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Economy and international financing

CO_2 emissions embodied in international trade

This article examines international trade from the perspective of the carbon dioxide (CO_2) emissions generated by the production and distribution of traded goods and services. It takes account of both the CO_2 produced within a country's national territory via its domestic output, and those emissions embodied in its exports or imports. China, for example, is a net exporter of CO_2 emissions while the United States is a net importer. More generally, advanced economies consume more CO_2 than they emit, while the opposite is true for emerging economies or commodity producers. These divergences are mainly attributable to the sectoral composition of countries' trade flows. Other factors that influence a country's CO_2 emissions are its scale (economic or population size), the emissions efficiency of its productive apparatus, and the degree to which it is integrated into global value chains.

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JEL codes
F15, F18,
F64

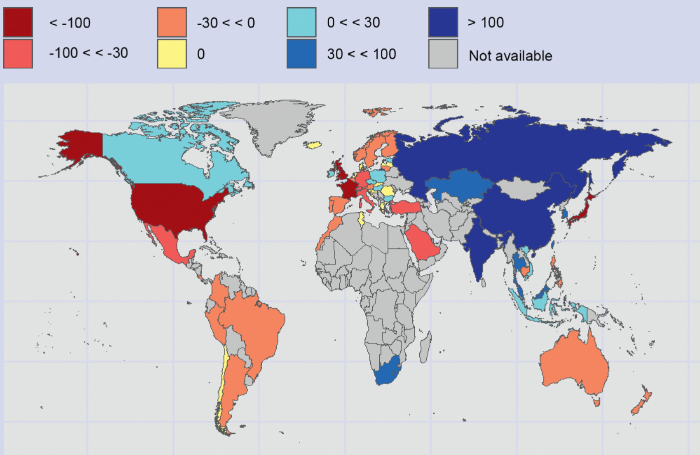
¼
CO_2 emissions associated with the production and distribution of traded goods and services (8 billion tonnes) as a share of total global emissions (32 billion tonnes) in 2015

24%
share of these emissions produced (exported) by China

15%
share of these emissions consumed (imported) by the United States

32%
share of global trade-embodied CO_2 emissions generated by the "energy and waste" sector

Trade balance in CO_2 emissions in 2015
(millions of tonnes)



Source: Organisation for Economic Co-operation and Development (OECD) inter-country input-output (ICIO) database, 2018 edition, and trade in embodied CO_2 database ($TECO_2$); authors' calculations.
Key: France has a CO_2 trade deficit of over 100 million tonnes, meaning that it imports 100 million tonnes of CO_2 more than it exports.

This article examines international trade from the perspective of the carbon dioxide (CO_2) emissions generated by the production and distribution of traded goods and services, rather than from the standard monetary value-based perspective. It takes account of the CO_2 emitted along the entire chain of production and distribution of exports and imports.

CO_2 emissions have become the main target of the climate agreements signed to limit global warming. The central goal of the Paris Agreement,[1] for example, is to keep the global temperature rise this century to below 2°C, by limiting and then reducing individual countries' greenhouse gas emissions.

The main statistical measure taken into account in these agreements is the emissions produced within a country's national territory, which are linked, among other things, to the domestic output of goods and services.[2] This measure differs from the real carbon footprint generated by a country's final demand – in other words by its standard of living. More specifically, it takes account of the emissions caused by the country's production of exports, which are in fact consumed abroad, but fails to take into account the emissions generated abroad by the imports it consumes domestically. As a result, national emissions do not provide an accurate picture of a country's actual carbon footprint since a portion of its output is exported, and a portion of its demand is satisfied by imports (David and Caldeira 2010).[3]

The emissions embodied in trade (around 8 billion tonnes in 2015) account for a quarter of total global emissions (approximately 32 billion tonnes). Thus, China's total domestic emissions (9.1 billion tonnes in 2015) differ from its actual carbon footprint (8 billion tonnes) by the amount of its CO_2 trade surplus (1.1 billion tonnes). This gap reflects the fact that a large share of the CO_2 produced in China goes towards satisfying foreign demand. Conversely, the United States' CO_2 trade deficit (–0.7 billion tonnes) needs to be added to its total domestic emissions (5.1 billion tonnes) in order to determine its total footprint (5.8 billion tonnes). More generally, advanced countries are net importers of CO_2 emissions, whereas emerging or commodity-producing countries are net exporters.

These gaps are influenced by the sectoral composition of each country's trade flows. The four most polluting sectors are responsible for more than three quarters of the total emissions embodied in global trade. As a result, countries specialising in these sectors or using them intensively as sources of inputs for their domestic production emit higher quantities of CO_2.

BOX 1

Details of the data used

The data used in this article cover all emissions stemming from the burning of fossil fuels in the production and distribution of traded goods and services (see Appendix 2 for methodology). These account for nearly all global CO_2 emissions and around two thirds of global greenhouse gas emissions (in CO_2 equivalent). They do not include emissions from industrial processes other than energy production (e.g. manufacture of cement) and LULUCF (land use, land-use change and forestry), or emissions of other greenhouse gases such as methane (CH_4), nitrous oxide (N_2O), and fluorinated gases (hydrofluorocarbon (HFC), perfluorocarbon (PFC) and sulphur hexafluoride (SF_6)).

Data in the article are constructed from three sources compiled by the Organisation for Economic Co-operation and Development (OECD): the trade in embodied CO_2 database (TECO$_2$), the trade in value added database (TiVA), and the inter-country input-output database (ICIO; Wiebe and Yamano, 2016).

1 United Nation's Framework Convention on Climate Change – UNFCC (2015).

2 To which are added direct household emissions. These mainly consist of residential emissions (e.g. use of gas for cooking) and direct emissions linked to private road transport (consumption of oil products).

3 A country's carbon footprint is the amount of greenhouse gas emissions associated with its domestic final demand (consumption by households, general government and non-profit institutions, and investment), regardless of whether the consumed goods and services are produced domestically or abroad.

This phenomenon is amplified by the rise of global value chains, which break production down into its different stages and encourage the offshoring of certain activities. This means that a share of the CO_2 exported by a country may be emitted abroad upstream in the value chain.

Moreover, international climate commitments may also contribute to the phenomenon. Emissions targets differ by country, which can provide an incentive to offshore highly polluting activities (Peters et al.; 2011).

1 China and the United States: the main contributors to global trade measured in CO_2 emissions

The CO_2 emissions embodied in international trade refers to all CO_2 emitted throughout the production and distribution of traded goods and services (see Appendix 2 for methodology). These emissions amounted to 8 billion tonnes in 2015, or a quarter of total global emissions (32.3 billion tonnes; International Energy Agency – IEA, 2015).

Total trade-embodied CO_2 emissions have increased by 10% since 2005, although there have been significant fluctuations over the period. This rise is modest compared with the 60% growth seen in global trade in monetary value terms.[4]

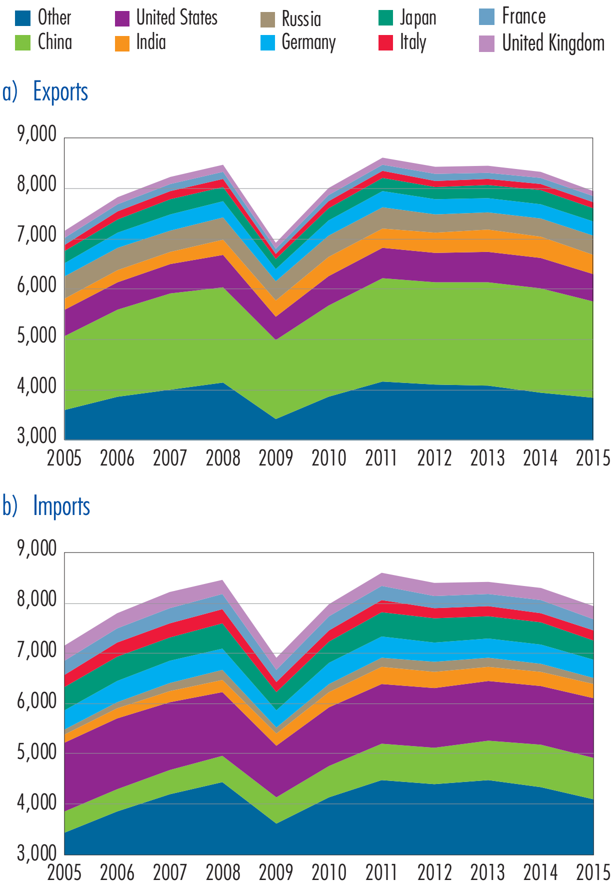
China is undeniably the biggest global exporter of CO_2, accounting for 24% of total trade-embodied emissions in 2015 compared with 20% in 2005. The next largest exporters are the United States (7%), India (5%), Russia (5%) and Germany (4%).

Similarly, the biggest importers are the world's major economies. The United States is the largest market, absorbing 15% of traded CO_2 in 2015, while China is the second-largest with 10%. This latter share has increased by 76% since 2005. The next largest importers are Japan (5%), Germany (5%) and India (4%).

The evolution of trade flows as measured by CO_2 is linked to the evolution of the monetary value of trade, as illustrated by the sharp drop in trade in 2009 during the global financial crisis (Cabrillac et al., 2016) (see Box 2). However, CO_2 emissions also depend on the carbon efficiency of a country's productive apparatus, in other words the quantity of emissions required to produce one unit of value added (see Box 3). Carbon efficiency has increased considerably: the average nominal carbon intensity of global export production declined by 31% over the 2005-15 period (see Appendix 1).[5]

C1 Geographical breakdown of trade-embodied CO_2 emissions

(millions of tonnes)



Source: OECD inter-country input-output (ICIO) database, 2018 edition, and trade in embodied CO_2 database (TECO$_2$); authors' calculations.
Note: CO_2 emissions resulting from the combustion of fossil fuels, excluding LULUCF (land use, land-use change and forestry), non-energy related industrial processes and the other main greenhouse gases.

4 Organisation for Economic Co-operation and Development (OECD) inter-country input-output (ICIO) database.
5 The change in nominal terms is attributable to the improvement in carbon efficiency per unit of value added and the change in prices.

BOX 2

Emissions corrected for scale effect

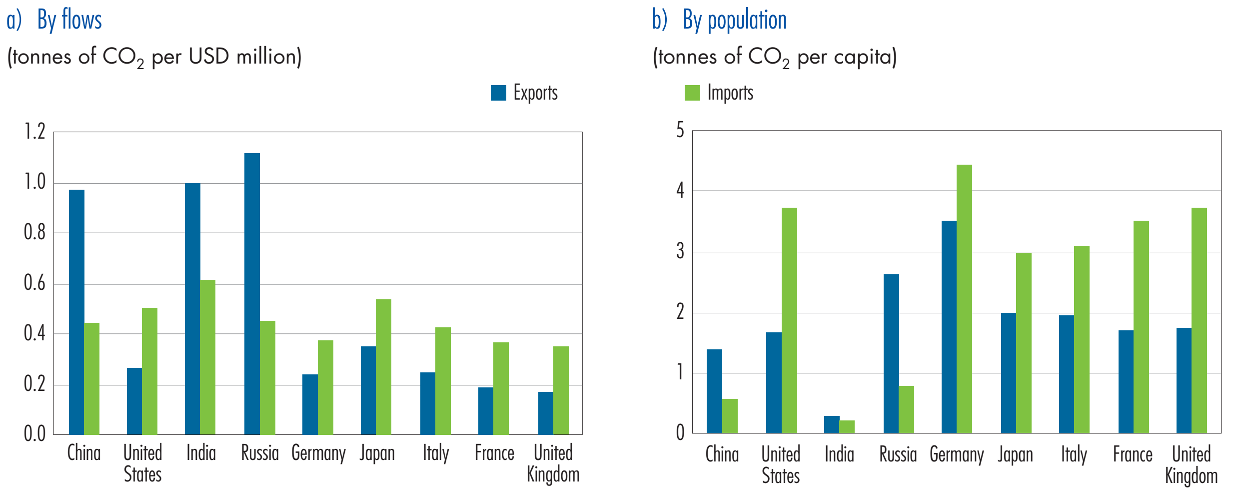
One of the main reasons why CO_2 emissions vary across countries is their difference in size (size of the economy or population). This is because the size of export and import flows in monetary value terms directly affects the amount of CO_2 they contain. Similarly, the size of a country's population also affects the amount of its emissions. To obtain a measure corrected for these factors, this box calculates the emissions for the countries in our sample adjusted for the size of trade flows and of population.

Advanced countries' exports are less CO_2-intensive than their imports. This indicates that their productive apparatus emits less CO_2 than that of their trading partners. The opposite is true for other countries in the sample – in other words their imports emit less CO_2 than their exports.

More generally, emissions linked to exports are more heterogeneous across countries than those linked to imports. This can be attributed to greater export specialisation, whereas imports are more homogeneous (Cezar et al., 2017).

Measured per capita, advanced countries' contributions to trade-embodied CO_2 emissions are considerably higher than those of other countries. This is true for both imports and exports, although it is more marked for imports. Germany has the highest CO_2 emissions per capita, at close to 4 and 4.5 tonnes respectively for exports and imports.

CO_2 content of global trade corrected for scale effect



Sources: World Bank and OECD inter-country input-output (ICIO) database, 2018 edition, and trade in embodied CO_2 (TECO$_2$) database; authors' calculations.
Note: CO_2 emissions resulting from the combustion of fossil fuels, excluding LULUCF (land use, land-use change and forestry), non-energy related industrial processes and the other main greenhouse gases.

2 Advanced economies: large centres of consumption and hence net CO_2 importers

A country's CO_2 emissions can be measured either by considering its domestic supply, in other words its domestic output (or effective emissions), or by considering its domestic demand, in other words the CO_2 consumed in the country (or its carbon footprint). The difference between these two measures is equal to the country's CO_2 trade balance, which reflects the difference between its output and consumption of this greenhouse gas.

Large advanced economies are large net consumers of CO_2. They consume more CO_2 than they produce, and as a result generate a CO_2 trade deficit. Their total footprint thus exceeds the amount of their effective emissions. Conversely, emerging and commodity-producing economies are net exporters of CO_2, which means their footprint is smaller than their effective emissions (see Chart 2).

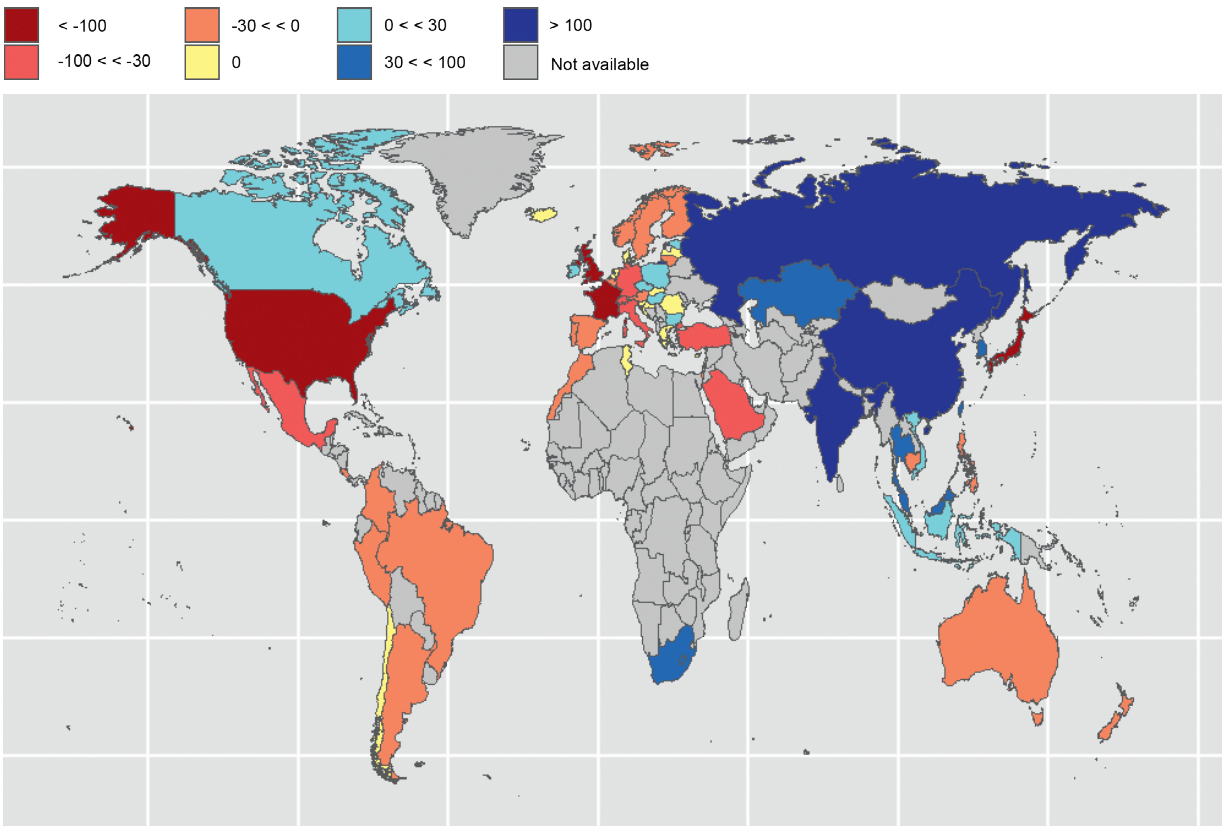
Germany and Japan's CO_2 trade balances provide a good illustration of this phenomenon. Despite running a trade surplus in monetary value terms (8.6% and 3.1% of GDP respectively), both countries have a trade deficit in CO_2 emissions (their output of CO_2 is lower than their total footprint), meaning that they are net importers of CO_2. Conversely, India and South Africa have a CO_2 trade surplus despite running a trade deficit in monetary value terms (–1.1% of GDP for India and –4.6% of GDP for South Africa).

The United States has the highest CO_2 trade deficit (–667 million tonnes of CO_2 in 2015), although it has declined since 2005 (–850 million tonnes). This deficit has to be added to the total amount of US effective CO_2 emissions (5.1 billion tonnes) in order to calculate the country's total carbon footprint (5.8 billion tonnes). The countries with the next largest CO_2 trade deficits are the United Kingdom (–130 million tonnes), Japan (–126 million tonnes) and France (–121 million tonnes). Next in line are Germany (–75 million tonnes) and Italy (–70 million tonnes).

At the other end of the scale, the countries with the largest surpluses (net CO_2 exporters) are China (1,094 million tonnes in 2015), Russia (266 million tonnes), India (103 million tonnes) and South Africa (94 million tonnes). The difference between China's effective emissions (9.1 billion tonnes in 2015) and its carbon footprint (8 billion tonnes) is thus equal

C2 Trade balance in CO_2 emissions in 2015

(millions of tonnes)



Source: OECD inter-country input-output (ICIO) database, 2018 edition, and trade in embodied CO_2 (TECO$_2$) database; authors' calculations.
Note: CO_2 emissions resulting from the combustion of fossil fuels, excluding LULUCF (land use, land-use change and forestry), non-energy related industrial processes and the other main greenhouse gases.

to its CO_2 trade surplus (1.1 billion tonnes). This gap reflects the fact that a significant share of the CO_2 emitted in China goes towards satisfying foreign demand.

One of the main causes of differences between countries is the energy sources they use – countries relying more intensively on fossil fuels generate more pollution (Davis and Caldeira, 2010). Disparities between countries can also be explained by the energy efficiency of their productive apparatus (see Box 3), the degree to which they are integrated into global value chains (see Box 4) and the sectoral structure of their trade flows (see Section 5). This sectoral specialisation is conditioned by transport costs (Shapiro, 2016).

In addition, differences in national legislation can lead to the offshoring (carbon leakage) of high-emission activities. Under the 1992 Rio Convention, responsibility for global warming was split between individual countries according to the "common but differentiated responsibilities" principle. Advanced economies were asked to put in place stricter standards for emissions reductions, which in some cases had the knock-on effect of causing them to shift manufacturing abroad (Peters et al. 2011).

BOX 3

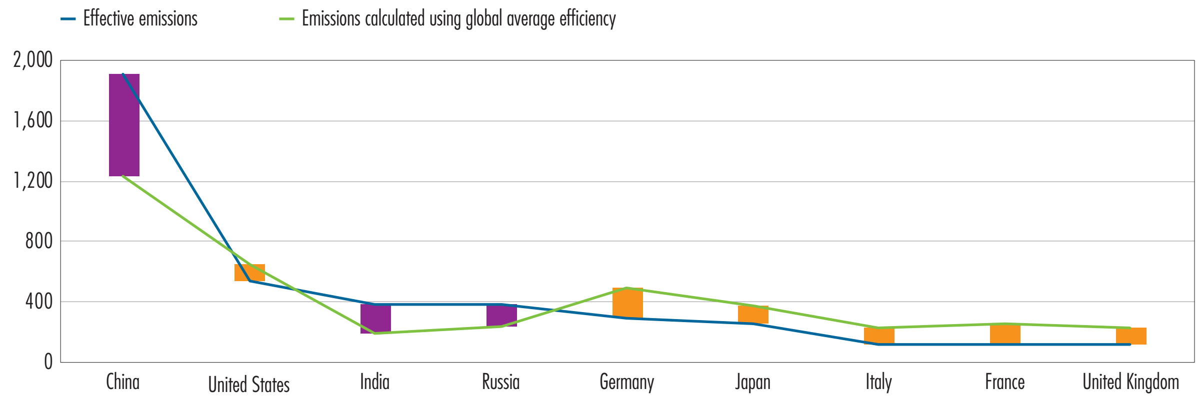
Efficiency of productive systems

A country's trade balance in CO_2 emissions reflects both the size of its trade flows in monetary value terms and the efficiency of its productive systems in terms of emissions per unit of exported value added. In the case of two countries with the same structure of production, the amount of CO_2 they trade will vary according to this emissions efficiency. For example, the emissions associated with the manufacture of one unit of the same good (a Bic ballpoint pen for example) will differ according to each country's individual characteristics.

In this box, we use a counterfactual scenario to identify the respective contributions of these factors to CO_2 exports (Kander et al., 2015). The scenario consists in estimating what each country's emissions would be if the efficiency of the productive apparatus of each sector involved in its output were equal to the global average. The sectoral distribution of each country's exports is therefore left unchanged, but we apply the same level of emissions efficiency to each country.

Effective and simulated CO_2 emissions in 2015

(millions of tonnes)



Sources: OECD inter-country input-output (ICIO) database, 2018 edition, and trade in embodied CO_2 (TECO$_2$) database; authors' calculations.
Key: If the efficiency of the United States' productive technology were in line with the global average, its exports would generate 646 million tonnes of emissions, i.e. 20% more than they actually do.

…/…

Thus, any emissions divergences between countries under our counterfactual scenario (red line) reflect only the sectoral distribution of each country's output and the size of its export flows (in terms of monetary value). Moreover, for each individual country, any difference between our counterfactual scenario and their effective emissions (gap between the blue and green lines) stems from the efficiency of their productive apparatus (see Appendix 2, "Counterfactual" section).

The CO_2 emissions efficiency of China's productive apparatus is low compared with the global average. Under our counterfactual scenario, its emissions would be 1.2 billion tonnes, compared with an effective export level of 2.0 billion tonnes. India and Russia's productive apparatus also shows some room for improvement in terms of CO_2 emissions. By contrast, the efficiency of the productive apparatus of the other countries in our sample is above the global average.

The divergences identified may also be attributable to other factors, however. Output data show the value and not the volume of exports. Thus, the results may also be explained by divergences in volume to price ratios (e.g. some countries are exporters of consumer goods while others specialise in "high-end" goods). In addition, the types of activity grouped together into individual sectors may differ according to the sectoral breakdown used. Therefore, using an average level of efficiency is only relevant if we assume that each country applies a similar sectoral breakdown (e.g. the "transport equipment" sector includes automobiles, aeronautics, trains, ships, etc.).

3 China is responsible for more than half the rise in CO_2 emissions between 2005 and 2015

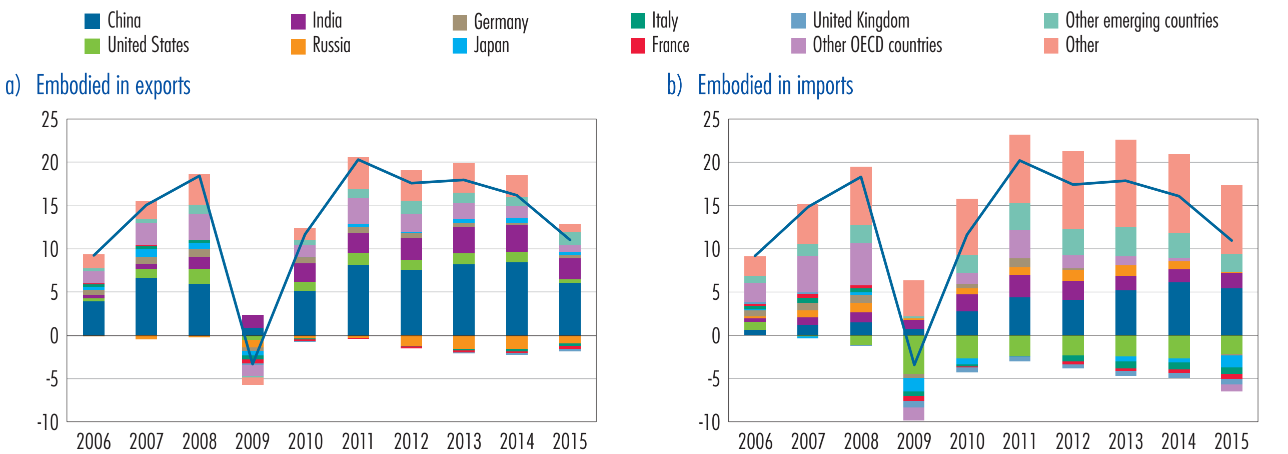
To understand the factors underlying the aggregate change in CO_2 emissions, we break down export and import flows according to their geographical origin.

With regard to exporting countries (see Chart 3), the majority of the rise in trade-embodied CO_2 over the period 2005-15 (11% growth) is found to have stemmed from China (6 percentage-point contribution to the rise) and India (2 percentage points), followed by other emerging countries (1.5 percentage points), and the rest of the sample (1 percentage point).

Among the advanced economies, the largest negative contributions to the change in total exported emissions are from Italy (–0.25 percentage point), the United Kingdom (–0.27 percentage point) and France (–0.35 percentage point) are the largest contributors to the fall in total exported emissions. By contrast, Germany and the United States both make a positive contribution (0.4 percentage point respectively), as does Japan (0.3 percentage point).

C3 Geographical breakdown of the cumulative change in CO_2 emissions

(% change; 2005 = 0)



Source: OECD inter-country input-output (ICIO) database, 2018 edition, and trade in embodied CO_2 ($TECO_2$) database; authors' calculations.
Note: See appendix for details of the countries included in the geographical zones.

Russia is a particularly strong negative contributor to the change in emissions (–1 percentage point), largely owing to the decline in its exports since 2012.

On the import side (see Chart 3b), the results are more mixed. Although Chinese and Indian demand both make significant positive contributions to the aggregate rise in traded CO_2 emissions (6 percentage points and 2 percentage points respectively), the largest contribution comes from the "Others" category (8 percentage points). Within this category, the major contributors are Saudi Arabia and South-East Asian countries (Vietnam, the Philippines and Thailand).

Conversely, advanced economies are found to have contributed negatively to aggregate CO_2 imports. The United States is the largest contributor (–2 percentage points), followed by Japan (–1.3 percentage points), Italy (–0.8 percentage point), the United Kingdom and France (–0.6 percentage point respectively).

BOX 4

CO_2 emissions and global value chains

The fragmentation of production across global value chains has led to a rise in the import content of global exports since the 1990s (Cezar, 2016). As a result, part of the CO_2 emitted during the manufacture of a country's exports in fact stems from a third-party country located upstream in the value change. The share of CO_2 in a country's exports that is produced abroad ranges from 5% for Russia to 47% for Italy (see Chart CA).

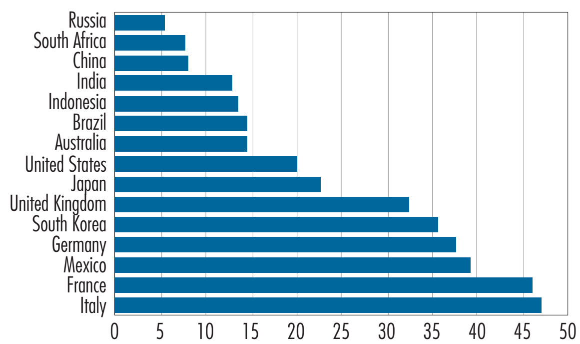
The share of foreign-produced CO_2 contained in a country's exports depends on the degree to which it is integrated into global value chains. Thus, those countries that are most integrated into the European value chain (Italy, France, Germany and the United Kingdom), or into other value chains (Mexico with its *maquiladoras*[1] or South Korea) have a high share of imported CO_2 in their exports. In addition, these countries tend to produce less pollution than their trading partners (see Box 3), contributing to an increase in the proportion of foreign emissions in their exports. Conversely, countries that are less integrated into global value chains and that produce relatively high levels of emissions have lower shares of imported CO_2 in their exports (Russia, South Africa and India).

Thus, the quantity of imported CO_2 does not accurately reflect a country's demand (and hence its carbon footprint) as part of this CO_2 is re-exported. In the case of South Korea, for example, 41% of imported CO_2 is exported, while for the United States the share is 9%. The differences between countries stem largely from their degree of integration into global value chains and the dynamics of their domestic market.

CO_2 that is imported and subsequently re-exported is recorded in a country's export flows. As a result, emissions may be counted more than once under the standard measures of trade used here. Taking into account only domestic emissions, and thus cancelling out the multiple

CA Share of imported emissions in exports in 2015

(%)



Source: OECD inter-country input-output (ICIO) database, 2018 edition, and trade in embodied CO_2 ($TECO_2$) database; authors' calculations.

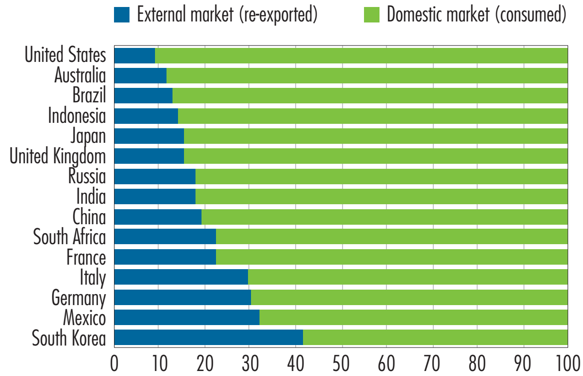
1 Factories that assemble imported goods, duty and tariff-free, and export the finished products.

…/…

border crossings linked to global value chains, the global CO_2 emissions embodied in world trade amount to 6.2 billion tonnes (compared with 8 billion under standard measures), and the contributions of each country change. For example, the CO_2 exported by France and actually emitted domestically amounts to 63 million tonnes compared with 114 million tonnes if all countries upstream in its global value chains are taken into account.

CB Use of CO_2 contained in imports in 2015

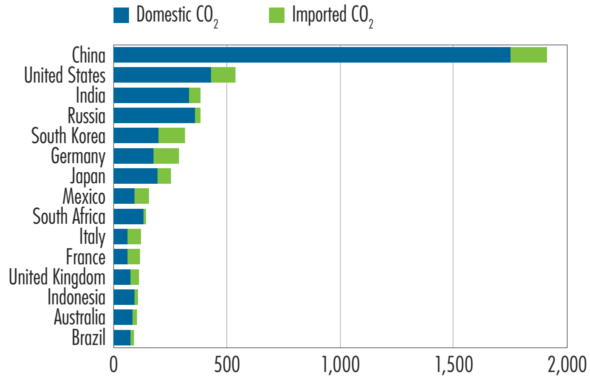
(%)



Source: OECD inter-country input-output (ICIO) database, 2018 edition, and trade in embodied CO_2 (TECO$_2$) database; authors' calculations.

CC Origin of exported CO_2 in 2015

(millions of tonnes)



Source: OECD inter-country input-output (ICIO) database, 2018 edition, and trade in embodied CO_2 (TECO$_2$) database; authors' calculations.

4 The "energy and waste", and "basic metals" sectors produce more than half the CO_2 emissions embodied in international trade…

The "energy and waste" sector is the largest global emitter of CO_2 as it provides intermediate inputs to other industries and thus contributes indirectly to their emissions. It is the source of close to 32% of the CO_2 emissions embodied in global exports. By contrast, it only makes a small contribution to direct exports due to difficulties in the transmission and distribution of energy and waste-related products and services.

Indeed, the sectoral breakdown of emissions can be measured either by direct exporting sector or by sector of origin. Direct emissions are those contained in the export flows of exporting sectors, and thus include the emissions produced by these sectors and those produced by all other sectors upstream in their production chain. Emissions by sector of origin measure the quantity of CO_2 produced by a given sector, regardless of its position in the production chain. They are exported directly by the sector itself, or indirectly via another sector (see Appendix 1 for sectoral aggregates).

After energy, the sectors of origin with the highest emissions are "basic metals" (18%), "transportation and storage" (14%) and "agriculture, mining and quarrying" (10%). Together, these four sectors are responsible for more than three quarters of global trade-embodied emissions. The other main contributors are "coal and petroleum products (refined and plastic)", "chemicals and pharmaceuticals" and "other manufacturing".

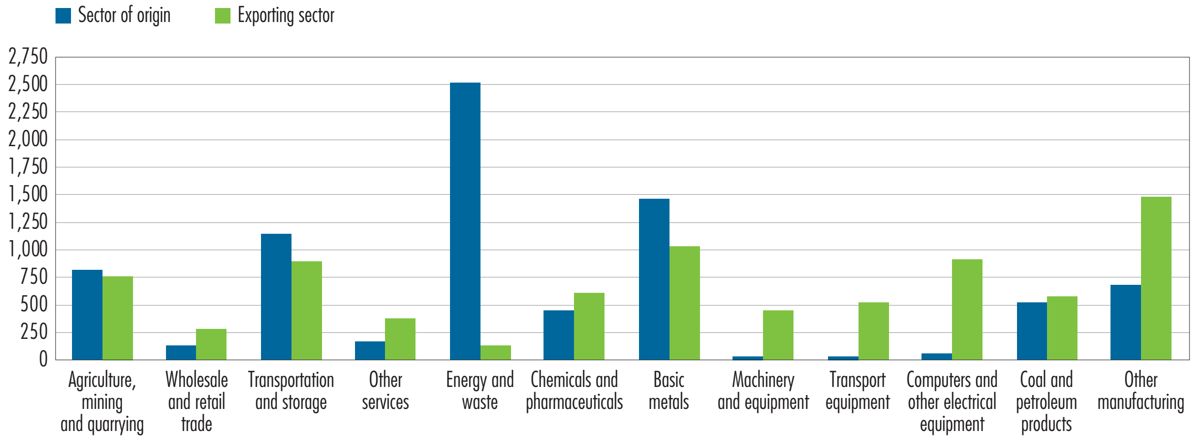
Services sectors have an asymmetrical profile, with emissions concentrated in the transportation sector, which includes road, air, maritime and rail transport when used as inputs in manufacturing.[6] Wholesale and retail trade directly export high levels of emissions, but are the original source of low levels of emissions as the CO_2 is mainly produced during transportation. The other categories of services emit very low levels of CO_2.

In terms of direct exports, the manufacturing sectors are responsible for the majority of the emissions embodied in global trade. "Transportation and storage" and "agriculture" are also major contributors.

6 As opposed to private transport which is not included in international trade statistics.

C4 Breakdown by sector of CO_2 emissions embodied in global trade in 2015

(millions of tonnes of CO_2)



Source: OECD inter-country input-output (ICIO) database, 2018 edition, and trade in embodied CO_2 ($TECO_2$) database; authors' calculations.
Key: The emissions associated with oil, for example, are allocated to different sectors depending on the stage of production and use: emissions from extraction are recognised under "agriculture, mining and quarrying", those from refining under "coal and petroleum products", and those from the use of oil as an energy source under "energy and waste".
Note: CO_2 emissions resulting from the combustion of fossil fuels, excluding LULUCF (land use, land-use change and forestry), non-energy related industrial processes and the other main greenhouse gases.

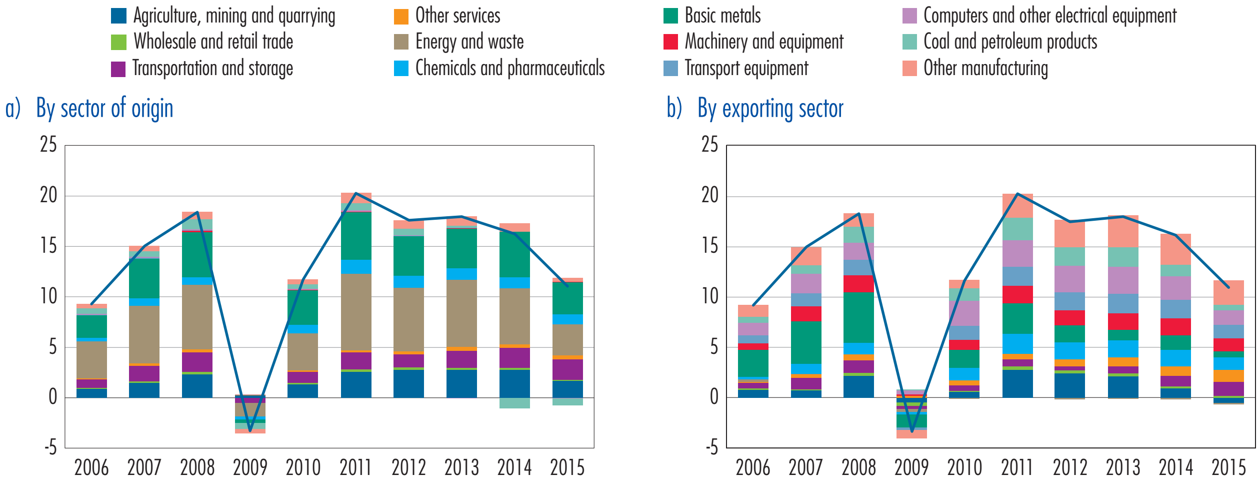
5 ... and are responsible for more than half of the rise in CO_2 emissions in trade since 2005

Nearly all sectors have contributed to the rise in trade-embodied CO_2 emissions since 2005. However, the most polluting sectors are also those that have made the biggest contribution to the rise.

Measured by sector of origin, the leading contributors are "energy and waste" (which accounted for 29% of the total variation in 2015) and "basic metals" (27%), followed by "transportation and storage" (18%) and "agriculture, mining and quarrying" (15%). The exceptions are "coal and petroleum products" (–6%) and "computers and other electrical equipment" (–1%) which have both contributed negatively to the change in aggregate emissions.

C5 Breakdown by sector of the cumulative variation in exports of CO_2 emissions

(% change, 2005 = 0)



Source: OECD inter-country input-output (ICIO) database, 2018 edition, and trade in embodied CO_2 ($TECO_2$) database; authors' calculations.

In terms of direct exporting sectors, the rise in emissions has primarily been driven by manufacturing and transportation. The largest contributors to the aggregate change are "other manufacturing" (2.4 percentage points of a total 11% rise), "computers and other electrical equipment" (1.5 percentage points), "transportation and storage" (1.4 percentage points) and "transport equipment" (1.3 percentage points).

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Appendix 1
Geographical and sectoral aggregates

CO_2 emissions intensity by sector of origin
(tonnes/USD million)

Code	Sector	Aggregate	2005	2010	2015
01T03	Agriculture	Agriculture, mining and quarrying	412	273	245
05T06	Mining and quarrying of energy producing materials	Agriculture, mining and quarrying	408	282	357
07T08	Mining and quarrying except energy producing materials	Agriculture, mining and quarrying	500	256	341
09	Mining support service activities	Agriculture, mining and quarrying	205	114	142
10T12	Food products, beverages and tobacco	Other manufacturing	259	194	165
13T15	Textiles, wearing apparel, leather and related products	Other manufacturing	376	248	156
16	Wood and products of wood and cork, except furniture	Other manufacturing	289	251	196
17T18	Paper products and printing	Other manufacturing	508	420	352
19	Coke and refined petroleum products	Coal and petroleum products (refined and plastic)	1,953	1,416	1,236
20T21	Chemicals and pharmaceutical products	Chemicals and pharmaceuticals	756	586	525
22	Rubber and plastics products	Coal and petroleum products (refined and plastic)	1,654	1,251	951
23	Manufacture of other non-metallic mineral products	Other manufacturing	3,061	2,478	2,248
24	Basic metals	Basic metals	3,889	3,335	3,294
25	Fabricated metal products	Other manufacturing	92	74	64
26	Computer, electronic and optical products	Computers and other electrical equipment	83	72	46
27	Electrical equipment	Computers and other electrical equipment	101	82	61
28	Machinery and equipment n.e.c.	Machinery and equipment	84	67	55
29	Motor vehicles, trailers and semi-trailers	Transport equipment	58	44	33
30	Other transport equipment	Transport equipment	71	63	49
31T33	Furniture; other manufacturing; repair and installation of machinery and equipment	Other manufacturing	1,268	930	750
35T39	Electricity, gas and water supply; sewerage, waste management and remediation activities	Energy and waste	9,395	7,206	6,876
41T43	Construction	Other services	102	78	80
45T47	Wholesale and retail trade, repair of motor vehicles and motorcycles	Wholesale and retail trade	71	53	49
49T53	Transportation and storage	Transportation and storage	1,293	1,023	983
55T56	Accommodation and food service activities	Other services	50	38	33
58T60	Publishing, audiovisual and broadcasting activities	Other services	44	33	27
61	Telecommunications	Other services	55	41	39
62T63	IT and other information services	Other services	47	38	34
64T66	Financial and insurance activities	Other services	40	31	26
68	Real estate activities	Other services	31	23	20
69T82	Professional, scientific and technical activities; administrative and support service activities	Other services	60	44	42
84	Public administration and defence; compulsory social security	Other services	109	81	63
85	Education	Other services	33	26	22
86T88	Human health and social work activities	Other services	36	26	27
90T96	Arts	Other services	61	43	39

CO_2 emissions intensity by country of origin

(tonnes/USD million)

Country	Geographical aggregate	2005	2010	2015
Argentina	Other emerging	880	436	308
Australia	Other OECD	612	417	454
Austria	Other OECD	336	294	261
Belgium	Other OECD	367	282	254
Bulgaria	Other OECD	1,619	936	827
Brazil	Other emerging	620	299	434
Brunei Darussalam	Other	451	465	389
Canada	Other OECD	590	502	474
Switzerland	Other OECD	199	154	119
Chile	Other OECD	619	432	491
China	China	2,336	1,413	981
Colombia	Other	579	328	476
Costa Rica	Other	374	266	187
Cyprus	Other OECD	525	416	411
Czech Republic	Other OECD	799	505	470
Germany	Germany	318	271	246
Denmark	Other OECD	535	424	381
Spain	Other OECD	421	272	269
Estonia	Other OECD	1,021	831	595
Finland	Other OECD	479	405	304
France	France	277	217	189
United Kingdom	United Kingdom	269	229	178
Greece	Other OECD	714	456	536
Hong Kong	China	652	552	449
Croatia	Other OECD	440	321	303
Hungary	Other OECD	530	418	391
Indonesia	Other emerging	1,183	560	615
India	India	1,403	1,072	999
Ireland	Other OECD	262	183	147
Iceland	Other OECD	602	485	417
Israel	Other OECD	413	283	231
Italy	Italy	328	272	249
Japan	Japan	367	300	352
Kazakhstan	Other	2,839	1,697	1,562
Cambodia	Other	503	452	444
South Korea	Other OECD	757	638	554
Lithuania	Other OECD	660	422	353
Luxembourg	Other OECD	167	115	88
Latvia	Other OECD	647	470	349
Morocco	Other	592	455	462
Mexico	Other emerging	527	488	423
Malta	Other OECD	417	237	205
Malaysia	Other	932	663	675
Netherlands	Other OECD	353	251	250
Norway	Other OECD	281	215	239
New Zealand	Other OECD	422	321	281
Peru	Other	509	366	287
Philippines	Other	748	414	361
Poland	Other OECD	961	523	492
Portugal	Other OECD	388	280	324
Romania	Other OECD	1,111	480	417
Rest of the world	Other	942	560	522
Russia	Russia	1,992	1,151	1,121
Saudi Arabia	Other	405	263	361
Singapore	Other	643	526	471
Slovakia	Other OECD	896	533	453
Slovenia	Other OECD	524	384	341
Sweden	Other OECD	259	199	153
Thailand	Other	1,041	661	654
Tunisia	Other	611	539	508
Turkey	Other emerging	592	509	500
Taiwan	China	900	689	590
United States	United States	436	351	270
Vietnam	Other	1,356	1,009	859
South Africa	Other emerging	1,837	1,470	1,692

Appendix 2
Methodology

The database used in this bulletin was constructed using three main sources, all compiled by the OECD. First, the trade in embodied CO_2 ($TECO_2$) and trade in value added (TiVA) databases were used to calculate CO_2 emissions intensities by sector (i.e. CO_2 per unit of value added). Second, the inter-country input-output tables (ICIO) were used to break down trade flows by country-sector pair participating in the production of those flows. Combining these two indicators allowed us to calculate the CO_2 emissions contained in trade flows, taking into account the structure of their production and the degree of integration of each country into global value chains.

The $TECO_2$ database shows the emissions produced by the burning of fossil fuels. These are calculated using International Energy Agency (IEA) data on the CO_2 emissions produced by fossil fuels (coal, hydrocarbons).[1] IEA data cover nearly all CO_2 emissions; the remainder stem from LULUCF (land use, land-use change and forestry) and industrial processes other than energy production. Note that IEA data do not cover all greenhouse gas emissions – some 20% of emissions by volume are excluded (Ahmad et al., 2003). The other main greenhouse gases are methane (CH_4), nitrous oxide (N_2O) and fluorine gases (hydrofluorocarbon (HFC), perfluorocarbon (PFC) and sulphur hexafluoride (SF_6)). These gases account for a third of global emissions in CO_2 equivalent (*Institut national de la statistique et des études économiques* – INSEE, 2018).

The $TECO_2$ database provides a geographical and sectoral breakdown of CO_2 emissions (Wiebe et al., 2016). It is compiled using statistics on the CO_2 produced to meet countries' final demand (demand-based approach). However, it does not take into account emissions from international aviation and maritime transport (3.5% of the total). To get around round this problem, we assumed that the structure of domestic transportation also applies to international transportation. This assumption probably led us to underestimate the emissions in question, especially those related to aviation.

The TiVA database provides a geographical and sectoral breakdown of international trade in value added (domestic or foreign). In this article, we used statistics on the value added produced to satisfy countries' final demand.

The ICIO database consists of international tables of annual inputs and outputs that break down bilateral trade flows in intermediate and final goods by sector and country. This makes it possible to trace the total value added produced globally each year back to its original source.

The breakdown into 65 countries and 36 sectors of origin (according to the International Standard Industrial Classification or ISIC Rev. 4) is the same for all three databases.

Emissions intensity of each country-sector pair

In a first step, we constructed the CO_2 emissions intensity for each country-sector pair, in other words the quantity of CO_2 emitted for each unit of value added. The intensity of sector k in country i ($\mathrm{Int}_{i,k}$) was calculated by dividing the CO_2 emissions produced by the sector ($\mathrm{EM}_{i,k}$), as listed in the $TECO_2$ database, by the value added produced by that sector ($\mathrm{VA}_{i,k}$), as indicated in the TiVA database. This calculation can be written as follows:

$$\mathrm{I}_{i,k} = \frac{\mathrm{EM}_{i,k}}{\mathrm{VA}_{i,k}}$$

The CO_2 emissions and value added for each sector are measured according to the principle of the output necessary to satisfy domestic final demand. The calculated intensities thus show the emissions associated with the production of one unit of value added by each country-sector pair. More specifically, they show the quantity of CO_2 emitted for each dollar of output.

1 See International Energy Agency (2015).

The contribution of each country-sector pair to global trade

In the second step, we calculated the total emissions produced throughout the production chain of international trade. This chain is defined as all the intermediate and final activities carried out by businesses in order to produce an exported good or service. The CO_2 emissions embodied in trade were calculated by combining the value added contained in global trade flows that was produced by each country-sector pair with the respective emissions intensity of each pair. These emissions may be produced within national territory or abroad. Combining the two variables gave the geographical and sectoral distribution of the emissions produced throughout global value chains, and their respective contributions to exports and imports. This provided a picture of global trade flows in CO_2 emissions.

$$\mathrm{EMX}_i = \sum_{jk=1}^{36*65} \mathrm{VAX}_{ijk} * \mathrm{I}_{jk}$$

Where EMX_i is the emissions embedded in the exports of country i, VAX_{ijk} is the value added produced by country-sector pair jk (domestic or foreign) that is contained in the exports of country i, and I_{jk} is the CO_2 emission intensity per unit of value added produced by country-sector pair jk. The contribution of each country-sector pair jk to the exports of country i (VAX_{ijk}) was calculated using the ICIO tables (Cezar, 2017, for more details). Imports were calculated using mirror data (i.e. the exports of country i to country j are deemed to be equivalent to j's imports from i).

Counterfactual

In Box 3, we constructed a counterfactual scenario to examine the impact of a country's productive apparatus. To do this, we calculated average sectoral intensities in order to estimate what a country's emissions would be if both it and its trading partners used production techniques that generated emissions equal to the global average, at constant production structure. The counterfactual for each country was constructed using the following equation:

$$\mathrm{EMX}_i^C = \sum_{k=1}^{36} \mathrm{I}_k * \mathrm{VAX}_{ik}$$

where $\mathrm{I}_k = \sum_{j=1}^{65} \mathrm{I}_{jk} * \frac{\mathrm{VAX}_{jk}}{\sum_{j=1}^{65} \mathrm{VAX}_{jk}}$

and $\mathrm{VAX}_{ik} = \sum_{j=1}^{65} \mathrm{VAX}_{ijk}$

The average intensity of each sector at the global level was calculated by weighting the result by each country's contribution to the global output for each sector.

To calculate the emissions exported by country i in our counterfactual, we identified each sector's contribution in terms of value added to i's exports ($\mathrm{VAX}_{i,k}$), regardless of its geographical origin. These contributions were then multiplied by the respective global average emissions intensity for that sector (I_k). This gave each sector's contribution to emissions exports. Thus, by combining global average sectoral intensities with the sectoral breakdown of each country's exports, we were able to construct a counterfactual scenario of the emissions exported by each country.

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