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CARBON CONTENT OF INTERNATIONAL TRADE[1]

- Trade affects greenhouse gas (GHG) emissions in multiple ways, and therefore the overall impact of trade on carbon emissions is complex to measure.
- In past decades, GHG emissions generated by the production and transport of exported and imported goods and services have increased and represent, on average, 20-30% of global GHG emissions.
- The amount of GHG emissions embedded in an economy's international trade is determined by a broad range of factors, including its economic size, the sectoral composition of its foreign trade, its level of participation in global value chains, the modes of transportation used for its imports and exports and the energy efficiency of its production system, which depends in part on environmental and energy policies.
- A few sectors, including energy and transportation, account for more than 75% of the GHG emissions embedded in international trade. The international transport sector generates 12% of global GHG emissions. For several sectors and economies, the share of transportation-related emissions in total GHG emissions embedded in trade exceeds the share of production-related emissions.
- While developed economies tend to be net importers of GHG emissions, developing economies and commodity dependent economies tend to be net exporters of GHG emissions. The international carbon emission transfer (from developed to developing economies) has, however, declined in recent years thanks in part to improvements in energy efficiency.
- Although international trade, like any economic activity, generates GHG emissions, for some products and services it can reduce total GHG emissions when production-related GHG emissions in the exporting country are lower than in the importing country and this difference in production-related GHG emissions exceeds transportation-related GHG emissions.
- Policy initiatives and advancements in environmental and energy efficiency technologies can reduce GHG emissions associated with the production and transportation of international trade. In that context, trade can play a role in diffusing green technologies and improving carbon efficiency.

1 INTRODUCTION

1.1. How does international trade affect climate change? To answer this question, different methods have been proposed. One popular approach, known as carbon emission accounting, estimates the amount of greenhouse gas (GHG) emissions embedded in international trade by assessing the level of GHG emitted during production, transport and consumption along supply chains in and between countries.

[1] This is an information note which represents research in progress. The opinions expressed in this paper are those of its authors. They are not intended to represent the positions or opinions of the WTO or its members and are without prejudice to members' rights and obligations under the WTO. Any errors are attributable to the authors. The note has been written by Ankai Xu, Enxhi Tresa, Marc Bacchetta, Francesco Bellelli and José-Antonio Monteiro.

1.2. Trade has complex effects on GHG emissions, which go beyond emissions from production and international transportation. Trade affects where production is taking place and, if the carbon intensity of production is not the same everywhere, this also affects the level of emissions. Importantly, trade also plays a critical role in diffusing green technology and can help countries transition to a low-carbon economy. Hence, trade has a multifaceted impact on carbon emissions. Reductions of emissions associated with trade are possible with technological innovation and international climate cooperation.

1.3. This note is structured as follows. Section 2 describes how GHG emissions embedded in trade are calculated and provides an overview of the latest trends. Section 3 looks at the determinants of GHG emissions embedded in international trade. Section 4 discusses the role of policies and international cooperation in reducing GHG emissions embedded in trade. Section 5 concludes.

2 CARBON EMISSIONS EMBEDDED IN TRADE

2.1. International trade, like any economic activity, generates GHG emissions. Tracking and measuring the GHG emitted during the production and consumption of goods and services is, however, a complex task because production often involves multiple inputs and may be carried out in different places. Carbon emission accounting measures the amount of GHG emissions embedded in economic activities, including international trade, by estimating the level of GHG emitted during production, transport and consumption along supply chains in and between countries.

2.2. Carbon emissions embedded in a product or service include the direct GHG emissions from its final production, assembly, packaging and shipping to the market (consumers). Embedded carbon emissions also account for all the indirect GHG emissions generated by the production and transportation of the inputs used to produce the final product or service, including the GHG emissions from the generation of the electricity used during production.

2.3. For example, the emissions embedded in a product as simple as chocolate cookies originate from many sources. GHG emissions are released to produce the energy used in the preparation, baking and packaging of the cookies as well as their transportation to the customers. Emissions are also associated with the cookies' ingredients (e.g. chocolate, flour, sugar). Each of these ingredients is responsible for emissions during their production and transportation. Similarly, the inputs used to manufacture these ingredients (e.g. land use change to cultivate crop, fertilisers for wheat, energy for grinding grains and toasting cocoa, etc.) generate GHG emissions.

2.4. This step-by-step analysis of all the emissions released in the production, transportation and distribution of a product or service is known as life cycle assessment. Carbon emission accounting based on such life cycle assessment can even include GHG emissions associated with the disposal of the product. Given its complexity and intensive data requirements, life cycle assessment is mostly used for product-, firm- or industry-specific carbon footprint analysis.

2.5. An alternative approach to estimate the carbon emissions embedded in economic activities of countries, including international trade, consists in breaking down aggregated national GHG emissions by sector and production stages using product- and/or sector-specific GHG emission intensity factors and input-output tables. Input-output tables describe how much of an industry's output is used by other industries and consumed by households and government within an economy. Measuring the carbon content of trade further requires cross-country input-output tables that estimate the value of input or output of a sector in a given country that is exported to or imported from a specific sector in another country.2

2.6. GHG emissions embedded in production differ considerably across economies. Developing economies tend to emit more GHG emissions per unit of output than developed economies. With a few exceptions, indirect GHG emissions embedded in production tend to be greater than direct GHG emissions embedded in production, as highlighted in Figure 1. The amount of indirect GHG emissions embedded in production tends to be higher in economies particularly active in downstream supply

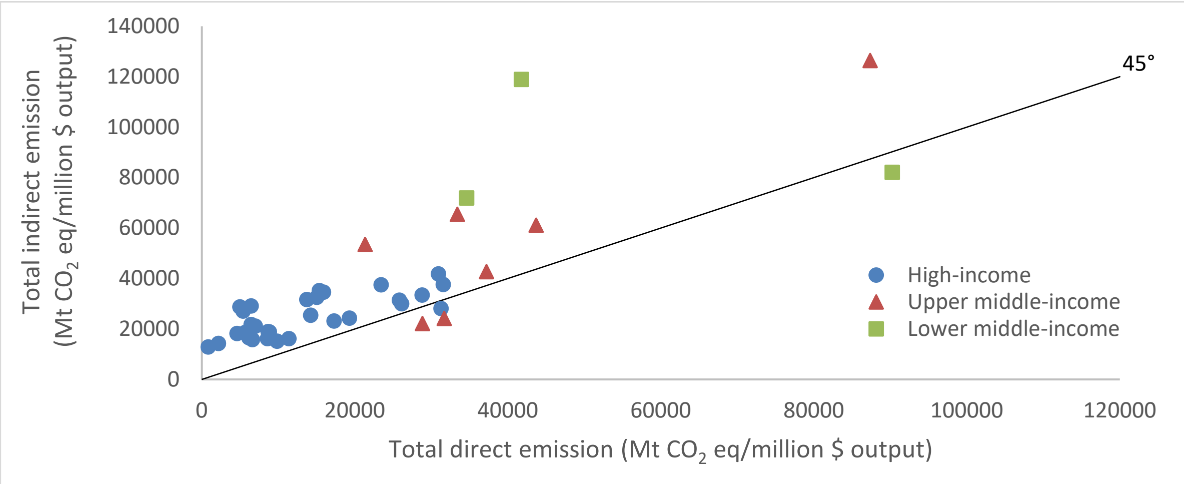
[2] Most carbon emission accounting studies do not account directly for the GHG emissions of international transport of each sector individually. Instead, they consider the transport sector as a standalone sector.

chains. Conversely, economies active in upstream supply chains tend to have lower indirect GHG emission embedded in production.

2.7. GHG emissions embedded in international trade only consider the direct and indirect GHG emissions associated with the production and transport of goods and services that are exported and imported. GHG emitted during the production and transport of goods and services produced domestically (without any foreign inputs) and consumed domestically are excluded from the calculation of carbon emissions embedded in trade.

2.8. Carbon emission accounting studies suggest that about 20-30% of total carbon dioxide emissions (CO2 which account for most GHG emissions) are associated with international trade (Peters et al., 2011; Meng et al., 2018; Zhang et al., 2020). For instance, the latest available estimates suggest that the production and transport of traded goods and services emitted 8 billion tonnes of CO2 in 2015, representing 25% of total CO2 emissions. While the value of international trade has increased by 60% since 2005, carbon emissions embodied in trade have increased by 10% between 2005 and 2015 (Cezar and Polge, 2020).

Figure 1: Indirect GHG emissions tend to be greater than direct GHG emissions

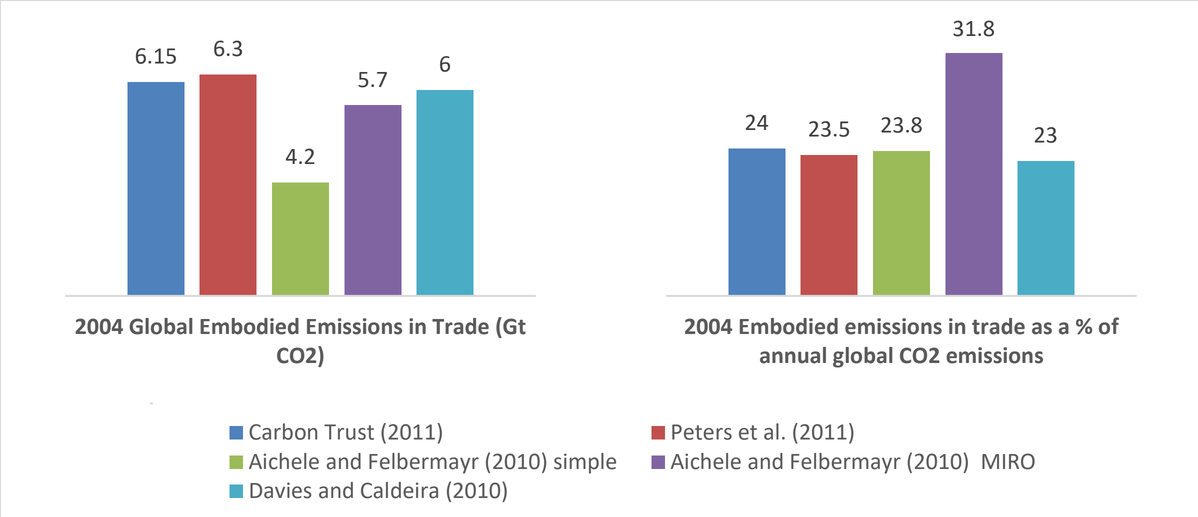


Source: Authors' computation using the WIOD database for 2009.
Note: The analysis considers both the production of goods and services, including transport. The total rate of emissions is computed by multiplying the emissions per output diagonal matrix with the Leontief inverse matrix, i.e. the matrix that considers direct and indirect intermediate goods used in final output production. The GHG emissions include CH_4, N_2O and CO_2, all expressed in CO_2 equivalence. Emissions are expressed in megatons (Mt) per million dollars of output.

2.9. Carbon emissions embedded in trade tend to fluctuate over the years. Prior to the global financial crisis, carbon emissions embedded in trade increased relatively steadily and reached their peak in 2008. They declined significantly during the global financial crisis, rebounded in 2010 and 2011, and have been decreasing slightly since 2012 (Wood et al., 2020).

2.10. The accuracy of these carbon content estimates remains, however, unclear because of data limitations, measurement errors and uncertainties due to different estimation approaches and numerous assumptions (including regarding emission intensity factors). As illustrated in Figure 2, the estimated level of carbon embedded in trade ranges from low to high by a factor of almost 1.5 depending on the different estimation approaches and assumptions (Sato, 2013).

Figure 2: Estimates of embedded GHG emissions in trade vary considerably



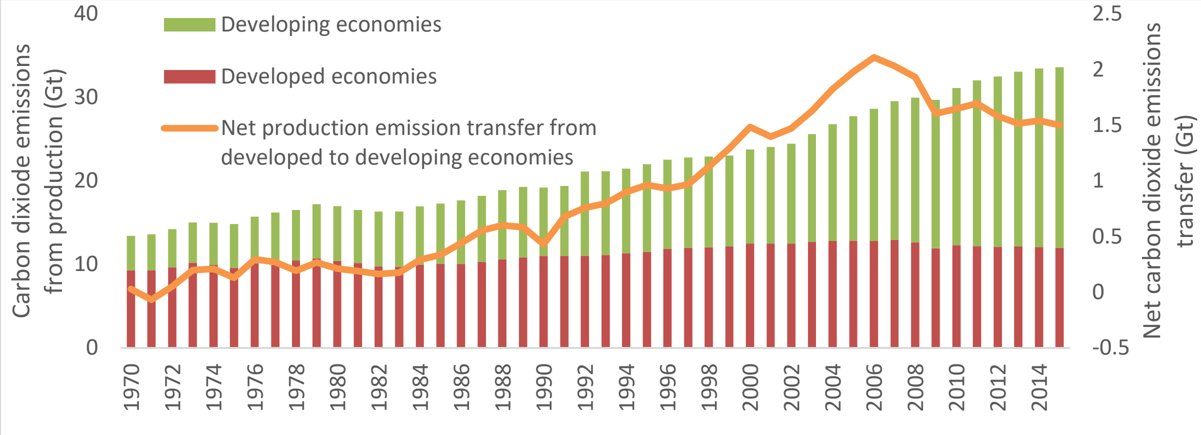
Source: Sato (2013)
Notes: The left panel plots the estimated global emissions embedded in trade by study, expressed in absolute volume. The right panel plots the corresponding share relative to global annual CO2 emissions.

2.11. Given that trade separates production and consumption across space, carbon emission accounting can be analysed from a production or consumption perspective. From a production perspective, GHG emissions embedded in the economy correspond to the quantity of GHG emitted by the domestic supply, namely the production of goods and services consumed domestically and exported. Conversely, from a consumption perspective, GHG emissions embedded in the economy correspond to the GHG emissions generated by the domestic demand, which encompasses the consumption of goods and services produced domestically and imported. The difference between the production and consumption perspectives determines the trade balance in GHG emissions, namely whether economies are net importers or exporters of GHG emissions. A trade deficit or surplus in GHG emissions is sometimes referred to as international GHG emission transfer.[3]

2.12. Carbon emission accounting studies suggest that high income economies consume more GHG than they emit, making them net importer of GHG emissions. Conversely, developing economies and commodity dependent economies tend to be net exporter of GHG emissions (Peters et al., 2011; Cezar and Polge, 2020; Wood et al., 2020). As highlighted in Figure 4, since the mid-1980s, with the rise of globalisation, developing economies have seen a rapid increase in production-related carbon emissions, in part due to the production for export and domestic investment in productive capacity. Conversely, the production-related carbon emissions in developed economies have, on average, declined. Although international carbon emission transfer (from developed to developing economies) has increased significantly faster than international trade and gross domestic product in the 1990s and early 2000s (Peters et al., 2011), it has been declining since 2006.

[3] An alternative approach, known as pollution terms of trade, computes the ratio of export GHG intensity to import GHG intensity (Antweiler, 1996).

Figure 3: Trade imbalances in GHG emissions have decreased in recent years



Source: Wood et al. (2020).
Note: Net emission transfers refer to the international carbon emission transfer, defined as the difference between the carbon emission embodied in production(including exports) and the carbon emission embodied in consumption (including imports).

3 THE DETERMINANTS OF CARBON EMISSIONS EMBEDDED IN TRADE

3.1. While carbon emission accounting provides interesting insights on the amount and evolution of GHG emissions embedded in trade, it is a purely descriptive analysis that is silent on the determinants of GHG emissions embedded in trade and more broadly on the impact of trade on GHG emissions. The amount of GHG emissions embedded in trade is determined by a broad range of factors, some of which might be unrelated to trade. The main determinants of GHG emissions embedded in trade include (1) the size of the economy; (2) the sectoral composition of trade flows; (3) the rise in global value chains (GVCs); (4) transportation; and (5) energy efficiency of the production systems. Although they are discussed individually, these factors interact with each other.

3.1 Size of the economy

3.2. GHG emissions embedded in trade differ across economies reflecting in part differences in the size of the economy. The largest exporters and importers of GHG emissions are large economies. This is because the monetary value of exports and imports determine, in part, the quantity of GHG emissions embedded. GHG emissions embedded in trade also depend on the size of the population because larger countries produce and consume more.

3.2 Sectoral composition of trade flows

3.3. Different industries are characterized by different carbon emission intensities. According to carbon emission accounting studies, a few sectors, including energy, basic metals, transportation, , coal and petroleum products, computer, electronic and electrical equipment, and chemicals and pharmaceuticals account, on average, for more than 75% of the total carbon emissions embedded in trade (Cezar and Polge, 2020; Yamano, N. and J. Guilhoto, 2020). Recent analysis further suggests that carbon emissions embedded in services trade are increasing faster than merchandise trade (Huo et al., 2021). Besides transportation, tourism and professional services are found to be the main contributors of GHG embedded in services trade.

3.4. Economies specialising in these GHG-intensive sectors or using intensively these goods and services as inputs for domestic production release larger quantities of GHG. Trade openness can further impact GHG emissions by shifting the production of these GHG-intensive activities to locations with different carbon emission intensities.

3.3 Rise in GVCs

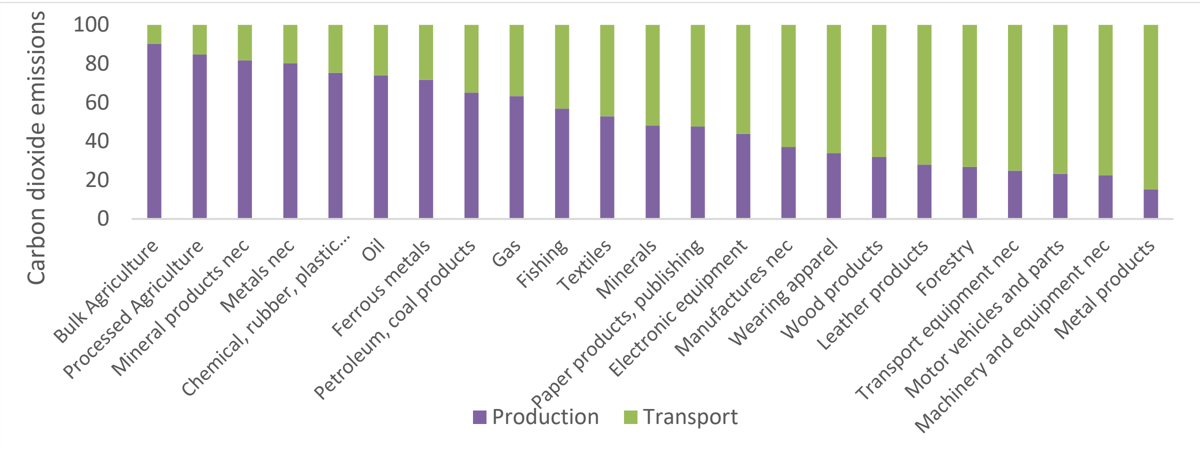
3.5. The rise in GVCs has increased the fragmentation of production processes and the offshoring of some tasks. As a result, economies more integrated in GVCs have increased their imports of intermediate inputs and thus, the amount of GHG emissions embedded in those imports. Conversely, the share of imported GHG emissions in exports is relatively lower for economies with lower GVC participation and large GHG emissions embedded in their domestic production (Cezar and Polge, 2020; Wood et al., 2020).

3.4 Transportation

3.6. The amount of GHG emissions embedded in trade also depends on the mode of transportation used, which itself depends on the type of goods and services being traded and the trading partners' geographical location. As discussed above, transportation is one of the sectors that contributes the most to GHG emissions embedded in international trade. While the domestic and international transport sector accounts for over 24% of global GHG emissions, emissions from international transport represent 12% of these global emissions (Ritchie, 2020). International transport emissions have been growing steadily at an average annual rate of 1.9% since 1990 (ITF, 2021). While passenger transportation accounts for more than two thirds of international transport emissions, the remaining transport emissions are associated with international freight transport (ITF, 2021). GHG emissions associated with international freight transport represent about 30% of all transport emissions and more than 7% of global GHG emissions (ITF, 2015).

3.7. International freight transport is also estimated to represent, on average, 33% of the carbon emissions generated by trade during the production and transport of goods traded internationally (Cristea et al., 2013). This average masks, however, large differences in the contribution of different economic sectors and economies to trade-related merchandise transport. Traded merchandise can be transported by air, road, rail and water, or via pipelines in the case of oil, gas, water and other materials. The most important mode of transport used for merchandise trade is sea transportation, which is the most efficient mode of transportation in terms of GHG emissions per volume of goods transported. Over half of international trade-related carbon emissions are, on average, from maritime shipping (ITF, 2021). However, unlike agricultural goods and fuels and mining products, manufactured goods are increasingly transported by air, the most GHG intensive mode of transportation. At the same time, road and rail transport are of particular importance for trade with neighbouring countries or within regional clusters. As a result, transportation accounts for a large share of the carbon emissions in many sectors, as highlighted in Figure 4.

Figure 4: The share of transport-related carbon emissions differs significantly across sectors



Source: Transport emission intensity from Cristea et al (2013), bilateral trade flows for year 2017 from GTAP.
Note: This figure shows the share of transport emissions over total trade-related emissions (transportation emissions and production emissions) per sector. The transport and trade-related emissions in 2017 are calculated by multiplying the intensity of emissions in 2004 (in million grams of CO_2 emissions per million USD value of trade) with the value of trade in 2017 per bilateral trade flow, and aggregated by sector. This method does not capture the change in emissions intensity of transport from 2004 to 2017.

4 HOW COULD TRADE-RELATED CARBON EMISSIONS BE REDUCED?

4.1. Given that trade contributes to GHG emissions, there have been calls to reduce international trade by producing and consuming "locally". Such calls raise the question of what the level of GHG emissions would be if economies only produced and consumed locally while ensuring a high level of welfare. Although international trade emits GHG, it also generates trade gains and contributes to increase society's welfare by supporting economic growth, lowering prices, and increasing consumer choice and product variety, including with respect to climate friendly goods, services and technologies. In addition, international trade can reduce carbon emissions when production-related carbon emission intensity in the exporting country is lower than in the importing country and the difference of production-related carbon emissions exceeds transportation-related emissions.

4.2. Although a situation of autarky is not observable, economists have used economic models to examine the question as a thought experiment. In a scenario where countries close borders to trade, domestic production of intermediate and final goods would need to rise to meet the demand for products that were previously imported. Compared with a hypothetical situation of autarky, international trade would increase global CO2 emissions by 5% or 1.7 gigatons of CO2 annually (Shapiro, 2016). This trade-related carbon effect would be almost equally driven by production and transportation. However, the gains from international trade, measured as the benefits for producers and consumers, exceed the environmental costs from carbon emissions by 2 orders of magnitude.

4.3. Furthermore, a quarter of all international trade flows, representing roughly 31% of trade in monetary value, could lead to a net reduction in carbon emissions compared to autarky despite transportation-related carbon emissions (Cristea et al., 2013). In many industries, such as bulk agriculture, this net carbon emission reduction could be substantial. However, for the remaining sectors trade is associated with an increase in carbon emissions. In the aggregate, this corresponds to an increase in emissions equal to 1274 million tons of CO2, of which 1178 million tons is due to transport emissions. For these cases, improvements in carbon efficiency in production and transportation are necessary to reduce trade-related GHG emissions.

4.4. Trade-related GHG emission abatement could be achieved by curbing the GHG emissions released by international transportation. Developing new efficient transport technologies, using sustainable and alternative fuels, improving transport infrastructure and promoting the substitution to more carbon-efficient alternative means of transportation (e.g. rail instead of road) are some of the strategies that can reduce trade-related GHG emissions. Different policy initiatives at the country and regional-level have been adopted to reduce these GHG emissions. For example, the European Union aims to reduce by at least 60% its carbon emissions compared to 1990 by, among other things, switching to more efficient modes of transportation, promoting electrification, as well as investing in research in hydrogen, advanced biofuels and renewable synthetic fuels (European Commission, 2016). Similarly Korea's pandemic recovery fund supports electrification of transportation. China and Japan aim also to reduce their transport-related carbon emissions as part of their carbon neutrality pledge (ITF, 2021). Some governments have also planned to stop the sale or registration of internal combustion engine cars and trucks by dates in between 2030 and 2050.

4.5. At the international level, different initiatives have also been launched to reduce the GHG emissions from the transport sector. Members of the International Maritime Organization (IMO) committed to reduce emissions by at least 50% by 2050 on 2008 levels while pursuing complete decarbonisation as soon as possible in this century. Part of the strategy builds on already-adopted mandatory energy-efficiency requirements for ships. Similarly, members of the International Civil Aviation Organization (ICAO) agreed to improve fuel efficiency by 2% annually through 2050 and to reach carbon neutral growth from 2020 onwards. The International Air Transport Association (IATA) recently also agreed a plan to reach net zero carbon emissions by 2050 thanks to sustainable aviation fuels, new aircraft technology, more efficient operations and infrastructure, and new zero-emissions energy sources, such as electric and hydrogen power.

4.6. International cooperation is required for a successful climate action. GHG emissions are global externalities. In the absence of international cooperation, the adoption of climate policies by individual countries is likely to be less than optimal from a global perspective. This is because climate policies in one country can have positive or negative spillovers in other countries, including the risk of carbon leakage (i.e. a situation in which carbon-intensive industries relocate to places with laxer climate regulation). Deployment of technological innovation is also required to meaningfully reduce GHG emissions released during trade-related production. In this respect, the WTO also has a role to play in facilitating trade of environmental goods and the diffusion of climate friendly technologies. Reducing trade barriers to climate friendly technologies will facilitate access and increase adoption of these technologies to help accelerating the transition towards a more sustainable economic model.

5 CONCLUSIONS

5.1. In past decades, GHG emissions released by the production and transport of exported and imported goods and services have increased, representing, on average, 20-30% of global GHG emissions. While advanced economies tend to be net importers of GHG emissions, developing and commodity dependent economies tend to be net exporters of GHG emissions. The evolution of GHG emissions embedded in trade is, however, dynamic, reflecting changes in economic size, the sectoral composition of trade, the participation in GVCs, the modes of transportation and the energy efficiency of the production systems, among others.

5.2. Although carbon emission accounting allows to estimate the amount of GHG emissions embedded in trade and determine whether economies are net importers or exporters of GHG emissions, the methodology faces some limitations. In particular, the estimates might be subject to measurement errors and uncertainties due to different estimation approaches and assumptions. In addition, the methodology is purely descriptive and does not explain how trade actually impacts GHG emissions.

5.3. In fact, international trade affects GHG emissions in different ways. Trade generates GHG emissions through the production, transportation, distributions and consumption of traded goods and services. Trade also increases emissions by stimulating economic activity through increased income. In addition, trade modifies the sectorial composition of the economy by allowing the production and consumption of goods to take place in different regions. Economies specialized in the production of GHG-intensive goods and/or services will likely be net exporters of GHG emissions for these goods and/or services. Conversely, economies using intensively these goods and/or services as inputs for domestic production will likely be net importer of GHG emissions for these goods and/or services. The amount of trade-related GHG emissions of some of these goods and services can still be relatively lower compared to a situation where the importing economy would have produced these goods and/or services domestically, when the GHG emissions from production and transportation in the exporting economy are lower than those that the importing economy would have released by producing them.

5.4. Trade also plays an important role in the adoption and dissemination of green technologies, including carbon efficient technologies, leading to a positive impact on decarbonisation. The amount of GHG emissions embedded in trade can be reduced by improving energy efficiency and promoting alternative and renewable energy. In that context, public policies are important to incentivize firms and consumers towards more sustainable decisions and behaviours. International cooperation has also an important role to play to maximize synergies in the efforts to reduce the carbon content of international trade, including through the adoption and diffusion of green technologies.

REFERENCES

Antweiler, W. (1996), "The Pollution Terms of Trade?", Economic Systems Research. 8, 361-365.

Cezar, R. and Polge, T. (2020), "CO_2 emissions embodied in international trade", Bulletin de la Banque de France, 228/1.

Cherniwchan, J., Copeland, B. R. and Taylor, M. S. (2017), "Trade and the environment: New methods, measurements, and results", Annual Review of Economics 9:59-85.

Cristea, A., Hummels, D., Puzzello, L., and Avetisyan, M. (2013), "Trade and the greenhouse gas emissions from international freight transport", *Journal of environmental economics and management*, 65(1), 153-173.

Copeland, Brian, R., and Scott Taylor, M. (2004), "Trade, Growth, and the Environment", Journal of Economic Literature, 42(1), 7-71.

European Commission (2016), "A European strategy for low-emission mobility", *European Commission Fact Sheets*, https://ec.europa.eu/commission/presscorner/detail/en/MEMO_16_2497

Garsous, G., and Worack, S. (2021), "Trade as a channel for environmental technologies diffusion: The case of the wind turbine manufacturing industry", OECD working paper.

Huo, J., Meng, J., Zhang, U., Gao, Y., Zheng, H, Coffman, D., Xue, J., Li, Y. and Guan, D. (2021), "Drivers of fluctuating embodied carbon emissions in international services trade", One Earth, 4(9), 1322-1332.

IPCC (2014), Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, https://www.ipcc.ch/report/ar5/wg3/

ITF (2015), The Carbon Footprint of Global Trade; Tackling Emissions from International Freight Transport, International Transport Forum, Paris, https://www.itf-oecd.org/carbon-footprint-global-trade.

ITF (2021), ITF Transport Outlook 2021, OECD Publishing, Paris, https://doi.org/10.1787/16826a30-en

Le Moigne, M., and Ossa., R. (2021), "Buy Green not Local: How International Trade Can Help Save Our Planet", Kühne Center for Sustainable Globalization.

Meinrenken, C.J., Chen, D., Esparza, R.A., et al. (2020), "Carbon emissions embodied in product value chains and the role of Life Cycle Assessment in curbing them", Scientific Reports, 10, 6184.

Meng, B., Peters, G. P., Wang, Z. and Li, M. (2018), "Tracing CO2 emissions in global value chains. Energy Economics", 73, pp. 24-42.

Peters, G. P., Minx, J. C., Weber, C. L., and Edenhofer, O. (2011), "Growth in emission transfers via international trade from 1990 to 2008", *Proceedings of the national academy of sciences*, 108(21), 8903-8908.

Poore, J., and Nemecek, T. (2018), "Reducing food's environmental impacts through producers and consumers", *Science*, 360(6392), 987-992.

Ritchie, H. (2020), "Cars, planes, trains: where do CO2 emissions from transport come from?", OurWorldinData.org.

Sato, M. (2014), "Embodied carbon in trade: a survey of the empirical literature", Journal of Economic Surveys, 28, 831-861.

Shapiro, J. S. (2016), "Trade costs, CO2, and the environment", *American Economic Journal: Economic Policy*, 8(4), 220-54.

Shapiro, J. S. (2021), "The environmental bias of trade policy", *The Quarterly Journal of Economics*, 136(2), 831-886.

Wood, R., Grubb, M., Anger-Kraavi, A., Pollitt, H., Rizzo, B., Alexandri, E., and Tukker, A. (2020), "Beyond peak emission transfers: historical impacts of globalization and future impacts of climate policies on international emission transfers", *Climate Policy*, 20(Sup1), S14-S27.

Yamano, N. and J. Guilhoto (2020), "CO2 emissions embodied in international trade and domestic final demand: Methodology and results using the OECD Inter-Country Input-Output Database", OECD Science, Technology and Industry Working Papers, No. 2020/11, OECD Publishing, Paris.

Zhang, Z., Guan, D., Wang, R., Meng, J., Zheng, H., Zhu, K., and Du, H. (2020), "Embodied carbon emissions in the supply chains of multinational enterprises", Nature Climate Change 10(12), pp. 1096-1101.