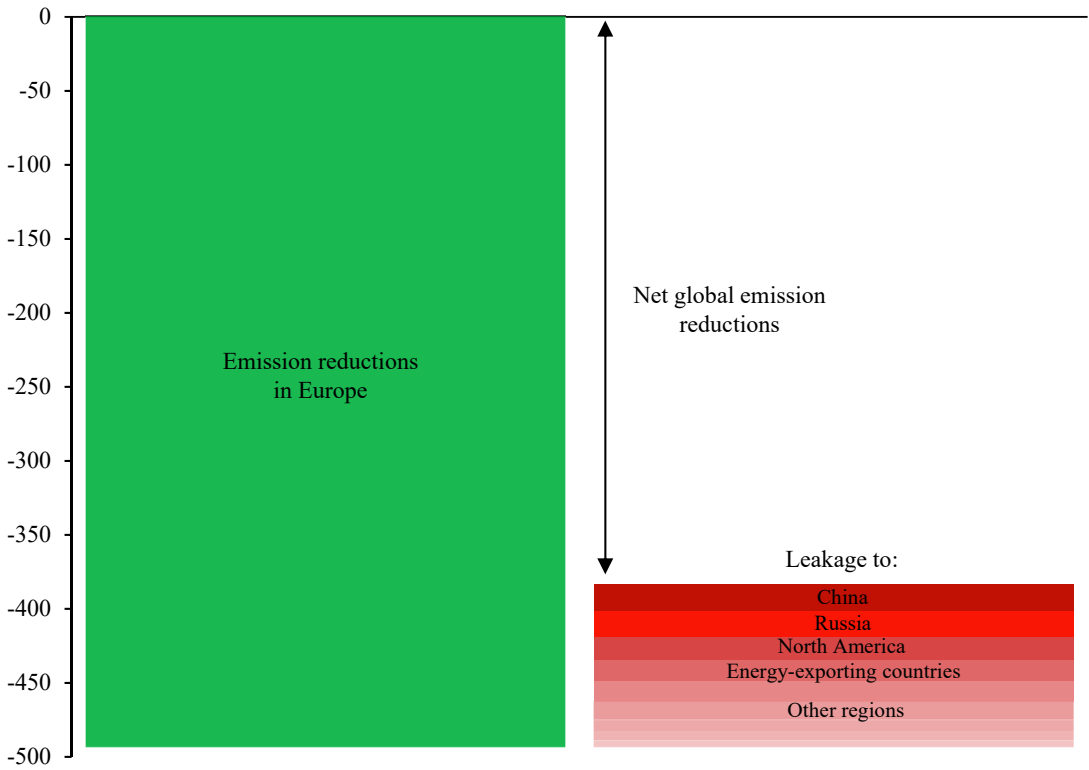


Figure 1: Emission reductions and increases under the carbon pricing reference scenario (in MtCO₂-eq.)

At the same time, however, emissions outside Europe increase by 109 MtCO₂-eq., most significantly so in China, Russia and North America. Given the closed setting of the CGE model, these emission increases can be causally attributed to the increase in carbon prices in

Europe: It turns out that part of the emissions abated there did not actually disappear, but have relocated, or “leaked”, into other jurisdictions.

The ratio of these emission changes implies a leakage rate of 22.2% – a value at the higher end of the ranges found in the literature (cf. [Böhringer et al., 2012](#), [Branger and Quirion, 2014](#), [Carbone and Rivers, 2017](#)). This is plausible since both the inclusion of process emissions and the focus on Europe as the abating region rather than on a broader coalition of countries (e.g. of all Annex 1 countries of the Kyoto Protocol) are factors that should increase the carbon leakage rate.

It is important to note here that the simulations performed in this study assume fixed technology and fixed preferences. The 13.31% emission reduction (compared with 2014 emission levels, which implies a 31.5% reduction compared with 1990 levels) is achieved purely through fuel change and demand adjustments on the extensive margin, driven by price pressure. In reality, technological progress – driven by both economic incentives and mission-oriented research – and changes in consumer habits are likely to play a major role and make substantially higher emission reductions possible without prohibitively high carbon prices, but these aspects are not within the scope of this study.

Next, departing from the reference scenario, three versions of an EU carbon border adjustment are introduced: In the first scenario, “Carbon border tax direct”, import tariffs are imposed on the three energy-intensive sectors metals, minerals and chemicals, at a level equal to the product of the region-specific direct sectoral carbon intensity and the European carbon price. The second scenario, “Carbon border tax indirect”, also takes into account indirect emissions (i.e. those emissions that occur in the power generation sector but are attributable to the use of electricity in other sectors) in calculating the sectoral carbon intensity. The third scenario, “Full carbon border adjustment”, adds to the import tariffs a set of export subsidies that fully

compensate domestic producers in the above-mentioned sectors for the costs incurred in the production of exported goods. Appendix A shows the equations underlying these scenarios; appendix C discusses the tariff and subsidy rates that apply.

Simulating these three different versions of the carbon border adjustment gives an idea of how strongly the outcome variables may change depending on the design of the measure. The verdict on two key features of the carbon border adjustment – the accounting of indirect emissions and the provision of export rebates – appears to be open at the time of writing,⁷ such that the quantitative assessment performed in this study might provide useful evidence to consider in the legislative process. Unchanged across the three scenarios is the choice of sectoral coverage, which is limited to the three sectors metals, minerals and chemicals. This is because it has been communicated clearly that an EU carbon border adjustment will be limited to “selected sectors”⁸, likely those covered already today by the free allocation system: a small set of industries with high carbon cost shares and trade intensities, as identified in the Commission’s “Carbon Leakage List”⁹, which is by and large congruent with the aforementioned sectors.

In fact, even beyond the design features discussed here, a large number of choices will have to be made due to political, legal and administrative reasons (cf. [Cosbey et al., 2019](#) and [Mehling et al., 2019](#) for a discussion of such considerations in both the EU and the US context). These decisions, regarding e.g. how equivalent climate regulation in other countries will be taken into account or how default values will be set when the actual carbon content of a product cannot be ascertained, will certainly have an impact on the effectiveness of the carbon border adjustment. However, in order to model the impact of these choices, the number of simulations

⁷ The “Inception Impact Assessment on the Carbon Border Adjustment Mechanism” published on 4.3.2020 is the latest document of the European Commission expressing its official views on design features of the mechanism. Various options for implementing the measure legally and administratively are discussed but no comment is made on whether indirect emissions will be accounted for and whether export rebates will be provided.

⁸ European Commission (2019): Communication on the European Green Deal.

⁹ Commission Delegated Decision (EU) 2019/708.

required to cover all relevant scenarios would quickly become unmanageable and the modelling would have to be much more granular. Therefore, this study retains a focus on the abovementioned, easily representable choices and assumes, for simplicity, that no equivalent regulation is in place in other regions of the world, and that all companies in one region and sector will be subjected to the same carbon tariffs.

Figure 2 shows the carbon leakage rates for all scenarios that have been modelled. It is visible that even the variation of two key design features generates a range of outcomes, with the carbon leakage rate ranging from 7.2% under the “Full carbon border adjustment” scenario to 14.8% under the “Carbon border tax direct” scenario”.

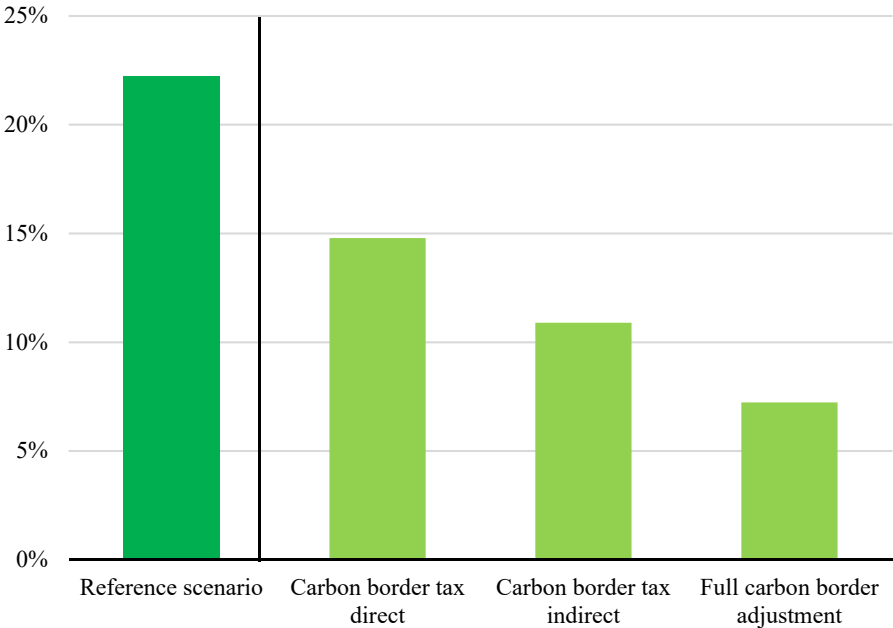


Figure 2: Carbon leakage rate under the reference and the carbon border adjustment scenarios

Most importantly, however, the introduction of a carbon border adjustment, independent of its exact design, indeed reduces the carbon leakage rate quite significantly, to between one third

and two thirds of its initial value. Quite plausibly, the more comprehensive the carbon border adjustment is, the more effective it will be in reducing the carbon leakage rate.

3.2 Channels of carbon leakage

To better understand how the carbon border adjustment affects carbon leakage, it is useful to look at sectoral emissions and bring the data together with theoretical insights about channels of carbon leakage.

Figure 3 shows absolute extra-European emission changes by sector, where “industry” covers all emissions in the sectors metals, minerals and chemicals; “power generation” covers all emissions in the electricity sector; and “transport and heating” covers all emissions in the transport sector and from fossil fuel combustion in private households.¹⁰

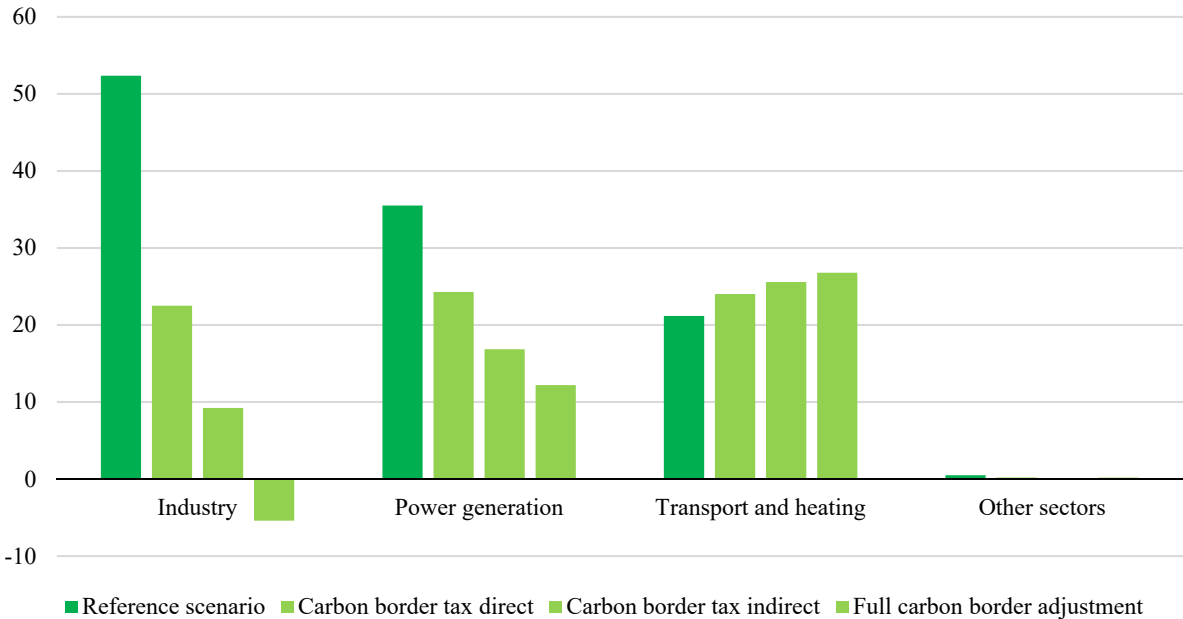


Figure 3: Changes in emissions outside Europe by sector and scenario (in MtCO₂-eq.)

First, one can note that in the reference scenario, the largest share of carbon leakage takes place in the sectors industry, power generation and heat and transport, in that order, while emissions

¹⁰ Emissions occurring in agriculture, forestry and land use change are not covered by the GTAP-E database.

in other sectors are hardly affected. This order changes as the carbon border adjustment is introduced, as it affects the three sectors very differently. As the carbon border adjustment becomes increasingly comprehensive, leakage in the industry sector decreases strongly and even turns negative – meaning that the increase of the European carbon price, coupled with a carbon border adjustment decreases industry emissions not just domestically but also in the rest of the world; leakage in the power generation sector is reduced more gradually; meanwhile, leakage in the transport and heating sector increases slightly.

This can be explained by the different nature of the two main channels of carbon leakage referred to in the introduction – the “competitiveness channel” and the “energy markets channel”: The industry sector, which comprises the production of carbon-intensive and internationally traded goods like steel, cement or chemicals, is the place where competitiveness effects can be expected to play out most. Since the carbon border adjustment is designed specifically to address the carbon price differential that drives this channel, it is no wonder that leakage in the industry sector subsides.

By contrast, transport and heating are sectors that generate a substantial amount of emissions but are not affected directly by import duties and export subsidies on carbon-intensive goods. Emissions in these sectors are directly bound to the consumption of the respective services (driving a car, heating a building) and the only way they are affected by regulation in other countries is through fossil fuel prices, i.e. through the energy markets channel: If carbon regulation makes the combustion of fossil fuels more expensive in the Europe, this reduces the demand for fossil fuels by European consumers, which (given the large size of Europe) depresses their prices internationally and thereby enables consumers in other jurisdictions to consume more of them, for example in the transport and heating sector. Since fossil fuel prices

are the driving force of this channel, there is little Europe – a net importer of fossil fuels (Eurostat, 2019) – can do to prevent it from happening.¹¹

In the power generation sector, both channels play a role: While electricity producers in different world regions do not compete directly with each other, the demand for electricity used in energy-intensive industries shifts together with shifts in industrial production; at the same time, price changes on energy markets can make the use of dirtier fuels in power generation more attractive and thereby give rise to energy markets leakage. Accordingly, the pattern of how the carbon leakage responds to the carbon border adjustment is an intermediate between the two aforementioned extremes.

Thus, the pattern of the aggregate carbon leakage rate is an overlap of different developments in different sectors: While leakage in the industry and power generation sectors can be reduced substantially, leakage through energy markets persists. This also explains why the carbon leakage rate cannot be expected to decrease to zero, even under the most comprehensive carbon border adjustment: Some degree of carbon leakage will always persist, but it will likely be of the less conspicuous sort, driven by gradual price developments on fossil fuel markets and overlaid with other fluctuations, rather than one-off relocation decisions of energy-intensive industries.

3.3 Impact on energy-intensive industries

Besides emissions, it is common practice in the carbon leakage literature to consider a measure's effect on output in the energy-intensive sectors. These sectors are of particular interest because they are disproportionately affected by carbon pricing and often politically

¹¹ In fact, the results of the simulation suggest that this channel even becomes more potent as coverage of the carbon border adjustment expands, because the latter suppresses demand for fossil fuels in trade-exposed sectors around the world, and thus makes its use in transport and heating even cheaper.

sensitive. Figure 4 shows changes in the real output of European energy-intensive industries for the different scenarios.

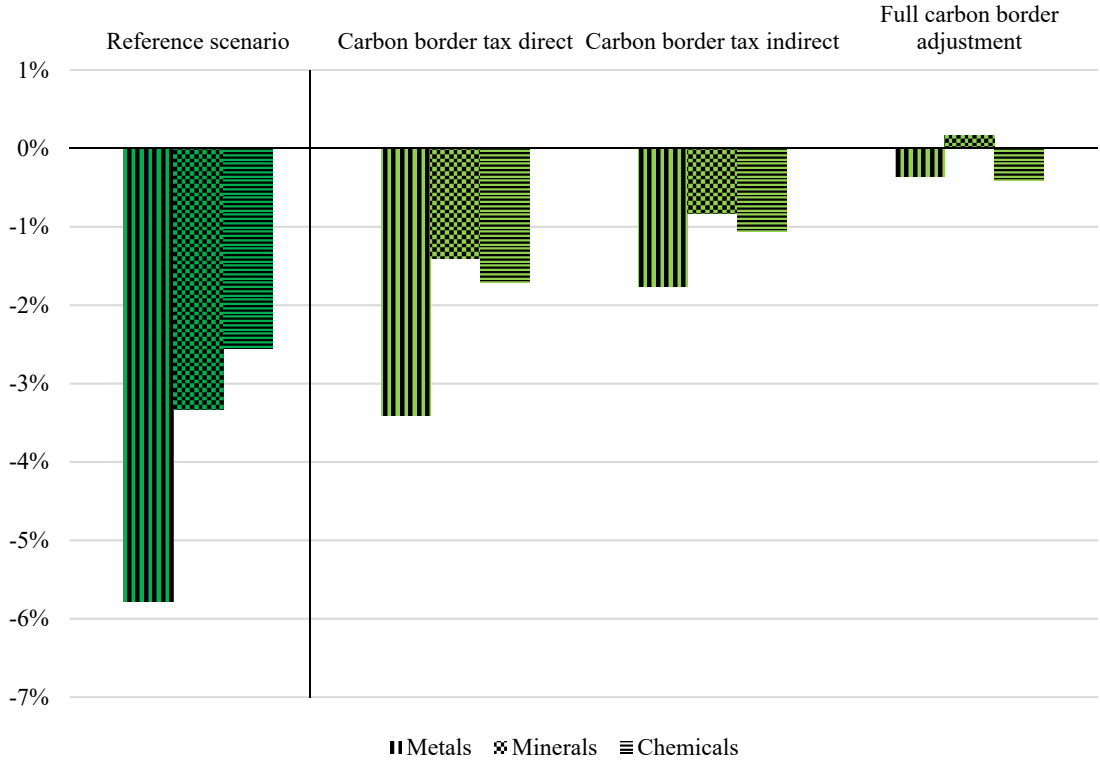


Figure 4: Changes in real output in Europe in the energy-intensive industries

The introduction of domestic carbon pricing in the reference scenario causes significant output losses in the European energy-intensive industries: In the metals sector, output is reduced by 5.8%, in the minerals sector by 3.3% and in the chemicals sector by 2.6%.¹² Carbon border adjustment is once again quite effective in reducing the downsides of increased domestic climate regulation – and the more comprehensive the adjustment is, the better: Output recovers in all sectors, most remarkably so under the full carbon border adjustment scenario, where they return very closely to their pre-carbon pricing levels.

¹² The difference in effect sizes between these sectors is likely attributable to the differences in carbon cost shares and trade intensity, cf. appendix C and Fallmann et al. (2015).

This observation confirms that the carbon border adjustment is an instrument targeted at offsetting competitive distortions in carbon-intensive and trade-exposed sectors. It also shows that a carbon border tax that is not accompanied by an export subsidy, which serves to level the playing field on foreign markets, is not capable of fully offsetting the output losses incurred by carbon pricing.

3.4 Comparison with the free allocation system

For a policy-relevant assessment, it is important to compare a proposed new carbon border adjustment system not with a hypothetical state without any anti-leakage instruments, but with the existing framework. The current framework relies on free allocation of emission allowances to sectors deemed to be at risk of carbon leakage, as well as the possibility for EU member states to provide state aid to industries exposed to significant indirect costs of the emissions trading system (i.e. the increased costs of electricity).¹³

This system is implemented in the model as two different scenarios: both grant an output subsidy to European producers in the energy-intensive industries at a level that is proportional to the carbon price, but in the one case the cost compensation is calculated on the basis of the direct sectoral carbon intensity (representing the simple free allocation system), while the other also includes indirect emissions in the calculation of sectoral carbon intensities (representing the free allocation plus state aid system). These scenarios are referred to as “Cost compensation direct” and “Cost compensation indirect” in the following. Since not all member states use the possibility of compensating indirect costs,¹⁴ the most realistic representation of the system currently in place would be somewhere between these two scenarios. Sectoral coverage is once

¹³ Cf. European Commission: Guidelines on certain State aid measures in the context of the system for greenhouse gas emission allowance trading post-2021 (2020/C 317/04).

¹⁴ 12 EU Member States implemented ETS state aid schemes during the third trading period (2013-2020), cf. Impact assessment accompanying the document “Communication from the Commission on Guidelines on certain State aid measures in the context of the system for greenhouse gas emission allowance trading post 2021” (SWD(2020) 190 final).

again restricted to the energy-intensive sectors metals, minerals and chemicals, since these are by and large those sectors that are currently eligible for the respective measures.¹⁵

Thus, additional simulations were run for these two scenarios, and figures 5 and 6 compare the results regarding carbon leakage rates and output losses in energy-intensive industries to those presented earlier.

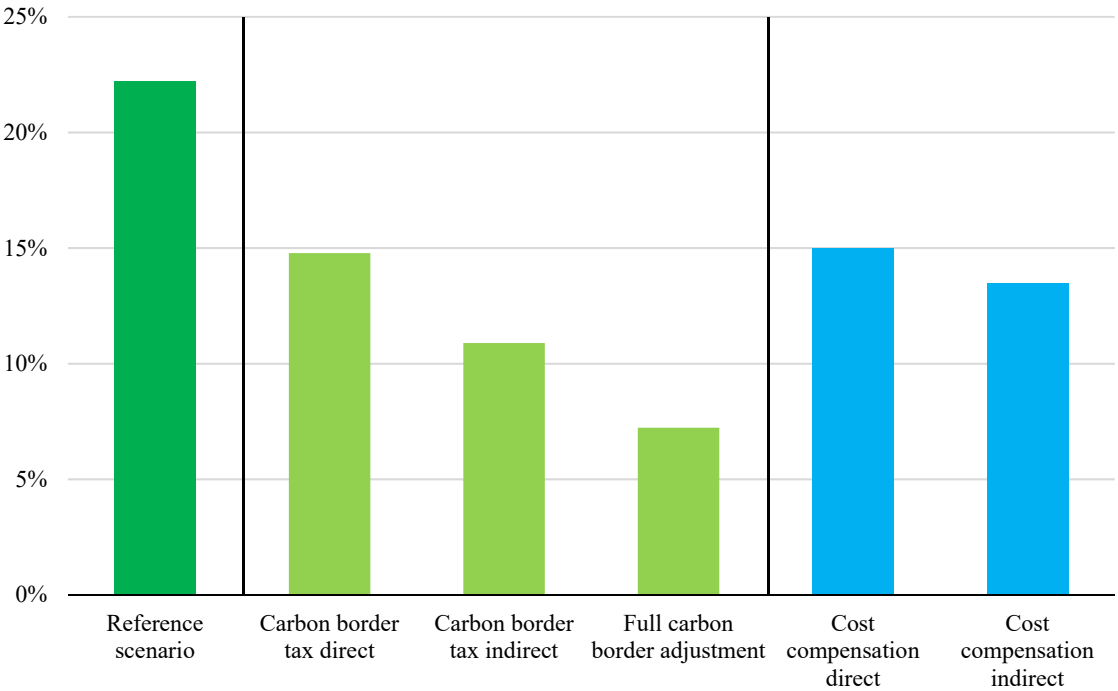


Figure 5: Carbon leakage rate for all simulated scenarios

¹⁵ Cf. for free allocation: Commission Delegated Decision (EU) 2019/708; For indirect cost compensation: European Commission: Guidelines on certain State aid measures in the context of the system for greenhouse gas emission allowance trading post-2021 (2020/C 317/04).

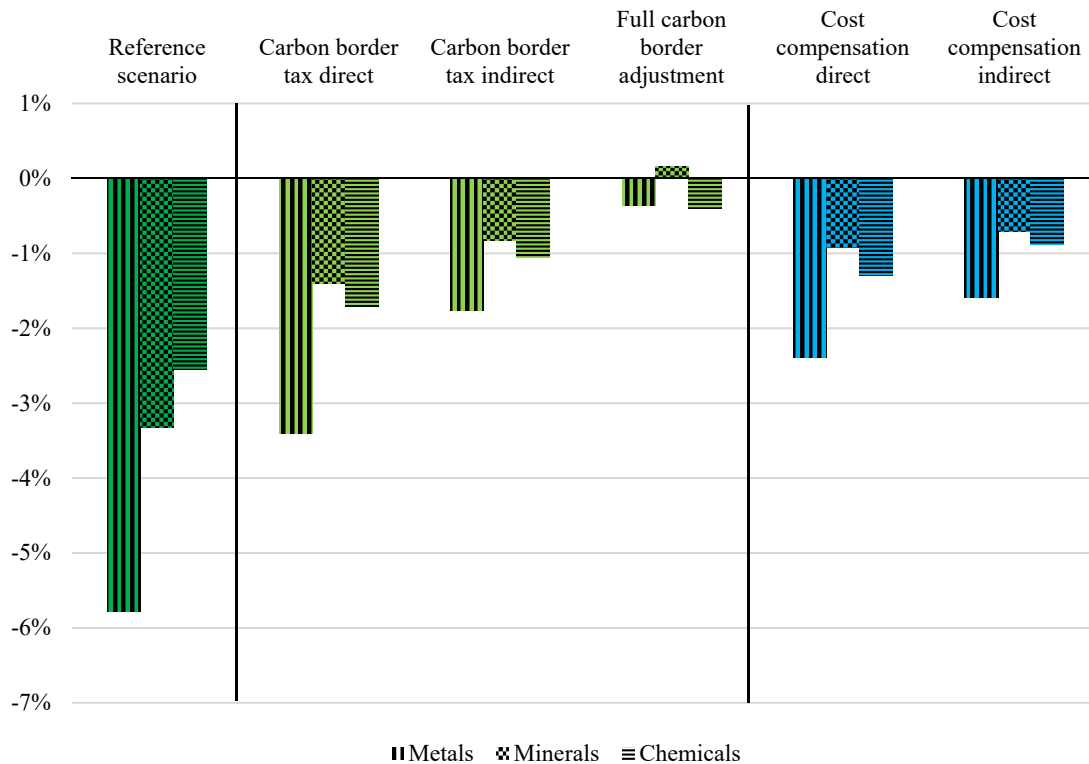


Figure 6: Changes in real industrial output in Europe in the energy-intensive industries for all simulated scenarios

Compared with the reference scenario, one can note that the free allocation/cost compensation system likewise achieves substantial gains in both dimensions, bringing the carbon leakage down to between 13% and 15% and energy-intensive industry output losses to about a third of their original values. Compared with the carbon border tax scenarios, the cost compensation scenarios show a similar effectiveness, with the carbon leakage rate reduction achieved being similar to the “Carbon border tax direct” scenario but somewhat lower than the “Carbon border tax indirect scenario”. On output in the energy-intensive industries, the cost compensation scenarios have a slight edge over the carbon border tax scenarios, but also do not fully offset output losses. However, the symmetrical full carbon border adjustment, which combines characteristics of taxation (for importers) and cost compensation (for exporters) remains the top performer in both categories.

A final consideration relevant for political decisions is the impact of different measures on government revenues. Since the GTAP-E model features only a passive government that redistributes its tax and tariff income in a lump-sum manner to the population, a back-of-the-envelope calculation outside the model is performed here to identify the direct budgetary impact of the respective measure: In the case of the cost compensation systems, the direct budgetary impact is the lost revenue from the carbon pricing scheme (i.e. the number of free allowances granted multiplied by the carbon price) and the cost of state aid; in the case of carbon border adjustment, this is revenue from import duties minus costs from export subsidies (i.e. import and export volumes multiplied by the respective tariff/subsidy rates, shown in appendix C). The results are shown in figure 7.

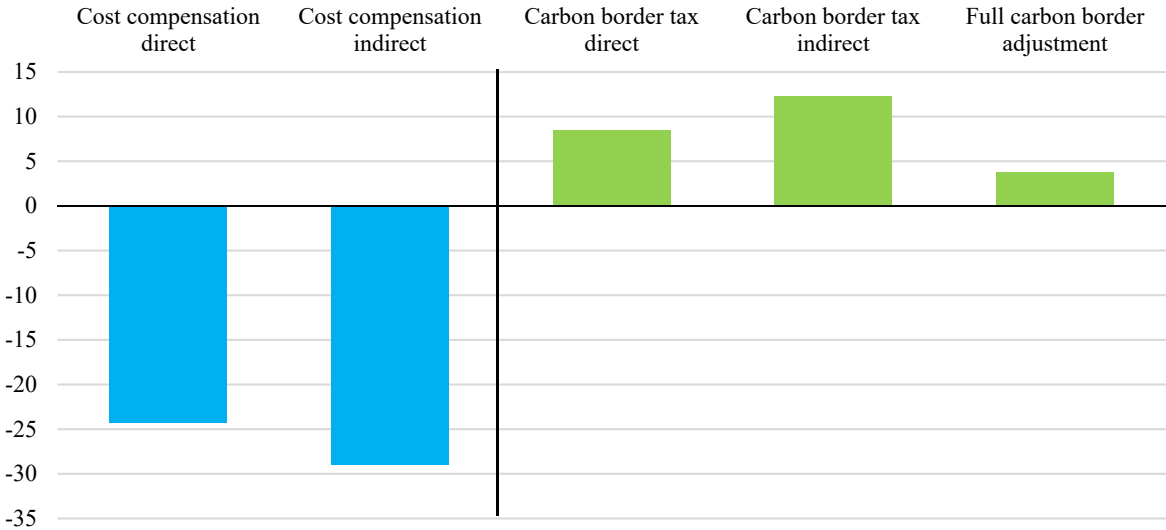


Figure 7: Direct budgetary impact of the anti-leakage instruments (in bn USD)

While the cost compensation schemes cost around 25 to 30 bn USD annually, the carbon border tax schemes generate positive revenue of up to 12 bn USD. The impact of the full carbon border adjustment is moderately positive, at a net revenue of 4 bn USD (the difference of 8 bn to the

previous scenario is the cost of the export rebates).¹⁶ If a carbon border adjustment were to replace the existing free allocation framework, the net budgetary impact of its introduction would be even more positive, up to 41 bn USD (in the case where the “Carbon border tax indirect” would replace the “Cost compensation indirect” scenario).

¹⁶ These estimates of potential revenue from the carbon border adjustment, based purely on model-internal calculations, come close to the EU’s official estimate of between 5 and 14 bn EUR (5.5-16 bn USD). Cf. “Questions and Answers on the MFF and Next Generation EU” (published 27.5.2020), https://ec.europa.eu/commission/presscorner/detail/en/qanda_20_935.

4. Conclusion and Policy Implications

The introduction of a carbon border adjustment by the EU would constitute a major development in international climate politics. Despite being advanced in rather technical terms as an “adjustment mechanism”, it is clear to all involved players that the introduction of carbon tariffs or equivalent measures would be a highly political move. It would be the first time that actual, hard trade measures are used to promote the climate objective, and thus mark a shift towards a more assertive stance towards countries that fail to implement stringent climate regulation. Domestically, it would signal a greater capacity to protect trade-exposed industries from unfair competition and to preserve a level playing field despite divergent regulation.

Given the importance of the proposal currently being prepared in Brussels, it is clear that costs and benefits should be carefully assessed and, where possible, pinned down quantitatively based on the best available methods. This is what this study has aimed to contribute to, focussing on the key question of whether and how much carbon leakage could be prevented by the introduction of a carbon border adjustment.

The main message to be taken away from the analysis is that the EU carbon border adjustment is indeed the most effective tool for tackling carbon leakage. While not being able to fully prevent carbon leakage from occurring, the instrument could reduce its incidence significantly: A sectorally limited carbon border adjustment, as is under discussion in the EU, would bring down the initial carbon leakage rate of 22% to between 7 and 15%, depending on the exact design of the measure. Under the current free allocation system, by contrast, it would stand at between 13 and 15%. This means that, depending on its design, a carbon border adjustment would at least perform on par and at best be twice as effective as the free allocation system.

A large part of the effectiveness of the measure depends on decisions that appear to be undecided to date: whether indirect emissions, attributable to the consumption of electricity,

are taken into account in the calculation of carbon tariffs, and whether export rebates on ETS costs are granted to domestic producers. Each of these features would take 4 percentage points off the carbon leakage rate and should therefore be evaluated carefully.

A closer look at sectoral emissions showed that carbon leakage occurs across all the major emitting sectors, namely industry, power generation and transport and heating, but that emissions in these sectors react very differently to the introduction of a carbon border adjustment, reflecting their respective propensity to be affected by competitiveness and energy market effects.

The simulation also showed that the shifts in energy-intensive industries production from Europe towards third countries that stem from unequal climate regulation would be close to fully offset if a carbon border adjustment were put in place, and that the instrument would generate public revenues of up to 41 bn USD annually.

These are encouraging results regarding the effectiveness of a carbon border adjustment, but it should be kept in mind that other, less quantifiable dimensions relating to domestic and international climate politics play just as important a role in determining the desirability of an EU carbon border adjustment.

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Appendix A: Main additions to the GTAP-E code

In order to put a carbon price on process emissions within the setting of the GTAP-E model, an ad-valorem output tax, $\tau_{i,r}^{process\ emissions}$, was introduced on carbon-intensive goods in proportion to their sectoral carbon intensity (process emissions in the sector, $Em_{i,r}^{process}$, divided by the value of output, $VO_{i,r}$) and to the EU carbon price, P_{EUR}^{carbon} :

$$\tau_{i,r}^{process\ emissions} = \frac{Em_{i,r}^{process}}{VO_{i,r}} * P_{EUR}^{carbon}$$

Furthermore, as the GTAP-E model does not feature a dedicated carbon border adjustment module, a carbon border tax (import adjustment) was added by introducing a region- and sector-specific import duty, $CBT_{i,r}$, equal to the product of the region- and sector-specific carbon intensity, $CI_{i,r}$ (defined below), and the EU carbon price:

$$CBT_{i,r} = CI_{i,r} * P_{EUR}^{carbon}$$

Similarly, an export adjustment was added by introducing an export subsidy, $S_{j,r}$, proportional to the domestic carbon intensity of a specific sector and the domestic carbon price:

$$S_{j,r} = CI_{i,EUR} * P_{EUR}^{carbon}$$

In the free allocation/cost compensation scenarios, the same formula applies for the output subsidy, which is granted on all domestically produced carbon-intensive goods.

The carbon intensity of sector i in region r is calculated as the sum of process emissions, combustion emissions and indirect emissions, divided by the value of its total output:

$$CI_{i,r} = \frac{Em_{i,r}^{process} + Em_{i,r}^{combustion} + Em_{i,r}^{indirect}}{VOA_{i,r}}$$

More precisely, this formula refers to the *indirect* carbon intensity; the *direct* carbon intensity is calculated by setting indirect emissions, $Em_{i,r}^{indirect}$, to zero.

While process and combustion emissions per country and sector are directly available in the compiled database, indirect emissions are calculated by determining how much of the total emissions incurred in domestic electricity generation, $Em_{elec,r}^{combustion}$, is attributable to the electricity consumption, $Q_{i,r}^{elec}$, of the sector at hand:¹⁷

$$Em_{i,r}^{indirect} = Q_{i,r}^{elec} * \frac{Em_{elec,r}^{combustion}}{\sum_j Q_{j,r}^{elec}}$$

Appendix B: Treatment of process emissions

Based on the insight by Bednar-Friedl et al. (2012) that the neglect of process emissions leads to a significant underestimation of carbon leakage, the approach of that paper was followed in this study to incorporate process emissions data into the simulation. The data is gathered from the UNFCCC inventory, where countries submit their annual emissions in different sectoral categories. Industrial process emissions are available for all countries at the level of the (rather broad) categories “metals production”, “mineral products” and “chemical processes”; more detailed data (with a split e.g. of metals into “iron and steel” and “non-ferrous metals”) is available only for Annex 1 countries. For many countries, the process emissions data are not available for 2014 (the base year of the GTAP dataset), but often only for 2004 or even 1994. Therefore, following the method described in appendix B of Bednar-Friedl et al. (2012), the most recently available data point was extrapolated by multiplying the combustion

¹⁷ This modelling assumes a uniform generation mix consumed by all electricity consumers (i.e. it does not account for subregional, temporal or contract-type differentiation of the carbon content of electricity), and that all electricity consumed is produced domestically (i.e. that there is no trade in electricity, which is in fact close to reality given that the regional aggregation chosen here is at the continent-level).

emissions recorded in GTAP for 2014 by the ratio of process emission (in each of the three sectors) to combustion emissions in the most recently available UNFCCC year. The results for each step of the procedure are shown in table B.1.

	Ratio of process emissions to combustion emissions by most recent UNFCCC inventory			Total combustion emissions in GTAP	Imputed process emissions for base year 2014, added to the GTAP database		
	Metals	Minerals	Chemicals		Metals	Minerals	Chemicals
Japan/Oceania	1%	3%	1%	1,440	17	38	7
Russia	8%	3%	3%	1,677	137	50	42
North America	1%	1%	1%	5,731	63	76	62
Europe	2%	4%	2%	3,420	84	147	53
China	3%	10%	1%	8,903	255	888	133
South and South-East Asia	0%	8%	1%	2,721	14	229	36
xEurasia	2%	8%	1%	1,138	21	86	12
Latin America	6%	6%	0%	1,460	84	91	5
Sub-Saharan Africa	5%	2%	0%	592	31	13	3
Energy-exporting countries	3%	7%	1%	2,938	80	207	40

Table B.1: Procedure to impute process emissions in the base year 2014 (emissions in MtCO₂-eq.)

Appendix C: Carbon tariff, cost compensation and export rebate schedule

Table C.1 shows the carbon tariff and rebate rates that would apply to imports if indirect emissions are excluded from the calculation of sectoral carbon intensities; table C.2. shows the same rates when indirect emissions are included. The tariff rates shown in table C.1 apply in the “Carbon border tax direct” scenario; those shown in table C.2 apply in both the “Carbon border tax indirect” and the “Full carbon border adjustment” scenarios. The rebate rates shown in table C.1 apply to all carbon-intensive goods produced in Europe under the “Cost compensation direct” scenario; those shown in C.2 apply to all carbon-intensive goods produced in Europe under the “Cost compensation indirect” scenario and to all carbon-intensive goods exported from Europe under the “Full carbon border adjustment” scenario.

	JPN/ OCN	RUSS	NOAM	CHN	SSEA	xEURAS	LAT	SSA	EEX	EUR (rebate)
Metals	0.7%	6.4%	1.3%	1.9%	5.8%	3.1%	3.2%	3.3%	3.7%	0.9%
Minerals	2.0%	6.1%	2.8%	6.5%	16.4%	7.3%	3.3%	3.2%	7.0%	2.6%
Chemicals	0.7%	4.1%	0.8%	1.2%	1.6%	1.5%	0.6%	1.0%	1.7%	0.5%

Table C.1: Carbon tariff and rebate rates, excluding indirect emissions

	JPN/ OCN	RUSS	NOAM	CHN	SSEA	xEURAS	LAT	SSA	EEX	EUR (rebate)
Metals	1.0%	10.4%	2.7%	3.3%	8.7%	5.3%	3.9%	6.9%	5.6%	1.1%
Minerals	2.2%	9.1%	4.0%	7.6%	18.1%	8.5%	3.7%	6.5%	7.9%	2.8%
Chemicals	0.9%	8.6%	1.4%	2.4%	2.9%	2.3%	0.8%	2.8%	3.6%	0.7%

Table C.2: Carbon tariff and rebate rates, including indirect emissions

As laid out in appendix A, these rates are calculated as the product of region-specific sectoral carbon intensities and the EU carbon price. The ad-valorem tariffs are designed to subject imported goods to the same carbon price as domestically produced goods and therefore quantify the share of a product's import price that would have had to be spent to pay for emission allowances if the EU ETS or an equivalent carbon pricing scheme had applied at the place of production. The rebate rate is calculated in the same way, as it is designed as an ad-valorem subsidy that compensates European producers for the carbon costs incurred on them.

Therefore, in addition to representing the applicable tariff and subsidy rates, the values shown in table C.2 can be interpreted as carbon cost shares, which allows for a comparison of carbon intensities across sectors and regions. Several interesting conclusions can be derived.

First, the tariff rates would be generally moderate, ranging from 0.8% for chemicals imports from Latin America to 18% applying to minerals imports from South/South-East Asia. They are neither low enough to be irrelevant nor high enough to dissuade trade in any goods category completely.

Second, there is a clear ranking in how strongly the three energy-intensive sectors are affected by carbon tariffs. The minerals sector (dominated by cement production) is targeted most strongly by the carbon tariffs, which reflects the fact that the ratio of emissions to economic value is highest in this area. Chemicals production, by contrast, appears to be much less carbon intensive; most countries are subjected to tariff rates of less than 3% in this sector. This may be because only certain chemical processes are carbon-intensive (notably ethylene and ammonia production), while much of the value creation in this sector takes place without emissions. Metals, which encompasses both the iron and steel and the non-ferrous metals sectors, has intermediate values that strongly vary between regions. This may be attributable to the size and age of installations or differences in production processes (e.g. the nearly emissions-free electric arc furnace vs. the carbon-intensive blast furnace process, which are the main production processes in the steel sector).

Third, one can observe strong heterogeneity between countries. The most advanced economies, namely Japan/Oceania, North America and Europe feature the lowest tariff/rebate rates, indicating newer installations and/or pre-existing regulation. By contrast, Russia and South/South-East Asia are subjected to high carbon tariffs, which indicates that their energy-intensive industries are very polluting. Such heterogeneity is encouraging evidence for the potential one can expect of a carbon border adjustment. It shows that there is substantial room for abatement, not only by shifting global demand towards cleaner producers (which is an effect represented in the static modelling pursued in this study), but also that the currently carbon-intensive producers could be incentivised to invest into new technology to reduce their exposure to carbon tariffs (which is not taken into account by the modelling).