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Abstract

The Paris Agreement calls on developed countries to take the lead in global efforts to stop climate change. The drawback with differentiated commitments is carbon leakage, that is, that emission-intensive industries migrate to countries with lower carbon prices. This risk has prompted the EU to introduce a Carbon Border Adjustment Mechanism as part of the “fit-for-55” agenda with the goal of reducing emissions by 55 percent by 2030. In practical terms, the CBAM will equalize the carbon price paid by domestic and foreign producers in the internal market. Other OECD countries are considering similar measures, which will primarily affect developing countries. The issue thus has a north-south dimension that may increase tensions in global trade and climate negotiations. This paper reviews the empirical evidence of carbon leakage from 1995 to 2018, finding that it has played a marginal role for global emissions. Yet, the perceived risk must be managed to allow the EU and other leading parties to lead the way to decarbonize the global economy without risking their own industrial base. The practical solution would be to negotiate new rules on trade-related climate measures that balance the interests of all parties, as proposed by the Secretary-General of the OECD.

Keywords

Climate change; the European Union; carbon border adjustments, WTO; the Paris agreement; trade-related climate-measures

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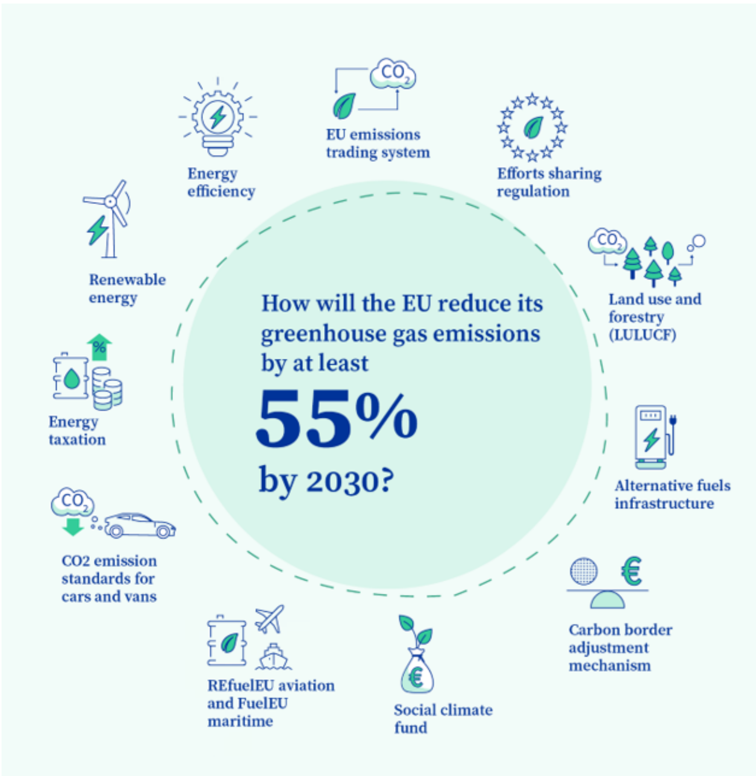
Table of contents

1. Background

The goal of the Paris Agreement is to limit global warming to well below 2 °C, preferably to 1.5 °C, compared to preindustrial levels. The goal was reaffirmed by the Conference of the Parties (COP27) that met in Sharm El-Sheikh, Egypt, in November 2022. The problem is thus not lack of ambition, but that the agreement relies on nationally determined contributions (NDCs) that fall short of the goal. According to the Intergovernmental Panel on Climate Change (2022), greenhouse gas emissions must peak by 2025 and be reduced by 43% by 2030 to meet the 1.5 °C target. And the fallback option of 2 °C, which involves far greater climate risks, would only buy a few additional years to turn the tide. Emissions would still have to come down by 27% by 2030, which is not achievable with current pledges. The pledges made thus far point to a 2.4 to 2.8 °C temperature increase by the end of the century, according to the Climate Action Tracker (2022), and only a handful of countries improved their offers at COP27. Time is thus quickly running out.

One party that is committed to act in line with scientific evidence is the European Union, which has raised its target from 40 to 55 percent reduction of greenhouse gases by 2030 compared to the 1990 level as an intermediate step to becoming climate neutral by 2050. The "fit-for-55" program is comprised of thirteen legislative acts illustrated in Figure 1, including energy taxes, emission standards, and emission trading. The downside is the increased cost that may put emission-intensive and trade-exposed industries (EITEs) at a competitive disadvantage vis-à-vis foreign firms operating under laxer regulations.

Figure 1. The fit-for-55 legislative package



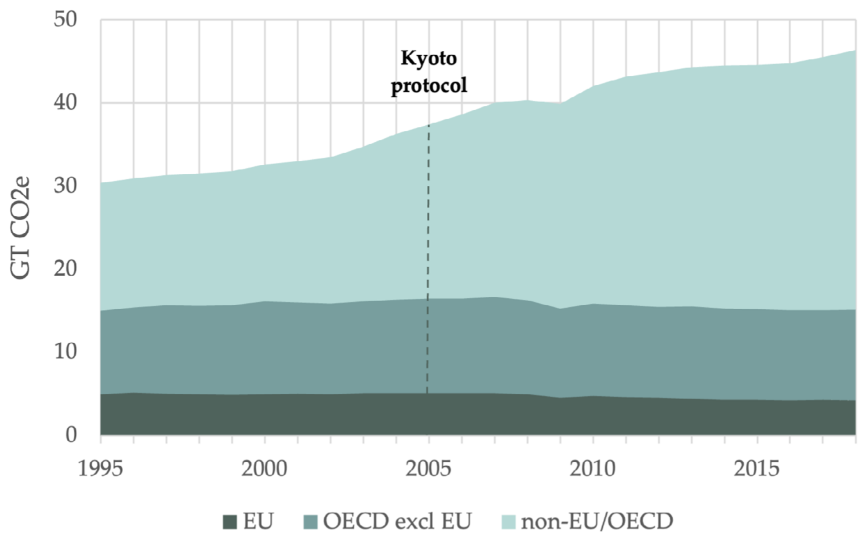
Source: https://www.consilium.europa.eu/en/infographics/fit-for-55-how-the-eu-will-turn-climate-goals-into-law/

To address the competitive concerns and associated risk of "carbon leakage", the fit-for-55 program includes a new Carbon Border Adjustment Mechanism (CBAM),[1] symbolized by a weighing bowl for a level playing field between domestic and foreign firms. The European Commission (2021b, page 1) justifies the measure in the following way:

> Climate change is a global problem that needs global solutions. As we raise our own climate ambition and less stringent environmental and climate policies prevail in non-EU countries, there is a strong risk of so-called 'carbon leakage' – i.e., companies based in the EU could move carbon-intensive production abroad to take advantage of lax standards, or EU products could be replaced by more carbon-intensive imports. Such carbon leakage can shift emissions outside of Europe and therefore seriously undermine EU and global climate efforts. The CBAM will equalize the price of carbon between domestic products and imports and ensure that the EU's climate objectives are not undermined by production relocating to countries with less ambitious policies.

Judging by the emissions of greenhouse gases between 1995 and 2018 plotted in Figure 2, leakage concerns seem to be justified. The plot shows that global emissions are increasing despite the mitigation of the EU and other industrial countries in the OECD group since the Kyoto protocol came into force in 2005, which set binding reduction targets for 37 industrialized countries and economies in transition. The reduction target averaged 5 percent compared to 1990 levels over the first commitment period 2008 to 2012, and by 18 percent over the second commitment period 2013 to 2020. Developing countries were asked to contribute to global efforts, but without binding targets.[2]

Figure 2. Global emissions of greenhouse gases between 1995 and 2018



Empirical studies on the Kyoto Protocol estimate the carbon leakage at between 10 and 30 percent, according to a survey by Caron (2022).[3] That is, a reduction of one ton of CO2 translates on average into a 0.7 to 0.9 ton reduction globally. The residual is offset by increased emissions elsewhere in the world. The estimates are uncertain, as revealed by the title of the survey: *Empirical evidence and projections of carbon leakage: some, but not too much, probably.* Moreover, the estimates are based on past carbon prices and the leakage may increase in the future when climate targets are

1 European Commission (2021a). The CBAM proposal of the Commission can be downloaded at: https://ec.europa.eu/info/sites/default/files/carbon_border_adjustment_mechanism_0.pdf. The final compromise between the European Parliament and the European Council has not been published as this report went into press.

2 https://unfccc.int/kyoto_protocol

3 Similar results are found by Böhringer, Carbone and Rutherford (2018) and Verde (2020). Also, a briefing requested by the European Parliament´s Committee on International Trade, authored by Felbermayr and Peterson (2020), reaches the same conclusion that the carbon leakage has up to now been modest.

raised unless commitments become more equal across countries, an aspiration that may be hard to achieve under the Paris Agreement that relies on nationally determined contributions. The IMF estimates that only 30 percent of global emissions are covered by carbon taxes or emission trading, with an average carbon price of $6 per ton compared to the EU average of €80 in 2022.[4]

In many views, the solution to the commitment gap is a border tax on the carbon content of imported products to offset the competitive advantages of foreign producers operating under laxer restrictions. Carbon Border Adjustments (CBAs), which is the generic term for border taxes on the carbon content of imported products – also known as carbon or climate duties – are being considered not only by the EU but also by UK, USA, Canada, and collectively by the Group of -Seven (G7) as part of a future "climate club" among the industrial nations.[5] These measures will primarily affect developing countries with lower commitments in the Paris Agreement. The issue of CBAs has thus a “north-south” dimension, which may aggravate the tensions in the global trading system and the climate negotiations if the two sides cannot agree on the rules. And currently, there is no rulebook on carbon border adjustments, which raises the issue if CBAs are consistent with the rules of the World Trade Organization (WTO) and the Paris Agreement.

A first issue is whether unilateral CBAs are consistent with the principle of nationally determined contributions in the Paris Agreement. The burden sharing rules in are laid down in Article 4, which, *inter alia*, provides that:

- In order to achieve the long-term temperature goal set out in Article 2, Parties aim to reach global peaking of greenhouse gas emissions as soon as possible, recognizing that peaking will take longer for developing country Parties, and to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty. (Article 4.1).
- Each Party’s successive nationally determined contribution will represent a progression beyond the Party’s then current nationally determined contribution and reflect its highest possible ambition, reflecting its common but differentiated responsibilities and respective capabilities, in the light of different national circumstances. (Article 4.3).
- Developed country Parties should continue taking the lead by undertaking economywide absolute emission reduction targets. Developing country Parties should continue enhancing their mitigation efforts, and are encouraged to move over time towards economy-wide emission reduction or limitation targets in the light of different national circumstances. (Article 4.4).
- Support shall be provided to developing country Parties for the implementation of this Article, … , recognizing that enhanced support for developing country Parties will allow for higher ambition in their actions. (Article 4.5).

Thus, there is no expectation that all parties should carry the same burden or adopt the same carbon prices, even if that would be the most efficient policy from a global point of view.[6] Rather, the agreement specifies that the developed countries that have historically been responsible for

4 See the IMF Staff Climate blog by Black, Parry, and Zhunussova (2022). The EU average carbon price is calculated from the spot auction price of emission rights in the European Energy Exchange (EEX).

5 See the report by Stern and Lankes (2022) for the German G7 Presidency in 2022. The Group of Seven (G7) is comprised of Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States. The EU as a regional organization is a "non-enumerated member" of the G7.

6 A global carbon tax or a global emission-trading system are the most efficient solutions according to most economists. For a discussion, see Stern (2008).

the largest emissions should take the lead. They are also expected to facilitate the contributions by developing countries technologically and financially, which was underscored at the COP27. The Paris Agreement is silent on the use of CBAs, and the legal status is therefore unsettled.[7]

As far as the World Trade Organization (WTO) is concerned, border tax adjustments to equalize the conditions for domestic and foreign firms have been discussed since the 1970 report of the GATT working group on Border Tariff Adjustments (BTA.[8] The working group agreed that *indirect* taxes on the consumption of goods and services can (and should) be adjusted at the border. For example, when a car is exported from Sweden to the United States, the Swedish sales tax is deducted, and the US sales tax is added. This procedure is consistent with the destination principle used for consumption taxes. However, the legal status of border adjustments of direct taxes on the production, including environmental charges, was not settled.

Carbon border adjustments may still be permissible under the general exceptions in Article XX, indent (b) and (g), if applied in a non-protectionist manner:

> Subject to the requirement that such measures are not applied in a manner which would constitute a means of arbitrary or unjustifiable discrimination between countries where the same conditions prevail, or a disguised restriction on international trade, nothing in this Agreement shall be construed to prevent the adoption or enforcement by any contracting party of measures: …
>
> (b) necessary to protect human, animal or plant life or health; …
>
> (g) relating to the conservation of exhaustible natural resources if such measures are made effective in conjunction with restrictions on domestic production or consumption;

However, since CBAs have not been used to this date, there is no legal precedent on the issue, and legal scholars differ on this matter.[9]

Notwithstanding the legal uncertainty and the burden sharing principles in the Paris Agreement, which are similar to those applied in the EU Effort Sharing Regulation, [10] the competitive concerns and the associated risk of carbon leakage have swayed the opinion in the EU in favour of carbon border adjustments. In fact, the issue has been debated in the EU since the Kyoto protocol came into force in 2005,[11] but it has not been urgent until now due to rising carbon prices in the emission trading system. The decision is also a consequence of the desire to phase out the free allocation of emissions rights, which the community industry would not accept unless the competitive concerns

7 The United Nations Framework Agreement on Climate Change (UNFCCC), which is the parent treaty of the Paris Agreement, includes an obligation to cooperate and abstain from unilateral measures that restricts trade unduly. Specifically, Article 3.5 provides: “The Parties should cooperate to promote a supportive and open international economic system that would lead to sustainable economic growth and development in all Parties, particularly developing country Parties, thus enabling them better to address the problems of climate change. Measures taken to combat climate change, including unilateral ones, should not constitute a means of arbitrary or unjustifiable discrimination or a disguised restriction on international trade.”

8 https://docs.wto.org/gattdocs/q/GG/L3799/3464.PDF

9 For different perspectives, see e.g. Horn and Mavrodis (2011), Cosbey, Droege, Fischer and Munnings (2019), National Board of Trade (2020).

10 The Effort Sharing Regulation (ESR) sets national targets for emission reductions from road transport, heating of buildings, agriculture, small industrial installations and waste management. The targets are differentiated on the basis of the per capita income of each member state. Effectively, this means that Sweden, Netherlands and other relatively rich member states will carry a larger burden than relatively poor member states such as Bulgaria and Romania.

11 The first proposal for a CBA was made in 2007 to address the expected carbon leakage of the Kyoto protocol. The proposal was called “FAIR” for Future Allowance Import Requirements and would effectively extend the Kyoto protocol to all trading partners by imposing the same requirements on imported products as on the domestic products. The proposal was not backed by all member states and was shelved. The next proposal, the Aviation Directive (2008/101/EC), would extend the EU emission-trading system to intercontinental flights. Specifically, all airlines that offered services to and from the EU would have to buy emission allowances from the EU. The proposal was withdrawn after retaliatory threats of a coalition of 23 countries, including the United States and China. The US Congress even passed a bill that explicitly forbade domestic airlines from paying the dues (Horn and Sapir, 2020). The third proposal was tabled by France in 2009 and was called the Carbon Inclusion Mechanism. The proposal failed. The issue then subsided until 2016 when France came back with a proposal for the cement sector, again unsuccessfully. The fifth and current CBAM proposal was launched in 2019 by the incoming Commission under Ursula von der Leyen as part of the European Green Deal, and this time it was backed by all member state. For further details on the successive round of CBA proposals, see the National Board of Trade (2020).

were addressed at the same time.[12] The CBAM has thus become political necessary to secure acceptance for the fit-for-55 program as a whole.

The proposal of establishing a carbon border adjustment mechanism (COM/2021/564) was presented by the Commission on 14 July 2021. It was followed by intensive internal consultations with the stakeholders. One sticking points was the treatment of “indirect emissions” in the CBAM, that is, whether foreign producers would have to buy carbon certificates also for the emissions that accrued among their suppliers of raw material and intermediate inputs, in particular electricity. The community industry argued that the indirect emissions should be included since the energy sector is covered by the EU ETS and the carbon costs are passed on to the consuming industries through higher market prices (ERCST, 2022a). Another sticking point was the issue of an export rebate for the carbon costs paid on exported units (ERCST, 2022b). Without such a rebate, the community industry would be at a disadvantage in the world market even if the playing field was levelled in the internal market.

On December 13, 2022, the Council and the European Parliament came to a provisional agreement on the final regulation of the carbon border adjustment mechanism. The text was yet to be published when this report went into press, but the main features are described in the press releases of the Council and the European Parliament.[13]

The stated purpose of the carbon border adjustment mechanism is to equalise the price of carbon paid for EU products operating under the EU Emissions Trading System (EU ETS) and the one for imported goods. This will be achieved by obliging companies that import into the EU to purchase so-called CBAM certificates to pay the difference between the carbon price paid in the country of production and the price of carbon allowances in the EU ETS. CBAM will cover iron and steel, cement, aluminium, fertilisers, and electricity, as proposed by the Commission. The final agreement between the Council and the European Parliament extended the coverage to hydrogen, indirect emissions under certain conditions, certain precursors as well as to some downstream products such as screws and bolts and similar articles of iron or steel. The details are yet to be published. Before the end of the transition period, the Commission is required to assess whether to extend the scope to other goods at risk of carbon leakage, including organic chemicals and polymers, with the goal to include all goods covered by the ETS by 2030. Moreover, the Commission shall assess the methodology for calculating indirect emissions and the possibility to include more downstream products.

The CBAM will apply from 1 October 2023, with an initial three-year transition period where the obligations of the importer shall be limited to reporting the emissions of the covered products. The requirement to buy carbon certificates will be phased in gradually from 2026 onward. To avoid double protection of EU industries, the length of the transition period and the full phase in of the CBAM will be linked to the phasing out of the free allowances under the ETS.

By 2025, the Commission shall assess the risk of carbon leakage for goods produced in the EU intended for export to non-EU countries and, if needed, present a WTO-compliant legislative proposal to address this risk. In addition, an estimated 47.5 million allowances will be used to raise new and additional financing to address any risk of export-related carbon leakage.

12 European Roundtable on Climate Change and Sustainable Transition, ERCST, (2021).

13 https://www.consilium.europa.eu/sv/press/press-releases/2022/12/13/eu-climate-action-provisional-agreement-reached-on-carbon-border-adjustment-mechanism-cbam/; https://www.europarl.europa.eu/news/en/press-room/20221212IPR64509/deal-reached-on-new-carbon-leakage-instrument-to-raise-global-climate-ambition; https://www.europarl.europa.eu/news/en/press-room/20221212IPR64527/climate-change-deal-on-a-more-ambitious-emissions-trading-system-ets

Finally, by the end of 2027, the Commission shall do a complete review of CBAM. The review shall include an assessment of progress made in international negotiations on climate change, as well as the impact on imports from developing countries, in particular the least developed countries (LDCs).[14]

The European Union is first out with a carbon border adjustment mechanism, but other OECD countries are considering similar measures, as noted before. The issue is thus of general interest.

Against this background, this report examines the following questions:

- *First*, how big is the problem of carbon leakage in the world?
- *Second*, has the risk of carbon leakage increased and therefore the need for carbon border adjustment measures?

The study is based on an analysis of global greenhouse gas emissions from 1995 to 2018.

The paper is organized as follows. Section 2 describes the three data sources we use and the concordance between them (TIVA, IEA, and EDGAR). Section 3 outlines the trends in global emissions between 1995 and 2018. Section 4 decomposes the emission growth into a scale effect, technology effect, and composition effect, in which the latter is a proxy for carbon leakage. Section 5 reviews whether the risk of carbon leakage has increased and therefore the need for carbon border adjustment measures. The issue is analysed by studying the convergence of the emission coefficients, which is a new approach in the carbon-leakage literature. The paper is concluded in Section 6.

14 The purpose of the review is not stated in the press release, but the reference to the progress made in international negotiations on climate change suggests that the CBAM will be used as a negotiation chip to elicit higher commitments. If other countries are doing their share, CBAM may not be needed in the future.

2. Data

2.1 Data sources

Three datasets are used in this study:

- *Trade in Value Added* by the OECD (2021).
- *Greenhouse Gas Emissions from Energy* by the IEA (2021).
- *Emissions Database for Global Atmospheric Research* by the European Commission Joint Research Centre (EC-JCR) and Netherlands Environmental Assessment Agency (PBL).

The three datasets are referred to as TIVA (2021), IEA (2021) and EDGAR (2021), respectively. The datasets and concordance between them are described in this section.

2.1.1 Trade in Value Added (TIVA, 2021)

The *Trade in Value Added* dataset by the OECD covers 67 countries/regions and 45 sectors with annual data from 1995 to 2018. The dataset is structured as a global input–output table with production, consumption and trade data by country and sector, divided into intermediate and final products.[15] When combined with the emission data described below, it can be used to trace the flows of greenhouse gases in the world economy, allowing us to calculate the climate footprints of each country both from the production and consumption sides.

2.1.2 Greenhouse Gas Emissions from Energy (IEA, 2021)

The *Greenhouse Gas Emissions from Energy* dataset by the IEA includes annual data on the CO2 emissions from fuel combustion by sector and country, calculated by multiplying the energy source used by each sector with the emission factors in the 2006 IPCC Guidelines for GHG inventories.[16] The IEA dataset also includes data for some other greenhouse gases on a five-year interval, but these are not used in this paper since the EDGAR database provides annual data on the same emissions.

2.1.3 Emissions Database for Global Atmospheric Research (EDGAR, 2021)

The *Emissions Database for Global Atmospheric Research* by the European Commission Joint Research Centre (EC-JCR) and the Netherlands Environmental Assessment Agency (PBL) includes data on several greenhouse gases. The emissions are measured on a spatial grid, which is correlated into emission sectors with geographical data on the location of energy and manufacturing facilities, road networks, shipping routes, human and animal population density and agricultural land use.[17] The emission data are divided into five categories: (1) energy; (2) industrial processes and product use; (3) agriculture, forestry, and other land use; (4) waste; and (5) other. The emissions reported under the energy heading correspond to the IEA data on emissions from fuel combustion and are not used here. From EDGAR, we retrieve data on nonenergy CO2 emissions, methane emissions (CH4) and nitrous oxide emissions (N2O).[18] The last two greenhouse gases are converted into carbon dioxide equivalents (CO2e) with the global warming potential (GWP) index reported by the IPCC.[19]

15 https://www.oecd.org/sti/ind/measuring-trade-in-value-added.htm

16 The IEA data are downloaded from the file “World_BIGCO2.ivt”.

17 For a full description of how the data are produced, see https://edgar.jrc.ec.europa.eu

18 The data on nonenergy carbon dioxide are downloaded from file “v6.0_EM_CO2_fossil_IPCC2006”, methane from file "v6.0_EM_CH4_IPCC2006", and nitrous oxide from file "v6.0_EM_N2O_IPCC2006".

19 The GWP index indicates the amount of global warming that a gas causes, on average, over a 100-year period. Carbon dioxide (CO2) has an index value of 1, methane (CH4) 25, and nitrous oxide (N2O) 298. A kilogram of CH4 is thus equivalent to 25 kilograms of CO2, and a kilogram of N20 is equivalent to 298 kilograms of CO2.

2.2 Concordance issues

The three databases use different sector definitions and must be concorded to a common denominator before we can put the data to work.

- TIVA is divided into ISIC sectors (International Standard Industrial Classification, Revision 4),
- IEA is divided into combustion sectors.
- EDGAR is divided into IPCC 2006 categories.

The data is concorded with the sector definitions in the TIVA dataset. The concordance is shown in Table 1 on the next page, followed by a discussion of how we resolve the issues with one-to-many relations, missing values, and unallocated emissions in the IEA dataset. CBAM sectors that will be included from the start are encircled by red boxes. Iron, steel, and aluminium are included in the basic metals industry of TIVA (D24), cement in the minerals industry (D23), fertilizer and hydrogen in the chemical and chemical products industry (D20), and electricity in the electricity, gas, steam and air conditioning supply industry (D35).

Table 1. The concordance between TIVA, IEA and EDGAR

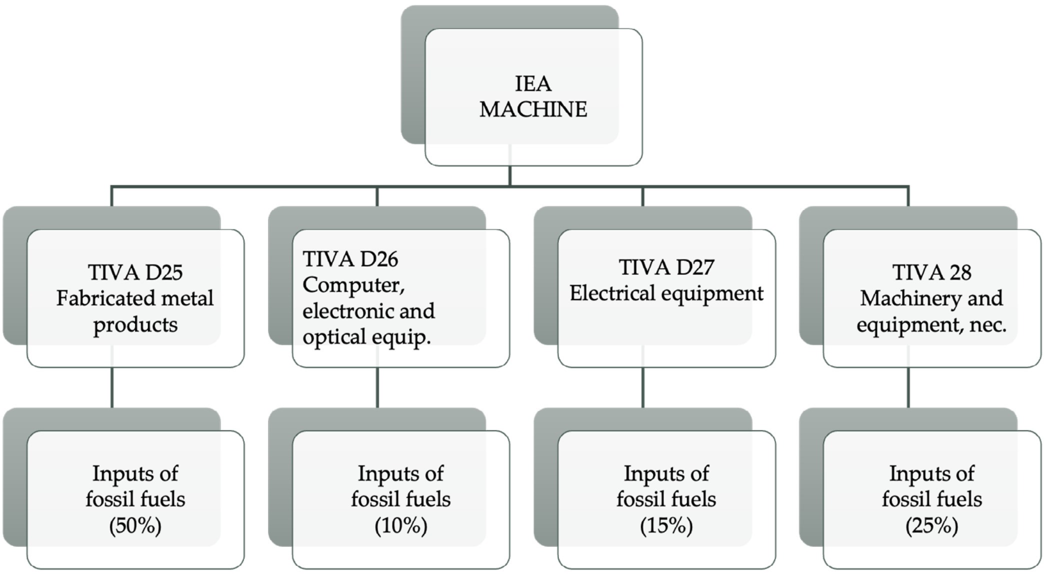
ISIC	TIVA	IEA	EDGAR
D01T02	Agriculture, hunting, forestry	AGRICULT	3.A.1-2, 3.C
D03	Fishing and aquaculture	FISHING	
D05T06	Mining and quarrying, energy-producing products	OTHEN	
D07T08	Mining and quarrying, nonenergy producing prod.	MINING	
D09	Mining support service activities	MINING	
D10T12	Food products, beverages and tobacco	FOODPRO	
D13T15	Textiles, textile products, leather and footwear	TEXTILES	
D16	Wood and products of wood and cork	WOODPRO	
D17T18	Paper products and printing	PAPERPRO	
D19	Coke and refined petroleum products	OTHEN	
D20	Chemical and chemical products	CHEMICAL	2.B
D21	Pharmaceuticals, medicinal chemical and botani-cal… products	CHEMICAL	
D22	Rubber and plastic products	INONSPEC	
D23	Other non-metallic mineral products	NONMET	2.A
D24	Basic metals	IRONSTL, NONFERR	2.C
D25	Fabricated metal products	MACHINE	
D26	Computer, electronic and optical equipment	MACHINE	
D27	Electrical equipment	MACHINE	
D28	Machinery and equipment, nec	MACHINE	
D29	Motor vehicles, trailers and semitrailers	TRANSEQ	
D30	Other transport equipment	TRANSEQ	
D31T33	Manufacturing nec; repair and installation	INONSPEC	
D35	Electricity, gas, steam and air conditioning supply	MAINPROD	
D36T39	Water supply; sewerage, waste, and remediation activities	COMMPUB	4A, 4B, 4C, 4D
D41T43	Construction	CONSTRUC	
D45T47	Wholesale and retail trade; repair of motor vehicles	COMMPUB	
D4**9**	Land transport and transport via pipelines	ROAD, RAIl, PIPELINE, TRN.	
D50	Water transport	DOMESNAV, MARBUNK	
D51	Air transport	DOMESAIR, AVBUNK	
D52	Warehousing and support activities for transporta-tion	COMMPUB	
D53	Postal and courier activities	COMMPUB	
D55T56	Accommodation and food service activities	COMMPUB	
D58T60	Publishing, audiovisual and broadcasting activities	COMMPUB	
D61	Telecommunications	COMMPUB	
D62T63	IT and other information services	COMMPUB	
D64T66	Financial and insurance activities	COMMPUB	
D68	Real estate activities	COMMPUB	
D69T75	Professional, scientific and technical activities	COMMPUB	
D77T82	Administrative and support services	COMMPUB	
D84	Public administration and defence; compulsory social security	COMMPUB	
D85	Education	COMMPUB	
D86T88	Human health and social work activities	COMMPUB	
D90T93	Arts, entertainment and recreation	COMMPUB	
D94T96	Other service activities	COMMPUB	
D97T98	Activities of households as employers; …	COMMPUB	

2.2.1 IEA and TIVA

2.2.1.1 One-to-many concordances

The emission data reported by the IEA are typically at a higher level of aggregation than the sectors in TIVA. A case in point is the MACHINE combustion sector in IEA that is correlated to four ISIC sectors in TIVA: Fabricated metal products (D25), Computer, electronic and optical equipment (D26), Electrical equipment (D27) and Machinery and equipment nec (D28). To split the aggregate emissions between the four sectors, we use TIVA data on the fossil-fuel inputs of each sector. The calculation is illustrated in Figure 3. For simplicity, we add the crude (D05T06) and the refined fuels (D19) reported in the TIVA input–output table without adjustments for the differences in emission factors.[20]

Figure 3. Example of one-to-many correlation between IEA and TIVA, using the fossil-fuel inputs as the allocation key



The same allocation rule is used for MINING (1:2), OTHEN (1:2), CHEMICAL (1:2), TRANSPEQ (1:2), INONSPEC (1:2) and COMMPUB (1:18).

2.2.1.2 Missing values in IEA

The IEA database has many missing values, especially for small developing countries and early years in the dataset. The missing values are filled in by apportion the data for a higher aggregate based on the fossil-fuel consumption for each sector. For example, if a country reports the aggregate emissions for the manufacturing sector (MANUFACT) but not for individual industries, we apportion the emissions based on the fossil-fuel consumption of each industry. If we have data for some manufacturing industries but not others, we retain these data and apportion the residual emissions based on the fossil-fuel consumption. If data are also lacking for the MANUFACT aggregate, which is true for a handful of small developing countries, we allocate the emissions based on the data reported for the total industry (TOTIND).

20 Yamano and Guilhoto (2020) of the OECD secretariat adjusted for the energy mix, but we have not been able to replicate their approach.

2.2.1.3 Transport emissions

The transport emissions reported by the IEA are particularly difficult to correlate with the TIVA data.

The IEA data on land transport emissions are divided into ROAD, RAIL, PIPELINE and TRNONSPEC. The ROAD aggregate includes both commercial and private traffic and must therefore be divided between the commercial sector in TIVA (D49) and the household sector in the final demand (HH). We use the same approach as Yamano and Guilhoto (2020) and split the ROAD emissions based on the disaggregated data on the consumption of different kinds of fuels. Specifically, all emissions from the combustion of motor gasoline are allocated to the household sector, and all emissions from the combustion of other fuels (primarily diesel) are allocated to the commercial sector (D49):[21]

$$Emissions_{HH,i} = motor\ gasoline\ in\ ROAD_i\ ,$$

$$Emissions_{D49,i} = other\ fuels\ in\ \mathrm{ROAD}_i + \mathrm{RAIL}_i + \mathrm{PIPELINE}_i + \mathrm{TRNONSPEC}_i\ .$$

Turning to the emissions from water and air transport, the IEA is only able to allocate domestic emissions (DOMESNAV and DOMESAV) to a particular country. The emissions from the combustion of bunker fuel for international transport are reported separately in two memorandum items, referred to as MARBUNK and AIRBUNK. These data are split by the IEA between the departure and arrival port but should be split between the flags of the carriers to be correlated with the TIVA data. For example, when Air France fuels in Stockholm for a flight to Paris, these emissions should be allocated to the French air transport sector, and when SAS fuels in Paris for a flight to Stockholm, these emissions should be allocated to the Swedish air transport sector. We use the global share of fossil-fuel consumption to apportion international emissions:[22]

$$Emissions_{D50,i} = DOMESMAR_i + \left(\frac{fossil_{D50,i}}{\sum_i fossil_{D50,i}}\right) * \sum_i MARBUNK_i\ ,$$

$$Emissions_{D51,i} = DOMESAIR_i + \left(\frac{fossil_{D51,i}}{\sum_i fossil_{D51,i}}\right) * \sum_i AVBUNK_i\ .$$

2.2.1.4 Autoproducers of electricity and/or heat

Autorproducers are defined by the IEA as undertakings that generate electricity and/or heat, wholly or partly for their own use as an activity that supports their primary activity. An example is a paper mill that uses residual products from raw material to generate electricity. The emissions of autoproducers are reported by the IEA without any breakdown between sectors and with the only guideline that these emissions should be allocated between “industry, transport and other sectors”. Yamano and Guilhoto (2020) allocated these emissions in full to the Basic metals industry (D24), in which autoproduction of electricity is known to be common. However, autoproduction is also prevalent in other sectors, such as the pulp and paper industry. In lack of data on the autoproduction of electricity, we allocate these emissions to the sectors that report the lowest emissions in relation to their reported fossil-fuel inputs; that is, to sectors that *ought* to have higher emissions than they report. Therefore, we use these emissions to adjust for suspicious outliers.[23]

21 In reality, of course, motor gasoline and diesel fuel are used both by private and commercial vehicles, but in different proportions, which we lack data on. The errors will hopefully cancel each other out.

22 Note that Yamano and Guilhoto (2020) did not account for the international emissions due to the lack of a good allocation rule, which results in the national emissions not summing to the global total.

23 Specifically, we estimate a log-linear model with the observable emissions on the left-hand side and the fossil-fuel consumption on the right-hand side. The unaccounted emissions from the autoproducers of electricity and/or heat are then allocated in proportion to deviation between the expected and actual emissions.

2.2.2 EDGAR and TIVA

Data on greenhouse gases other than from the combustion of fossil fuels are retrieved from the EDGAR database. We include methane (CH4), nitrous oxide (N2O) and nonenergy emissions of carbon dioxide (CO2). [24] The two first gases are converted into CO2 equivalents (CO2e) with the conversion rates used by the IPCC. The concordance between the IPCC categories in EDGAR and the ISIC sectors in TIVA is shown in Table 2.

Table 2. Concordance between EDGAR and TIVA

TIVA	TIVA sectors	EDGAR
D01T02	Agriculture, hunting, forestry	3.A.1, 3.A.2, 3.C
D20	Chemical and chemical products	2.B
D23	Other mineral products	2.A
D24	Basic metals	2.C
D36T39	Water supply; sewerage, waste, and remediation activities	4A, 4B, 4C, 4D

We refer to these emissions as "process emissions". One example is the production of clinkers, an intermediate step in cement manufacturing, which involves a process in which calcium carbonate (CaCO3) is calcinated and converted to lime (CaO), producing CO2 as a by-product.[25] Another example is steel production, which uses coal as a reducing agent to transform iron ore (Fe2O3) into pig iron (2Fe), with CO2 as a by-product.[26] Methane and nitrous oxide are caused by ruminating animals and when the soil is prepared for forestry and agriculture. Leakage of methane and nitrous oxide is also common in the chemical industry and in the sewerage, waste, and remediation sector.

24 The EDGAR database also includes data on ozone, chlorofluorocarbons, hydrofluorocarbons and perfluorocarbons, but these data are incomplete for many countries and are therefore ignored.

25 https://www.ipcc-nggip.iges.or.jp/public/gp/bgp/3_1_Cement_Production.pdf

26 https://leard.frontlineaction.org/coking-coal-steel-production-alternatives/

3. Trends in global emissions

We begin by presenting the broad trends in global emissions from 1995 to 2018, which is the period we can follow with our data. We distinguish between "developed" and "developing" countries, in which the former is defined as all current members of the EU and OECD. We do not account for changes in the development status during this period or the accessions of new members to the EU (2004, 2007, and 2013). The UK is grouped with the EU, as was true until February 2020. The affiliation of the 66 countries in the TIVA dataset are listed in Table 3. The rest-of-the-world region is defined as developing.

Table 3. Countries and group affiliation

ISO3	Country	Group	ISO3	Country	Group
AUT	Austria	EU/OECD	ISL	Iceland	OECD
BEL	Belgium	EU/OECD	ISR	Israel	OECD
CZE	Czech Republic	EU/OECD	JPN	Japan	OECD
DNK	Denmark	EU/OECD	KOR	Korea	OECD
EST	Estonia	EU/OECD	MEX	Mexico	OECD
FIN	Finland	EU/OECD	NZL	New Zealand	OECD
FRA	France	EU/OECD	NOR	Norway	OECD
DEU	Germany	EU/OECD	CHE	Switzerland	OECD
GRC	Greece	EU/OECD	TUR	Turkey	OECD
HUN	Hungary	EU/OECD	USA	United States	OECD
IRL	Ireland	EU/OECD	ARG	Argentina	Developing
ITA	Italy	EU/OECD	BRA	Brazil	Developing
LVA	Latvia	EU/OECD	BRN	Brunei Darussalam	Developing
LTU	Lithuania	EU/OECD	KHM	Cambodia	Developing
LUX	Luxembourg	EU/OECD	CHN	China	Developing
NLD	Netherlands	EU/OECD	TWN	Chinese Taipei	Developing
POL	Poland	EU/OECD	HKG	Hong Kong	Developing
PRT	Portugal	EU/OECD	IND	India	Developing
SVK	Slovak Republic	EU/OECD	IDN	Indonesia	Developing
SVN	Slovenia	EU/OECD	KAZ	Kazakhstan	Developing
ESP	Spain	EU/OECD	LAO	Lao	Developing
SWE	Sweden	EU/OECD	MYS	Malaysia	Developing
GBR	United Kingdom	EU/OECD	MAR	Morocco	Developing
BGR	Bulgaria	EU	MMR	Myanmar	Developing
CYP	Cyprus	EU	PER	Peru	Developing
HRV	Croatia	EU	PHL	Philippines	Developing
MLT	Malta	EU	RUS	Russian Federation	Developing
ROU	Romania	EU	SAU	Saudi Arabia	Developing
AUS	Australia	OECD	SGP	Singapore	Developing
CAN	Canada	OECD	ZAF	South Africa	Developing
CHL	Chile	OECD	THA	Thailand	Developing
COL	Colombia	OECD	TUN	Tunisia	Developing
CRI	Costa Rica	OECD	VNM	Viet Nam	Developing

Note: All current members of the EU and/or the OECD are defined as "developed" countries, and all other countries as "developing", including the rest-of-the-world (ROW) region

3.1 The difference between production and consumption emissions

The climate "footprints" of a country can be measured either from the production side or the consumption side. We report both measures to offer different perspectives on the growing emissions in the world.

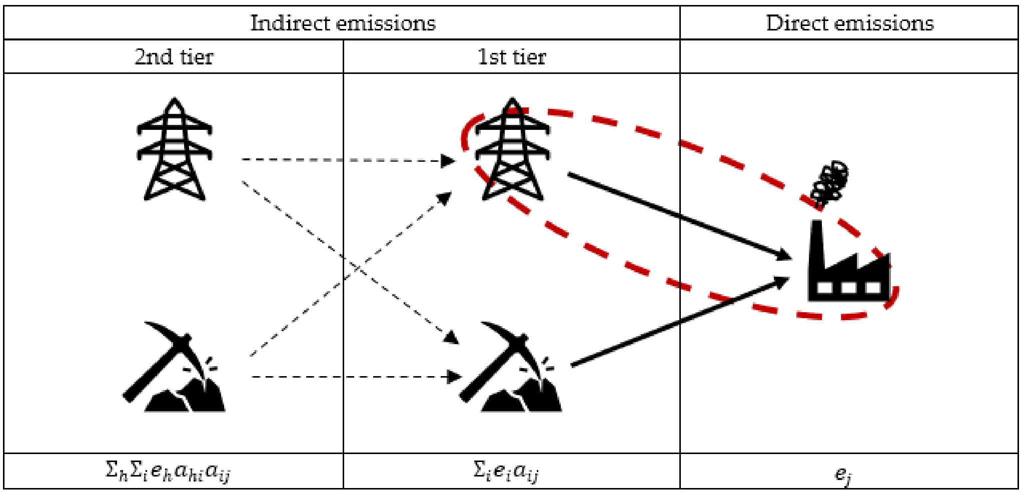
3.1.1 Production emissions

Production emissions are generated as a by-product of the production of goods and services. The emissions are primarily caused by the combustion of fossil fuel and to a lesser extent by other inputs and production processes. The direct emissions can be mitigated either by shifting to less polluting fuels (from coal to oil, to natural gas, to renewable energies) or by altering the production process more fundamentally; for example, by shifting from coal to hydrogen as an agent to reduce the oxygen in the iron ore in the manufacturing of steel. Emissions can also be captured and stored with CCS technologies, but such technologies are still in their infancy.

3.1.1.1 Direct and indirect emissions

The emissions recorded by the IEA and EDGAR are the *direct emissions* of an industry; that is, emissions from sources that are owned or controlled by the reporting entity. The production may also generate *indirect emissions* in the supply chain when the inputs are produced, divided between electricity, heat and steam (Scope 2 emissions) and other inputs (Scope 3 emissions).

Figure 4. The distinction between direct and indirect emissions



Note: The grid icon represents electricity, heat and steam (Scope 2) and the pick icon other inputs (Scope 3 emissions). The coverage of the CBAM if Scope 2 emissions are included is indicated by the red dashed ellipse. Third and higher tiers in the supply chain are not included in the figure.

The indirect emissions can be measured by summing the emission coefficients of each input with the input weights in the final product, using the input–output coefficients reported in the TIVA database. The calculation is illustrated in Figure 4, in which the inputs are divided into Scope 2 emissions represented by the "grid" icon and Scope 3 emissions represented by the "pick" icon. The coverage of the CBAM under the assumption that Scope 2 emissions are included are indicated by the red dashed ellipse.

3.1.2 Consumption emissions

The comparison between countries is normally based on production emissions, which is the data reported by the IEA and EDGAR. However, the comparison can also be based on the calculated embedded emissions in the consumption basket of each country, which can be calculated with the input-output data of the TIVA dataset by adding the emissions along the supply chain from raw materials to final assembly, illustrated n Figure 4.

The two indicators give the same answer as so far as the global emissions are concerned. All emissions produced somewhere are also consumed somewhere. The difference is in the attribution of responsibility. Does the responsibility rest with the producers that have the direct control over the emissions, or the consumers that make up the demand? Rather than taking a stand on this issue, we will report both measures.

3.2. Developed versus developing countries

In this section we report the emissions of developed and developing countries from both the production and consumption sides, distinguishing also between combustion, process, and household emissions from driving and residential heating.

Figure 5. Combustion emissions

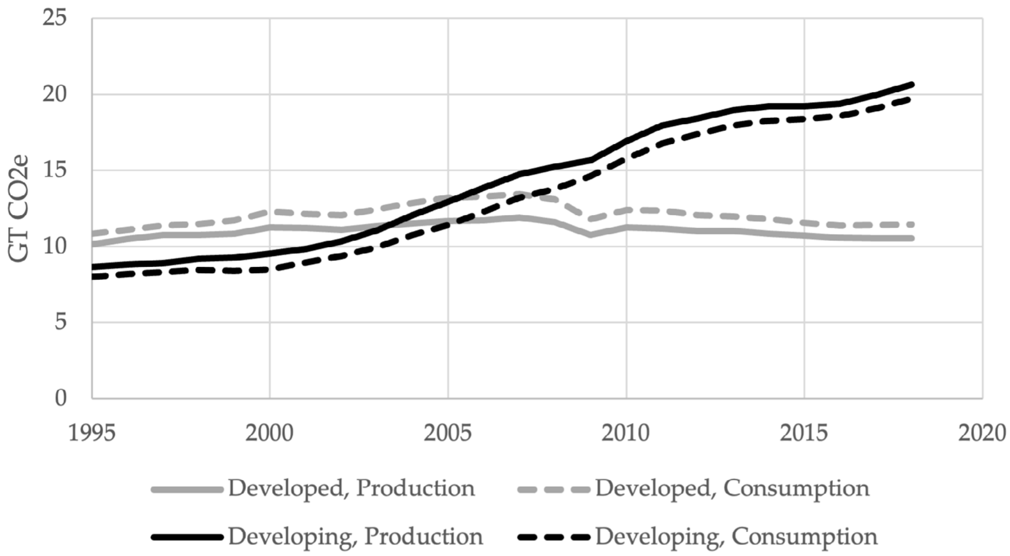


Figure 5 plots the emissions from the combustion of fossil fuels retrieved from the IEA (2021) database, which makes up the lion´s share of the greenhouse gases. The design of the graph combining production and consumption emissions is borrowed from the OECD (2021).[27] The plot shows that emissions from the developed countries peaked around 2007/2008, whereas the emissions of the developing countries are still growing. The trends are the same whether the emissions are measured from the production or the consumption side. The gap between production and consumption emissions measures the net trade of greenhouse gases, with developing countries being the net exporters and developed countries the net importers. The pattern reflects the international division of labour in which, simplifying slightly, developing countries specialize in the extraction of raw materials and process industries, while developed countries specialize in high-tech manufacturing industries and services that by nature are less emission-intensive.

27 Our plot differs slightly from the OECD's plot because we compare developed and developing countries whereas the OECD compared OECD and non-OECD countries. The difference is Bulgaria, Cyprus, Croatia, Malta, and Romania are members of the EU but not the OECD. The consumption emissions also differ slightly because of different concordance methods. The corresponding OECD plot is available at: https://www.oecd.org/industry/ind/carbondioxideemissionsembodiedininternationaltrade.htm

Figure 6. Process emissions

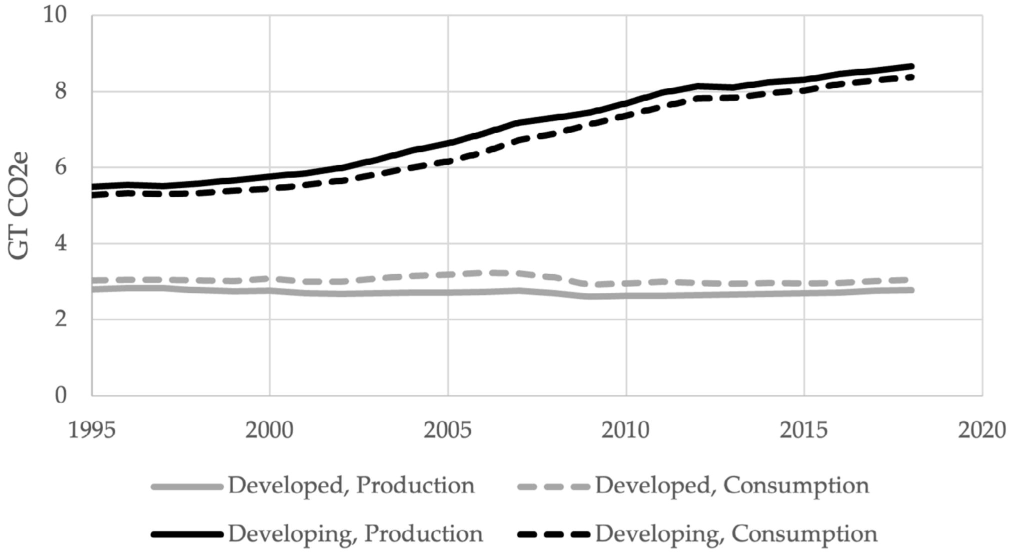


Figure 6 plots the process emissions retrieved from the EDGAR (2021) database. Process emissions are concentrated in five sectors in the TIVA dataset, three of which are covered by the CBAM, namely, Chemical and chemical products (D20), including fertilizers and hydrogen; Other mineral products (D23), including cement; and Basic metals (D24), including iron, steel and aluminium. Process emissions, especially methane and nitrous oxide, are also common in Agriculture, hunting, and forestry (D01T02); and Water supply; sewerage, waste, and remediation activities (D36T39), which are sectors that are not covered by the CBAM, at least not from the start. As shown in the plot, process emissions are higher in developing countries than in developed countries, and are also growing over time. The pattern reflects both the division of labour in the global economy and differences in the emission coefficients.

Figure 7. Direct household emissions from driving and residential heating

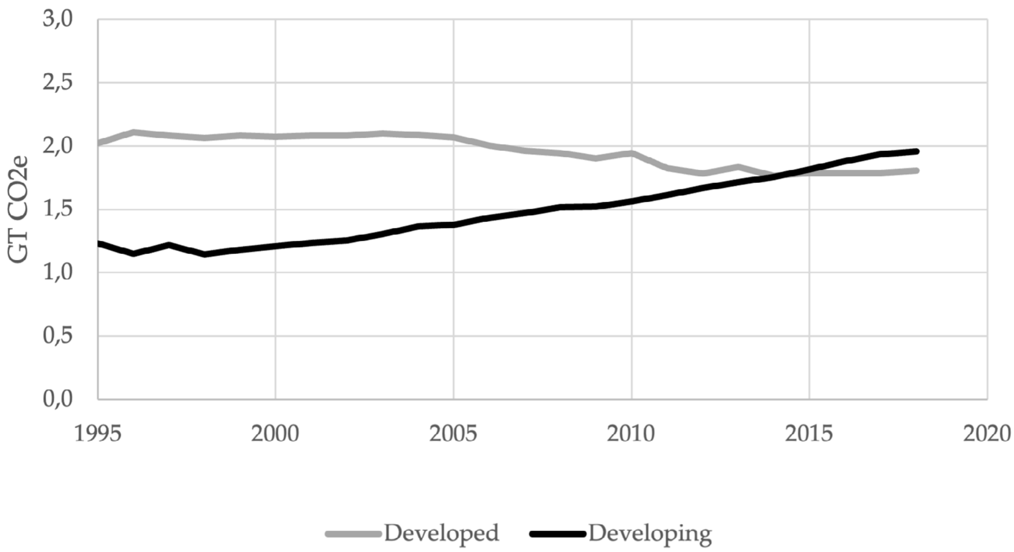


Figure 7 shows the direct emissions caused by the households from driving and residential heating. As these emissions are "consumed" at the same time as they are produced, the plot does not make a distinction between the two sides of the coin. Like combustion and process emissions, the trends are moving in the opposite direction, that is, are falling in the developed countries and increasing in the developing, reflecting the gradual convergence of incomes and consumption in the world and faster population growth in developing countries.

Figure 8. Total emissions – production vs. consumption-based accounting

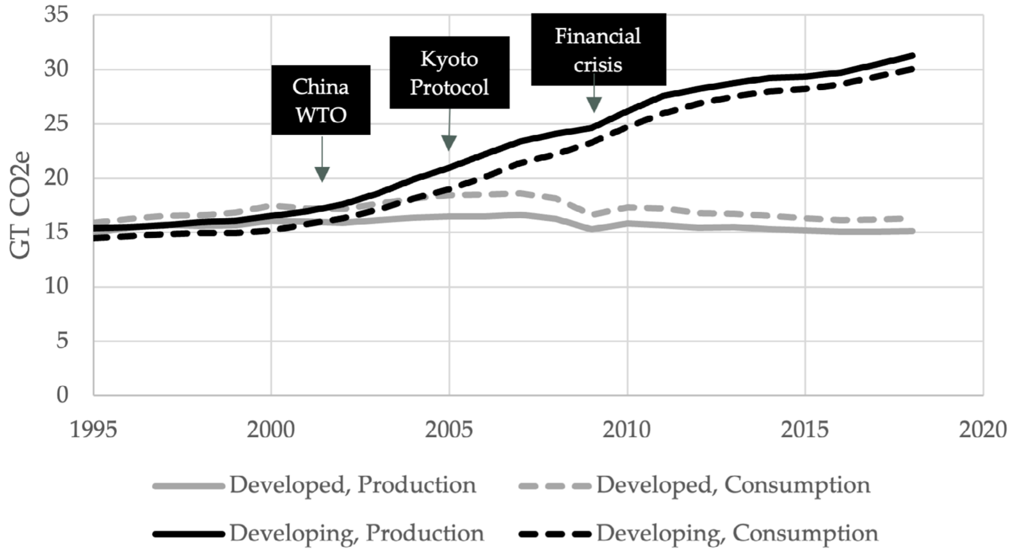


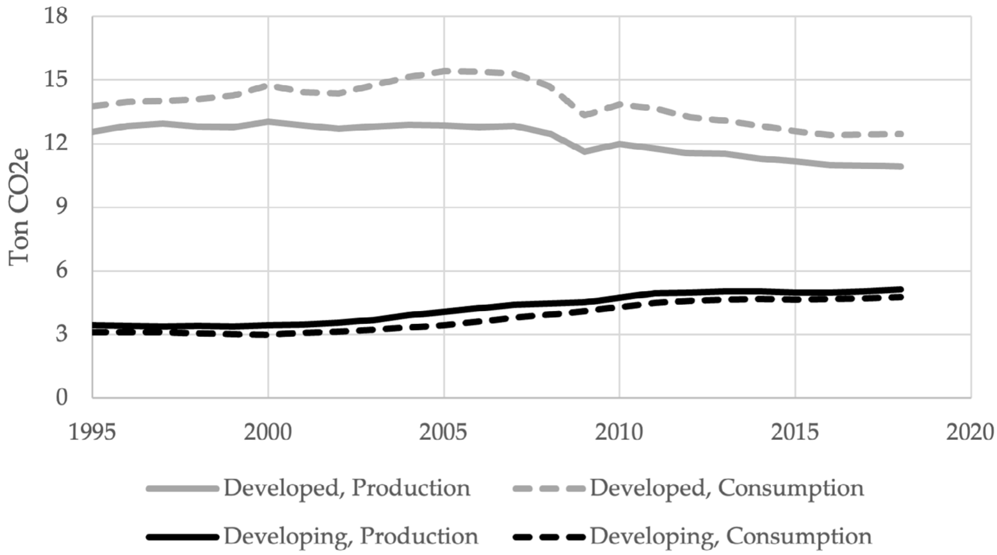
Figure 8 shows the grand total of the three emissions sources reviewed before. The data show that the emissions of the developed countries peaked two-three years after the Kyoto protocol came into force in 2005, although the initial drop in 2008-2009 had more to do with the economic recession during the financial crisis than reduced emission coefficients. By contrast, the emissions of developing countries have accelerated after the millennium shift, and the question is if there is a causal link between reduced emissions of the developed countries and increased emissions of developing, or if it is just a "side-effect" of increased economic growth in developing countries?

If we study the plot carefully, we observe no jump in the emissions of the developing countries in conjunction with the introduction of the Kyoto protocol, as would be expected if main driver was carbon leakage. Rather, the acceleration started around the time China became a member of the WTO at the end of 2001,[28] which was followed by a period of rapid economic growth that doubled the Chinese emissions in less than a decade. The economic growth in other developing countries, including India, also took off during this period due to market-oriented reforms, adding further impetus to the emissions of the global south. The preliminary conclusion is therefore that carbon leakage is not the main driver of growing global emissions in the post-Kyoto period, an issue that we shall substantiate in section 4 of the paper.

28 China became a member of the WTO on 11 December 2001.

Despite the rapid growth in the aggregate emissions of developing countries, per capita emissions are, on average, less than half of the emissions of the developed countries, although the gap has narrowed since the Kyoto protocol began limiting the emissions of the developed countries. This is shown in Figure 9. In fact, the per capita emissions of China are now on par with the emissions of the EU, though still less than half of the emissions of the USA, as shown in the next section of the paper.

Figure 9. Per capita emissions - production vs. consumption-based accounting



3.3 Emissions by country

The emissions by country are reported for three years, 1995, 2005 and 2018, in Table 4 and Table 5, divided between production and consumption emissions. The EU is treated as one region. The table is sorted in descending order after total emissions in 2018.

Table 4. Greenhouse gas emissions by country/region – production side

	Total emissions (MT CO2e)			Global share (%)			Per capita (ton CO2e)		
Country/region	**1995**	**2005**	**2018**	**1995**	**2005**	**2018**	**1995**	**2005**	**2018**
China	4 401	7 360	12 687	14,48	19,66	27,36	3,6	5,6	9,0
USA	5 926	6 625	5 733	19,50	17,70	12,37	22,2	22,4	17,5
EU	4 981	5 097	4 194	16,40	13,62	9,05	10,3	10,3	8,2
India	1 481	1 963	3 394	4,88	5,24	7,32	1,5	1,7	2,5
Russian Federation	1 873	1 780	1 952	6,17	4,76	4,21	12,6	12,4	13,3
Japan	1 385	1 424	1 300	4,56	3,81	2,80	11,0	11,1	10,3
Brazil	778	997	1 201	2,56	2,66	2,59	4,9	5,4	5,8
Indonesia	439	574	920	1,45	1,53	1,98	2,3	2,6	3,5
Korea	515	581	743	1,70	1,55	1,60	11,4	12,1	14,4
Mexico	481	651	730	1,58	1,74	1,57	5,2	6,2	5,8
Canada	556	672	694	1,83	1,79	1,50	19,0	20,9	18,8
Saudi Arabia	229	363	619	0,76	0,97	1,34	12,7	15,6	18,5
Turkey	239	322	567	0,79	0,86	1,22	4,0	4,7	6,9
Australia	433	530	545	1,43	1,41	1,18	23,9	26,1	21,7
South Africa	325	449	509	1,07	1,20	1,10	7,8	9,4	8,8
Thailand	271	342	409	0,89	0,91	0,88	4,6	5,2	5,9
Vietnam	116	201	409	0,38	0,54	0,88	1,6	2,4	4,3
Argentina	252	317	349	0,83	0,85	0,75	7,2	8,2	7,8
Taipei	202	293	331	0,67	0,78	0,71	9,5	12,9	14
Malaysia	123	209	285	0,40	0,56	0,62	5,9	7,9	8,8
Kazakhstan	214	194	263	0,70	0,52	0,57	13,7	12,8	14,3
Philippine	127	150	224	0,42	0,40	0,48	1,9	1,8	2,1
Colombia	135	140	168	0,44	0,37	0,36	3,7	3,3	3,5
Myanmar	73	94	135	0,24	0,25	0,29	1,6	2,0	2,6
Chile	65	97	117	0,21	0,26	0,25	4,5	6,0	6,3
Singapore	80	77	114	0,26	0,21	0,25	22,7	18,1	20,3
Morocco	49	71	101	0,16	0,19	0,22	1,9	2,3	2,9
Peru	49	59	85	0,16	0,16	0,18	2,0	2,1	2,7
New Zeeland	73	88	84	0,24	0,23	0,18	20,0	21,2	17,2
Israel	59	74	79	0,19	0,20	0,17	10,6	10,7	8,9
Norway	61	73	69	0,20	0,20	0,15	14,1	15,8	12,9
Switzerland	57	58	56	0,19	0,15	0,12	8,1	7,8	6,6
Hongkong	43	48	55	0,14	0,13	0,12	6,9	7,1	7,3
Tunisia	24	30	38	0,08	0,08	0,08	2,6	3,0	3,3
Cambodia	20	25	37	0,07	0,07	0,08	1,9	1,8	2,4
Lao	9	10	31	0,03	0,03	0,07	1,8	1,8	4,4
Costa Rica	12	12	16	0,04	0,03	0,03	3,4	3,0	3,2
Brunei	7	7	9	0,02	0,02	0,02	23,5	20,0	20,1
Iceland	4	5	5	0,01	0,01	0,01	14,6	17,7	15,3
Rest of the World	4 214	5 367	7 104	13,87	14,34	15,32	3,2	3,3	3,4

Table 5. Greenhouse gas emissions by country/region – consumption side

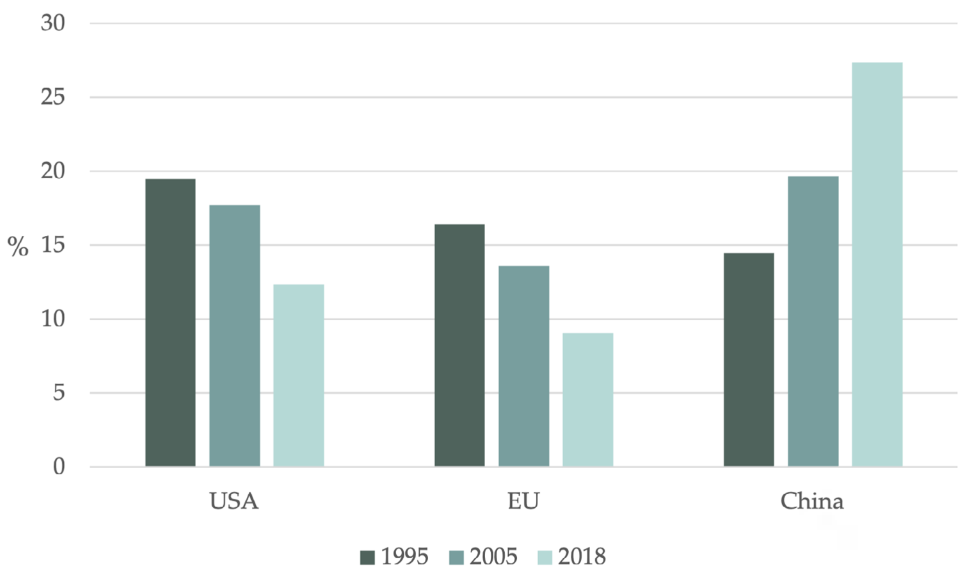
	Total emissions (MT CO2e)			Global share (%)			Per capita (ton CO2e)		
Country/region	**1995**	**2005**	**2018**	**1995**	**2005**	**2018**	**1995**	**2005**	**2018**
China	4 194	6 552	12 475	13,80	17,51	26,91	3,5	5,0	8,9
USA	6 139	7 305	6 173	20,20	19,52	13,31	23,0	24,7	18,9
EU	5 422	5 900	4 735	17,85	15,76	10,21	11,3	12,0	9,3
India	1 451	1 934	3 387	4,77	5,17	7,30	1,5	1,7	2,5
Russian Federation	1 499	1 329	1 587	4,94	3,55	3,42	10,1	9,3	10,8
Japan	1 643	1 683	1 499	5,41	4,50	3,23	13,1	13,2	11,8
Brazil	752	923	1 060	2,48	2,46	2,29	4,7	5,0	5,1
Indonesia	436	556	916	1,44	1,49	1,98	2,2	2,5	3,5
Korea	552	696	768	1,82	1,86	1,66	12,2	14,5	14,9
Mexico	473	692	738	1,56	1,85	1,59	5,2	6,6	5,9
Canada	511	656	648	1,68	1,75	1,40	17,4	20,4	17,5
Saudi Arabia	218	325	590	0,72	0,87	1,27	12,0	13,9	17,7
Turkey	255	381	586	0,84	1,02	1,26	4,2	5,5	7,1
Australia	400	526	510	1,32	1,41	1,10	22,1	25,9	20,3
South Africa	281	392	435	0,92	1,05	0,94	6,8	8,2	7,5
Thailand	279	351	428	0,92	0,94	0,92	4,7	5,4	6,2
Vietnam	117	187	414	0,38	0,50	0,89	1,6	2,2	4,4
Argentina	250	282	341	0,82	0,75	0,73	7,2	7,3	7,7
Taipei	215	282	288	0,71	0,75	0,62	10,1	12,4	12,2
Malaysia	114	176	276	0,37	0,47	0,59	5,5	6,6	8,5
Kazakhstan	191	149	237	0,63	0,40	0,51	12,2	9,8	12,9
Philippine	141	153	248	0,46	0,41	0,54	2,1	1,8	2,3
Colombia	129	143	170	0,42	0,38	0,37	3,5	3,4	3,5
Myanmar	72	81	127	0,24	0,22	0,27	1,6	1,7	2,4
Chile	61	92	110	0,20	0,25	0,24	4,3	5,7	5,9
Singapore	88	95	145	0,29	0,25	0,31	24,9	22,3	25,8
Morocco	54	77	108	0,18	0,21	0,23	2,0	2,6	3,1
Peru	51	59	87	0,17	0,16	0,19	2,1	2,1	2,7
New Zeeland	67	89	81	0,22	0,24	0,18	18,3	21,5	16,6
Israel	69	92	99	0,23	0,24	0,21	12,4	13,2	11,1
Norway	62	77	73	0,21	0,20	0,16	14,3	16,6	13,7
Switzerland	91	100	98	0,30	0,27	0,21	12,9	13,5	11,5
Hongkong	94	99	67	0,31	0,26	0,14	15,1	14,4	9,0
Tunisia	27	34	39	0,09	0,09	0,08	2,9	3,3	3,4
Cambodia	20	26	38	0,07	0,07	0,08	1,9	1,9	2,5
Lao	9	11	23	0,03	0,03	0,05	1,9	1,9	3,2
Costa Rica	13	15	20	0,04	0,04	0,04	3,7	3,7	3,9
Brunei	6	6	8	0,02	0,02	0,02	21,2	17,1	18,7
Iceland	4	6	5	0,01	0,02	0,01	14,0	19,6	15,8
Rest of the World	3 932	4 895	6 728	12,94	13,08	14,51	3,0	3,0	3,2

As noted before, the main development over this period was the rise of China as an economic superpower and emitter of greenhouse gases, especially when measured from the production side. The production emissions of China increased threefold from 1995 to 2018, and the share of the global total rose from 14.5 percent to 27.4 percent. While Chinese emissions per capita are still only half of the per capita emissions of the USA, they are now on par with the per capita emissions of the EU. Additionally, India became a significant economic power and emitter of greenhouse gases. Measured from the production side, India´s share of global emissions rose from 4.9 to 7.3 percent between 1995 and 2018, and from the consumption side from 4.8 to 7.3 percent. However, from a per capita perspective, the emissions of India are still less than a third of the emissions of the EU and only a sixth of the per capita emissions of the USA.

3.4 The 50-percent club

The three largest emitters of greenhouse gases in the world are China, the USA, and the EU. Between them, they are responsible for half of the global emissions, and this share has been constant over the studied period.[29] What changed was the composition of the emissions, and quite dramatically so, as shown in Figure 10. The combined share of the USA and EU fell by 14.5 percentage points, whereas the share of China increased by 15.0 percentage points. Being responsible for half of the global emissions, the "50-percent club" is the key player in international negotiations. Without an agreement on the rules and burden sharing among the three of them, it will be hard to achieve a global climate agreement that will meet the 1.5 °C goal of the Paris Agreement.

Figure 10. The 50-percent club – share of global emissions 1995, 2005, and 2018



29 The combined share of the USA, EU and China was 50.4% in 1995, 51.0% in 2005, and 48.8% in 2018.

4. Decomposing global emissions

In this section, we decompose the growth in the global emissions of greenhouse gases into a *scale effect, a technique effect and a composition effect, in which the last part is* a proxy for carbon leakage. With decomposition, we mean isolating the individual contributions of the increased scale of global production, improved production technologies (reduced emission coefficients per unit of output), and changes in the composition of the world economy (shifts in the location of emission-intensive production).

The three-way decomposition was introduced at the conceptual level by Grossman and Krueger (1993) in a study on the potential environmental effects of the North American Free Trade Agreement (NAFTA) that came into force in 1994.[30] The NAFTA extended the free trade agreement between Canada and the USA to Mexico, which raised two sets of concerns in the northern states. The first concern was that labour-intensive industries would migrate to Mexico to take advantage of lower wages, thereby putting downwards pressure on the blue-collar wages in Canada and the USA. The second concern was that polluting industries would migrate to Mexico to take advantage of lower environmental standards, putting downwards pressure on the environmental standards in Canada and the USA.

To structure the analysis, Grossman and Kruger (1993) proposed a model that divided the environmental impact into a scale effect, a technique effect, and a composition effect. The anticipation was that the NAFTA would increase the economic growth, which in and of itself would lead to higher emissions at given emission coefficients. This was called the scale effect. In turn, growing incomes would lead to higher demands for environmental protection, which over time would reduce the emissions per unit of output and offset part or potentially all of the scale effect. This was called the technique effect. The NAFTA would also change the composition of the economy, that is, the division of labour in the integrated NAFTA economy. The presumption of a negative composition effect rested on the presumptions that the differences in the protection of the environment were large enough to induce a relocation of polluting sectors to Mexico, which is an empirical issue that have been studied extensively in the academic literature with mixed results.[31]

This model was extended to a general North–South trade model by Copeland and Taylor (1994), in which “North” signifies developed countries with strict standards and “South” for developing countries with lax standards. The typical result in “North–South” models is that pollution will increase at first in the South when trade and investment flows are liberalized because of the scale and composition effects but that it will fall after a certain per capita income has been reached because of the income-elastic demand for a cleaner environment and stricter regulations.

The dynamic relationship is known as the environmental Kuznets curve (EKC) after the Nobel laureate Simon Kuznets (1955), who discovered the same hill-shaped relationship between economic growth and income inequality. Specifically, income inequality tends to worsen during the first development stages and then improve gradually as a country approaches middle-income status. The empirical literature on the EKC suggests that it holds for many local pollution problems; that is, pollution problems that a country has full control over (Dinda, 2004). Whether it holds for greenhouse gases and other global environmental problems is still an open question.

30 For an excellent introduction to the trade and environment literature, including the link between globalization and climate change, see the chapter by Copeland, Shapiro, and Taylor (2022) in the Handbook of International Economics and International Trade, volume 5. The chapter includes a similar decomposition as ours, but with older data.

31 See for example the retrospective analysis of Gladstone, Liverman, Rodríguez and Santos (2021), and the references therin.

4.1 Scale, technique, and composition

Based on the conceptual framework developed by Grossman and Krueger (1993) and Copeland and Taylor (1994), we shall derive a three-way decomposition formula for the global emissions. Let j={1,2,…,45} index the 45 sectors in TIVA and i={1,2,…,67} the 66 individual countries plus the ROW region. Let $E_{j,t}$ denote the aggregate emissions in sector j in year t={1995,1996,…,2018},

(1) $$E_{j,t} = \sum_i e_{ij,t} y_{ij,t},$$

which equals the emissions per unit of output $(e_{ij,t})$ times the output $(y_{ij,t})$, summed over all countries.

Between two years, we observe changes in the emission coefficients due to technological progress and changes in the energy mix, denoted $\Delta e_{ij,t} = e_{ij,t} - e_{ij,t-1}$, and changes in the output level, denoted, $\Delta y_{ij,t} = y_{ij,t} - y_{ij,t-1}$. After some manipulations of the terms, we arrive at the following three-way decomposition of the emission growth, where $\bar{e}_{j,t-1}$ is the production weighted average emission coefficient in year *t-1*:

(2) $$\Delta E_{j,t} = \underbrace{\sum_i \Delta e_{ij,t} y_{ij,t-1}}_{technique} + \underbrace{\sum_i \bar{e}_{j,t-1} \Delta y_{ij,t}}_{scale} + \underbrace{\sum_i (e_{ij,t} - \bar{e}_{j,t-1}) \Delta y_{ij,t}}_{composition}.$$

The first term is the *technique effect* that measures the changes in the aggregate emissions resulting from the changes in the emission coefficients in each country between *t-1* and *t*, evaluated at the output levels in the previous year *t-1*. The technique effect is negative if the emission coefficients fall over time. The second term is the *scale effect* that measures the changes in the aggregate emissions associated with the changes in the output levels, evaluated at the average emission coefficient in the previous year. The scale effect is positive if aggregate production is growing. The third term is the *composition effect*, which is positive if production is growing faster in countries with above average emission coefficients and negative if output is growing faster in countries with below average emission coefficients.

Summing over all sectors, we arrive at the formula for the global decomposition of the greenhouse gases between two years:

(3) $$\Delta E_t = \underbrace{\sum_j \sum_i \Delta e_{ij,t}\, y_{ij,t-1}}_{technique} + \underbrace{\sum_j \sum_i \bar{e}_{j,t-1} \Delta y_{ij,t}}_{scale} + \underbrace{\sum_j \sum_i (e_{ij,t} - \bar{e}_{j,t-1}) \Delta y_{ij,t}}_{composition}.$$

The global formula (3) is not as clean as the sector formula (2) since it is a combination of *within*- and *between*-sector effects. The two dimensions can in principle be separated at the cost of additional interaction terms, but we leave that for future research to keep things simple. The composition effect is positive if production is growing faster in countries with above-average emission coefficients in the sectors that matters and negative if production is growing faster in countries with below-average emission coefficients.

Decomposition should be performed on output data in constant prices since the emission coefficients will otherwise trend downwards because of price inflation. The standard TIVA dataset is denominated in current prices, but the OECD also produce a dataset in previous year prices (PYPs) that allow us to calculate the real changes from year to year,

(4) $$\Delta y_{ij,t}^{PYP} = y_{ij,t}^{PYP} - y_{ij,t-1},$$

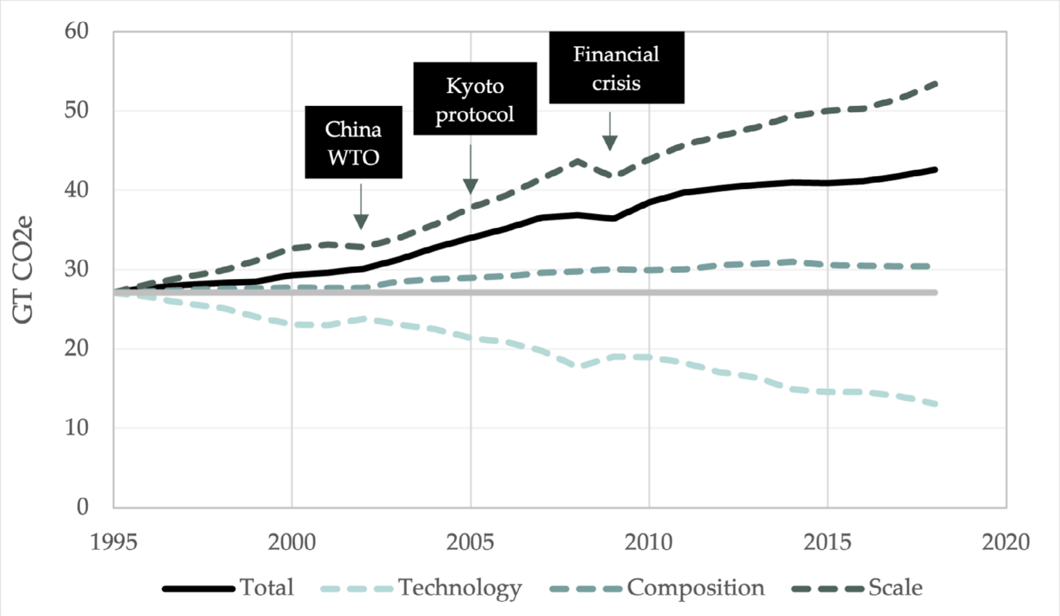
(5) $$\Delta e_{ij,t}^{PYP} = \frac{E_{ij,t}}{y_{ij,t}^{PYP}} - \frac{E_{ij,t-1}}{y_{ij,t-1}}.$$

For example, the changes between 1995 and 1996 are calculated with current prices for 1995 and previous year prices for 1996 (i.e., 1995 prices). The annual changes can then be chained to decompose the emission growth over multiple years.

4.2 Decomposition of global emissions

The decomposition of the global production emissions between 1995 and 2018 is plotted in Figure 11, excluding household emissions that are irrelevant for the issue of carbon leakage. The solid black line plots the actual emissions, and the dashed lines the three-way decomposition of the emissions. The reference value in the initial year (27.1 GT of CO2e in 1995) is marked by the grey horizontal line.

Figure 11. Decomposition of global CO2e emissions between 1995 and 2018



The *scale effect* is indicated by the dashed line with the darkest hue. The *scale* effect may be thought of as a counterfactual scenario in which production is growing without any year-to-year changes in the emission coefficients or composition of the global economy. In this scenario, the global emissions would have been twice as high in 2018 as in 1995, or 53.4 GT CO2e compared to 27.1 GT CO2e in 1995.

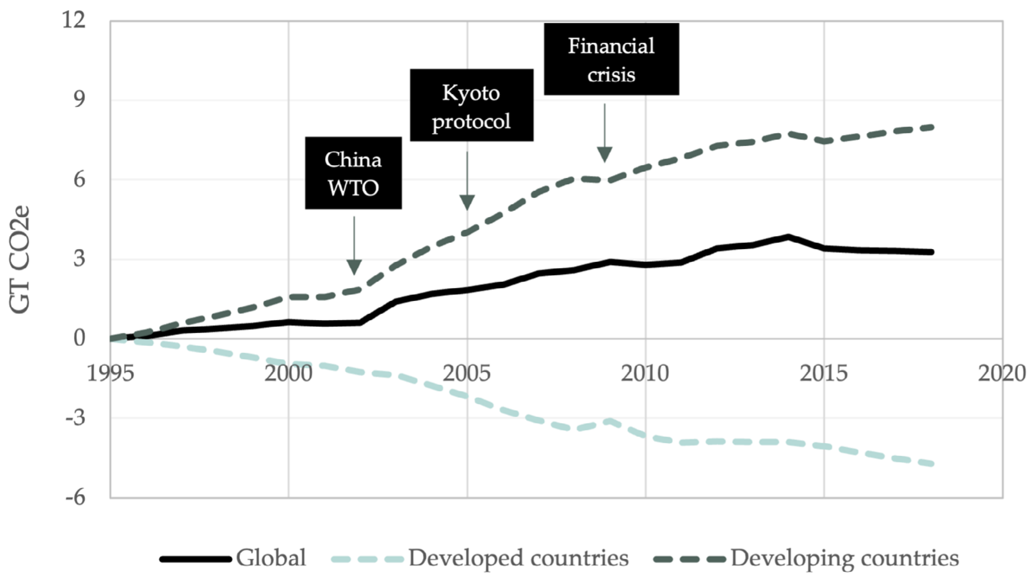
The *technique effect* is indicated by the dashed line with the lightest hue. The technique effect is pushing in the opposite direction. If it had not been for the growing scale and the changing composition of the global economy, we would already be on track to halt the climate change.

The composition effect is indicated by the dashed line with the middle hue. The annual changes were positive for most years up to 2014 and has since stabilized or even began falling somewhat.

4.2.1 Is the composition effect the same as carbon leakage?

The changing composition of the world economy contributed 3.3 GT CO2e out of the 15.5 GT CO2e growth in the global emissions between 1995 and 2018, that is, 21 percent of the net growth, which is in line with the previous estimates of the carbon leakage reported by surveys of Caron (2022) and Verde (2020), respectively. The question is whether the composition effect is one and the same as "carbon leakage" in a *causal sense or a result of other correlated* factors. That is, are the changes in the composition of the world economy driven by different climate policies or by other factors that pull in the same way, such as lower wages and higher growth in developing countries?

Figure 12. A closer look at the composition effect – cumulated changes since 1995



To analyse the causality issue, we magnified the composition effect in Figure 12 and divided it between developed and developing countries. The plot shows that the structural changes in the world economy added to the greenhouse gas emissions of developing countries and reduced the emissions of developed countries, with a net positive impact of 3.3 GT CO2e globally in 2018 compared to 1995. The pattern is thus consistent with the carbon-leakage hypothesis.

However, whether it is a *causal* relationship is debatable; that is, if firms are relocating from developed to developing countries to escape higher emission prices at home, let alone if developing countries are actively attempting to lure polluting investments by refraining from raising carbon prices. If it was a causal relationship, the carbon leakage would presumably have accelerated in approximately 2005 when the Kyoto protocol came into effect and limited the CO2 emissions of the developed countries but not the developing countries. However, we do not see any jumps in the composition effect at that time. Rather, it accelerated in 2002 after China had become a member of the World Trade Organization, which was followed by an investment boom in China, including in carbon-intensive industries. Furthermore, the composition effect has levelled off in recent years, and possibly even turned downward, which contradicts the view that the risk of carbon leakage has gone up because of diverging carbon prices, an issue we will return to in Section 5 of the paper.

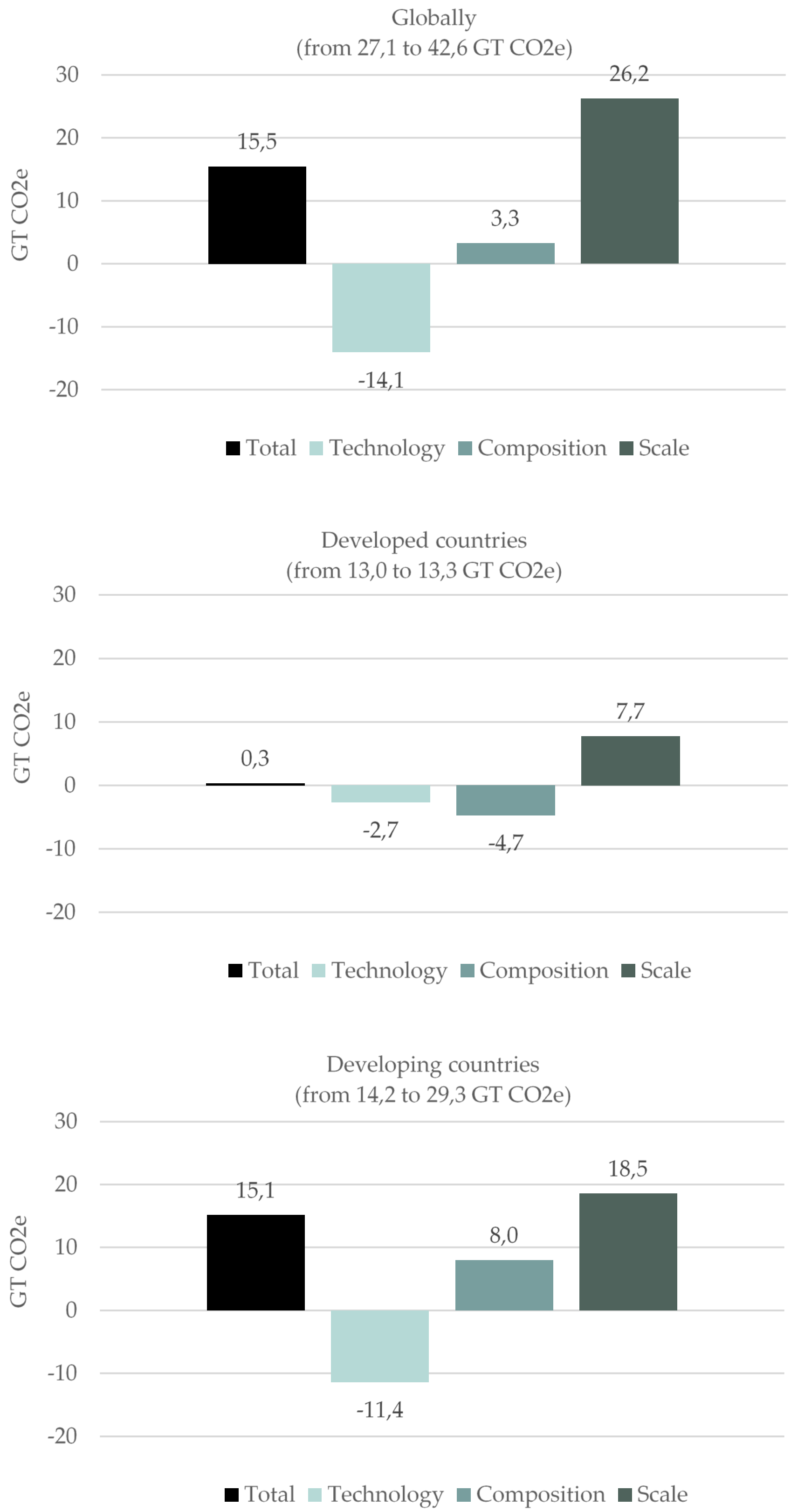
All things considered, the composition effect may not be "carbon leakage" in a *causal* sense, at least not in its entirety. It may just be a transitional phase in the development process. Indeed, the fact that the composition effect is seemingly levelling off or even turning down suggests that developing countries are travelling along the environmental Kuznets curve as the developed countries did before them. The challenge is to make the industrial transition as clean as possible through financial assistance, technological transfers, and capacity building, which incidentally are the instruments mandated by Article 4.5 of the Paris Agreement.

4.2.2 Developed versus developing countries

The decomposition of the cumulative emissions from 1995 to 2018 are shown in Figure 13. Over the studied period, global emissions increased by 15.5 GT, divided into a scale effect of +26,2 GT, a technique effect of -4.1 GT and a composition effect of +3.3 GT. A further decomposition shows that developing countries accounted for the entire increase in emissions over this period. The structural changes measured by the composition effect added 8.0 GT to the emissions of developing countries and reduced the emissions of the developed countries by 4.7 GT, with a net contribution of 3.3 GT globally.

Even if the "carbon leakage" had been *zero* over this period, global emissions would still have increased by 45 percent or by 12.2 GT CO2e in absolute terms. Thus, to halt climate change while maintaining economic growth, we must reduce the emissions per unit of output faster than the economy is growing. Carbon border adjustment measures may play a small role if they spur innovation and adoption of clean technologies, but it is not a panacea that will solve the climate crisis in and of itself. Moreover, the same effect could probably be achieved in a more cooperative way through financial assistance, technology transfers, and capacity building.

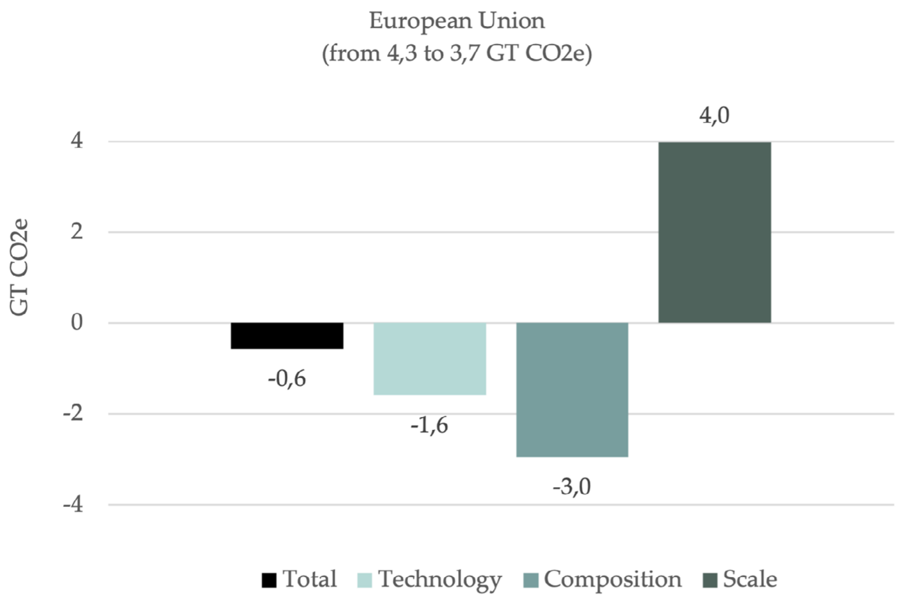
Figure 13. The drivers of CO2e emissions between 1995 and 2018



4.3 The European Union

Finally, let us have a look at the changes in the emissions of the European Union between 1995 and 2018. The EU has demonstrated that it is possible to reduce the emissions with continued economic growth by putting a price on the emissions and through other policy instruments. The annual emissions measured from the production side fell from 4.3 to 3.7 GT CO2e over this period, which is a reduction of 13.3 percent. However, as shown in Figure 14, only 35 percent of the reduction was due to reduced emission coefficients per unit of output. The other 65 percent was due to structural changes in the economy, specifically, the shift from carbon-intensive process industries to manufacturing sectors and services that are inherently less polluting. The structural change has thus helped the EU to reach its *territorial* reduction target, at the same time as the foreign emissions may inadvertently have gone up. Whether this development could have been avoided with a carbon border adjustment mechanism is an open question.

Figure 14. Decomposition of the growth in the CO2e emissions of the EU between 1995 and 2018



5. Has the risk of carbon leakage increased?

In this section, we ask whether the risk of carbon leakage has increased and therefore the need for carbon border adjustment mechanisms.

If we compare the carbon price in the EU ETS with the global average, the risk of carbon leakage would seem to have increased in the last couple of years. As shown in Figure 15, the market price for one ton of CO2e has risen sharply since 2018 and is currently trading in a range of €60 to €100 per ton in the EU ETS, compared to the global average of $6 per ton (≈ €6) according to the IMF.[32] The price gap may increase further when the fit-for-55 program is launched unless carbon prices are raised in all countries simultaneously, which is not likely given that only a handful of countries improved their offers at COP27. The competitive concerns of the EU would thus seem to be justified.

Figure 15. The market price for one ton of CO2e in the EU ETS (January 2012 - December 2022)

Source: European Energy Exchange (EEX), spot auction prices.

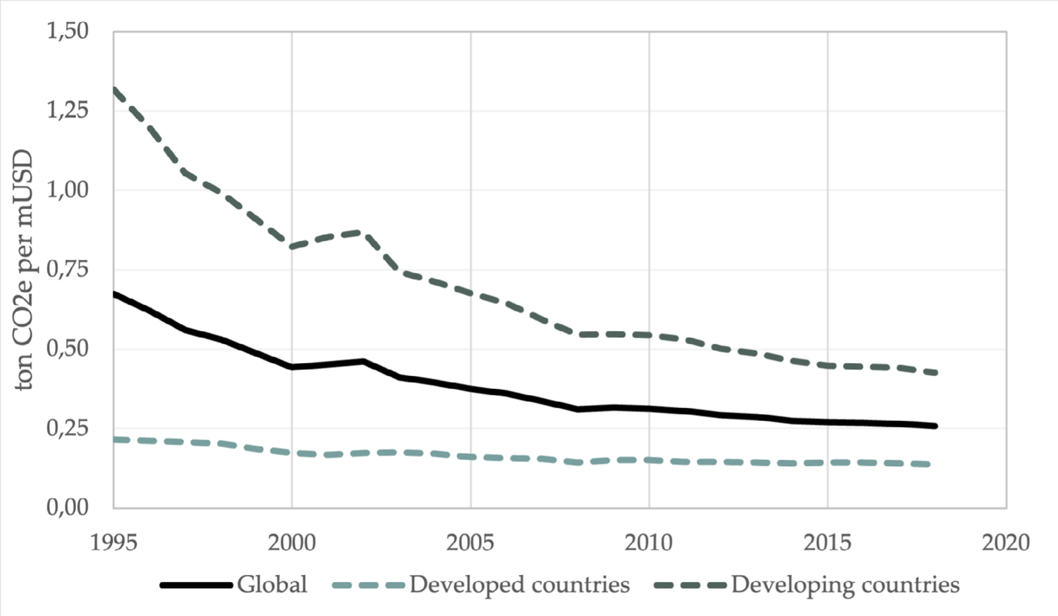
However, if we compare the emissions per unit of output in different sets of countries, the risk of carbon leakage has decreased. In fact, the emission coefficients fell more in developing countries than in developed countries over the 1995 to 2018 period, which suggests that it matters less today than before where the production is located. In this section, we will document the "convergence paradox" and explain why the emission coefficients are converging despite diverging carbon prices.

5.1 Emission coefficients are slowly converging

We begin by documenting the fall in the average emission coefficients in the world, divided between developed and developing countries. The emission coefficients per unit of output in 2018 prices are calculated by chaining the coefficients backwards from 2018 to 1995. In a few cases, the backwards deduction results in small negative coefficients that are rounded to zero. The average emission coefficients are calculated with constant 2018 output weights of each sector and country. This procedure isolates the effects of the fall in the emission coefficients from changes in the global composition of output. The result is shown in Figure 16, in which the global average emission coefficient is marked by the solid black line, the average of the developing countries by the dashed dark line, and the average of the developed countries by the dashed light line.

32 The global average is quoted from the IMF Staff Climate blog by Black, Parry, and Zhunussova (2022).

Figure 16. Average emissions per unit of output evaluated at the output composition in 2018



The average emission coefficients fell by approximately 62 percent between 1995 and 2018, or from 0.67 to 0.26 ton per unit of output in constant 2018 prices. The coefficients fell approximately twice as fast in the developing countries, which started from a higher level, or by 68 percent (from 1.32 to 0.43 ton per unit of output) compared to 36 percent (from 0.22 to 0.14 per unit of output) in the developed countries. Thus, there is still a large gap in the average emissions per unit of output. But the gap has clearly converged over time and hence also the risk of carbon leakage in the sense that a relocation of polluting industries would be less harmful today than in the past.

Table 6. CO2e emissions per unit of output in 1995 and 2018 (tons per million USD in 2018 prices)

		1995			2018		
ISIC	TIVA	WLD	IND	DEV	WLD	IND	DEV
D01T02	Agriculture, hunting, and forestry	3,45	1,38	4,22	1,09	1,00	1,12
D03	Fishing and aquaculture	0,11	0,15	0,10	0,06	0,16	0,04
D05T06	Mining and quarrying, energy producing products	0,17	0,05	0,21	0,13	0,11	0,14
D07T08	Mining and quarrying, nonenergy producing prod.	0,32	0,13	0,41	0,17	0,12	0,19
D09	Mining support service activities	0,76	0,04	1,34	0,26	0,07	0,42
D10T12	Food products, beverages and tobacco	0,19	0,06	0,31	0,04	0,04	0,04
D13T15	Textiles, textile products, leather and footwear	0,33	0,08	0,39	0,03	0,04	0,03
D16	Wood and products of wood and cork	0,27	0,08	0,46	0,04	0,04	0,04
D17T18	Paper products and printing	0,46	0,17	0,78	0,09	0,09	0,08
D19	Coke and refined petroleum products	1,32	1,20	1,43	0,59	0,49	0,68
D20	Chemicals and chemical products	1,52	0,68	2,19	0,50	0,40	0,59
D21	Pharmaceuticals, medicinal chemical and botani-cal… products	0,05	0,04	0,08	0,02	0,02	0,03
D22	Rubber and plastic products	0,60	0,23	0,98	0,31	0,08	0,54
D23	Other mineral products	4,84	1,56	6,27	1,46	0,98	1,68
D24	Basic metals	1,01	0,51	1,31	0,66	0,26	0,90
D25	Fabricated metal products	0,12	0,04	0,20	0,02	0,01	0,04
D26	Computer, electronic and optical equipment	0,09	0,03	0,12	0,01	0,01	0,01
D27	Electrical equipment	0,13	0,06	0,17	0,01	0,02	0,01
D28	Machinery and equipment, nec	0,16	0,03	0,30	0,02	0,01	0,03
D29	Motor vehicles, trailers and semitrailers	0,07	0,03	0,14	0,01	0,01	0,02
D30	Other transport equipment	0,08	0,03	0,18	0,02	0,01	0,03
D31T33	Manufacturing nec; repair and installation	0,43	0,09	0,95	0,11	0,04	0,23
D35	Electricity, gas, steam and air conditioning supply	8,34	2,78	14,28	3,22	2,00	4,53
D36T39	Water supply; sewerage, waste, and remediation activities	7,67	2,16	17,85	2,04	0,81	4,32
D41T43	Construction	0,07	0,02	0,13	0,03	0,02	0,05
D45T47	Wholesale and retail trade; repair of motor vehicles	0,06	0,03	0,13	0,02	0,01	0,02
D49	Land transport and transport via pipelines	2,24	1,43	3,19	1,53	1,16	1,95
D50	Water transport	3,68	1,12	6,59	1,27	0,77	1,83
D51	Air transport	1,79	1,21	2,59	1,08	0,97	1,25
D52	Warehousing and support activities for transporta-tion	0,10	0,05	0,22	0,07	0,03	0,16
D53	Postal and courier activities	0,18	0,08	0,38	0,06	0,07	0,06
D55T56	Accommodation and food service activities	0,05	0,05	0,06	0,01	0,01	0,01
D58T60	Publishing, audiovisual and broadcasting activities	0,02	0,01	0,04	0,01	0,00	0,01
D61	Telecommunications	0,05	0,01	0,12	0,01	0,00	0,02
D62T63	IT and other information services	0,02	0,01	0,04	0,00	0,00	0,01
D64T66	Financial and insurance activities	0,02	0,01	0,05	0,01	0,00	0,01
D68	Real estate activities	0,01	0,01	0,03	0,00	0,00	0,01
D69T75	Professional, scientific and technical activities	0,04	0,02	0,13	0,01	0,01	0,03
D77T82	Administrative and support services	0,07	0,03	0,18	0,02	0,01	0,04
D84	Public administration and defence; compulsory social security	0,06	0,06	0,06	0,03	0,03	0,02
D85	Education	0,03	0,02	0,05	0,02	0,02	0,01
D86T88	Human health and social work activities	0,02	0,01	0,06	0,01	0,01	0,01
D90T93	Arts, entertainment and recreation	0,05	0,02	0,12	0,01	0,01	0,02
D94T96	Other service activities	0,05	0,02	0,09	0,02	0,01	0,03

Table 6 provides detailed data on the convergence at the sector level. For example, the average emissions of the Electricity, gas, steam, and air conditioning supply sector (D35) fell from 2.78 to 2.00 per unit of output in developed countries (IND) and from 14.28 to 4.53 in developing countries (DEV), presumably reflecting the gradual shift from fossil-fuel to sustainable energy sources. A similar convergence pattern can be seen in other sectors, although not as pronounced as for the energy sector.

Another insight from the sector analysis is that the emission coefficients vary between different sectors, from almost no emissions in the services sector, apart from transport services, to high emissions in the power sector (in countries that generate electricity with fossil fuel). There is also a significant difference between energy-intensive process industries and other manufacturing industries, in which the latter are almost as clean as most service sectors currently. The pattern of specialization thus plays a key role in how much greenhouse gases a country emits.

5.2 EU versus the rest of the world

Let us also compare the emissions of the EU with the rest of the world, divided into other developed countries (OECD excl. EU) and developing countries. The coefficients are weighted by the output of each region in 2018. The result is presented in Figure 17. The first observation is that the average emission coefficients of the EU and other developed countries were almost identical in 1995, but that the coefficients fell slightly faster in the EU, presumably because of more stringent climate policies. However, the average gap was still very small in 2018; therefore, the motivation for the CBAM must be the gap to the developing countries, which is still significant despite the convergence in the last decades.

Figure 17. Average emissions per unit of output - EU versus the rest of the world

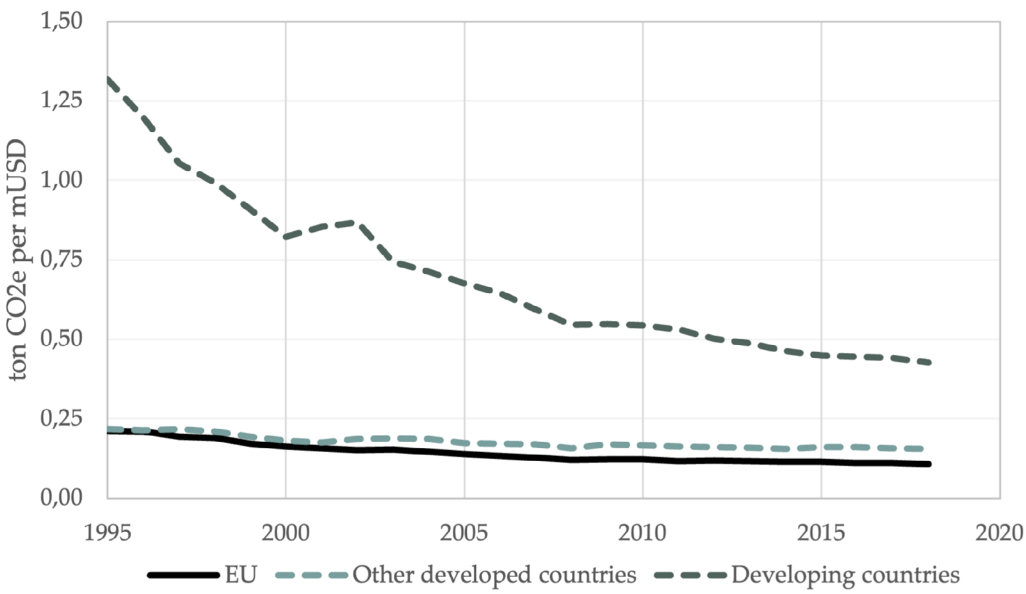


Table 7. CO2e emissions per unit of output in 1995 and 2018 – EU versus rest of the world

		1995			2018		
ISIC	TIVA	EU	OTH	DEV	EU	OTH	DEV
D01T02	Agriculture, hunting, and forestry	1,13	1,53	4,22	0,85	1,09	1,12
D03	Fishing and aquaculture	0,31	0,11	0,10	0,24	0,14	0,04
D05T06	Mining and quarrying, energy producing products	0,13	0,05	0,21	0,08	0,11	0,14
D07T08	Mining and quarrying, nonenergy producing prod.	0,21	0,11	0,41	0,11	0,12	0,19
D09	Mining support service activities	0,09	0,04	1,34	0,06	0,07	0,42
D10T12	Food products, beverages and tobacco	0,07	0,05	0,31	0,03	0,04	0,04
D13T15	Textiles, textile products, leather and footwear	0,06	0,09	0,39	0,02	0,05	0,03
D16	Wood and products of wood and cork	0,07	0,09	0,46	0,02	0,05	0,04
D17T18	Paper products and printing	0,15	0,18	0,78	0,07	0,11	0,08
D19	Coke and refined petroleum products	1,04	1,26	1,43	0,45	0,51	0,68
D20	Chemicals and chemical products	0,86	0,58	2,19	0,32	0,45	0,59
D21	Pharmaceuticals, medicinal chemical and botanical… products	0,04	0,03	0,08	0,01	0,03	0,03
D22	Rubber and plastic products	0,16	0,28	0,98	0,02	0,12	0,54
D23	Other mineral products	1,49	1,60	6,27	0,81	1,09	1,68
D24	Basic metals	0,66	0,45	1,31	0,25	0,27	0,90
D25	Fabricated metal products	0,05	0,03	0,20	0,01	0,02	0,04
D26	Computer, electronic and optical equipment	0,04	0,03	0,12	0,01	0,00	0,01
D27	Electrical equipment	0,06	0,06	0,17	0,01	0,02	0,01
D28	Machinery and equipment, nec	0,03	0,02	0,30	0,01	0,01	0,03
D29	Motor vehicles, trailers and semitrailers	0,05	0,02	0,14	0,01	0,01	0,02
D30	Other transport equipment	0,03	0,03	0,18	0,01	0,01	0,03
D31T33	Manufacturing nec; repair and installation	0,06	0,11	0,95	0,02	0,05	0,23
D35	Electricity, gas, steam and air conditioning supply	2,52	3,00	14,28	1,00	2,81	4,53
D36T39	Water supply; sewerage, waste, and remediation activities	1,71	2,70	17,85	0,48	1,20	4,32
D41T43	Construction	0,02	0,02	0,13	0,01	0,02	0,05
D45T47	Wholesale and retail trade; repair of motor vehicles	0,04	0,02	0,13	0,01	0,01	0,02
D49	Land transport and transport via pipelines	1,01	1,69	3,19	0,96	1,28	1,95
D50	Water transport	0,82	1,38	6,59	0,63	0,89	1,83
D51	Air transport	0,63	1,50	2,59	0,62	1,14	1,25
D52	Warehousing and support activities for transportation	0,07	0,04	0,22	0,03	0,02	0,16
D53	Postal and courier activities	0,07	0,08	0,38	0,03	0,09	0,06
D55T56	Accommodation and food service activities	0,02	0,06	0,06	0,01	0,01	0,01
D58T60	Publishing, audiovisual and broadcasting activities	0,02	0,01	0,04	0,01	0,00	0,01
D61	Telecommunications	0,03	0,01	0,12	0,00	0,00	0,02
D62T63	IT and other information services	0,01	0,01	0,04	0,00	0,00	0,01
D64T66	Financial and insurance activities	0,01	0,01	0,05	0,00	0,01	0,01
D68	Real estate activities	0,01	0,01	0,03	0,00	0,00	0,01
D69T75	Professional, scientific and technical activities	0,02	0,01	0,13	0,01	0,01	0,03
D77T82	Administrative and support services	0,02	0,03	0,18	0,01	0,01	0,04
D84	Public administration and defence; compulsory social security	0,02	0,07	0,06	0,01	0,04	0,02
D85	Education	0,01	0,02	0,05	0,01	0,02	0,01
D86T88	Human health and social work activities	0,02	0,01	0,06	0,01	0,01	0,01
D90T93	Arts, entertainment and recreation	0,02	0,02	0,12	0,01	0,01	0,02
D94T96	Other service activities	0,02	0,02	0,09	0,01	0,01	0,03

The average emission coefficients per sector are shown in Table 7. The data show that the emission coefficients in the EU are slightly lower than those of other developed countries (OTH) in most sectors and significantly lower than those of developing countries (DEV).[33] However, the absolute gap has been reduced over time in most sectors, including in the CBAM sectors marked by red boxes. Thus, there is little evidence that the risk of carbon leakage has increased, at least up to 2018.

5.3 The convergence paradox

How do we explain the "convergence paradox", that is, that emission coefficients are converging at the same time as emission prices are diverging?

One reason may be that countries that do not price emissions directly use other tools for the same purpose, for example, direct regulations of emissions and public incentives for sustainable energies. Another reason may be that the first steps in the climate transition may not cost very much since there are many "low-hanging fruits" to pick in the carbon tree for countries that are behind. For leading countries, the only remaining fruits are the "high-hanging fruits" at the top of the tree, and these are more costly to pick and require significantly higher carbon prices to incentivize the firms.

A corollary of the convergence paradox is that the comparison between countries should be based on *carbon-price equivalents* of all policy measures rather than just the carbon price to be even-handed. The OECD has developed a methodology for comparing countries that use different policy mixes to reduce emissions,[34] divided into

- market-based instruments (carbon taxes and emission trading),
- nonmarket-based instruments (e.g., emission standards), and
- technology support policies (e.g., research and development grants and financial support for renewable energies).

This method is more cumbersome than simply comparing carbon prices, but it may be necessary to satisfy the legal requirements of the WTO. As the final regulation of the CBAM was yet to be published at the time this report went into press, we cannot say with certainty whether the EU will allow adjustment for nonmarket-based instruments and technology support polices in the calculations of the carbon duties.

33 The main exception is fishing and aquaculture, presumably because of the distant-water fleet of the EU that fish outside Africa, South America and other distant waters, thus consuming a lot of fossil fuels.

34 Kruse, Dechezleprêtre, Saffar, and Robert (2022).

6. All things considered

In the title of this paper, we ask if the risk of carbon leakage justifies the CBAM. In the end, this is a matter of judgment. Looking back at the 1995 to 2018 period, we cannot detect any clear-cut signs of carbon leakage. True, polluting industries have grown disproportionally in developing countries with higher emission coefficients, but that started before the first commitment period of the Kyoto protocol that imposed binding emission targets on the developed countries. The reason may simply be that rapidly growing economies such as China and India need steel and cement to build the economy and fertilizers to feed the growing population. To produce bulky goods locally may be more sensible than to import them from faraway destinations, especially considering the transport emissions.

Moreover, our analysis shows that the emission coefficients have begun to converge despite the divergence in carbon prices, which indicates that the risk of carbon leakage is no greater than before, possibly less. But then again, this may change if the fit-for-55 program of the EU is not matched by other countries, which may be hard to achieve under the Paris Agreement that depends on voluntary contributions.

The main challenge for the global community is that the technology to produce without CO2 emissions is not keeping up with the growing scale of the world economy. This is where the focus ought to be, that is, on green innovations and diffusion of climate friendly technologies. Yet, the perceived risk of carbon leakage must be managed somehow. Otherwise, it may not be politically feasible for the EU and other developed countries to take the lead, as is stipulated in the Paris Agreement.

When the CBAM is introduced, imports are likely to decrease due to the administrative burden, even if emission prices are not prohibitive. If the border adjustments are seen as a protectionist measure as opposed to an environmental measure, tensions may arise in the global trade system. It is therefore important to anchor the proposal in the WTO and in the climate negotiations.

The OECD Secretary-General, Mathias Corman, has suggested that negotiations begin on an international framework for carbon pricing and border adjustments to avoid conflicts arising over trade-related climate measures.[35] The negotiations could also include climate subsidies of the type that the US intends to introduce in the Inflation Reduction Act[36] and which is now being considered also by the EU to level the playing field.[37] The OECD has offered to take the lead in this process in the same way as it did in the negotiations on a minimum tax on multinational companies to avoid harmful tax competition.[38] A starting point for these talks could be the principles defined by Cosbey (2021).

The climate crisis can only be solved through international cooperation.

35 *Financial Times,* 13 September 2021, “OECD seeks global plan for carbon prices to avoid trade wars”.
36 https://www.whitehouse.gov/cleanenergy/inflation-reduction-act-guidebook/
37 https://www.euractiv.com/section/economy-jobs/news/the-geoeconomics-of-europes-answer-to-the-us-inflation-act/
38 https://www.oecd.org/tax/international-community-strikes-a-ground-breaking-tax-deal-for-the-digital-age.htm

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