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Tracing Carbon Dioxide Emissions along Global Value Chains

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The rise of global value chains (GVCs), which are regarded as one of the most important features of the 21st century economic globalization (Baldwin, 2013, WTO-IDE, 2011, Antràs and de Gortari, 2020), has not only enabled global firms to achieve greater economic efficiency (Bloom et al., 2012, Melitz and Trefler, 2012), but also helped both the developed and developing economies to utilize their comparative advantages and gain value-added, income and job opportunities (Gereffi and Fernandez-Stark, 2016, Meng et al., 2020, Meng and Ye, 2022). However, along with value creation through global production sharing, GVCs have also generated or are associated with massive greenhouse gas emissions and pollution at energy-intensive production stages in different countries as a by-product (Meng et al., 2023). Moreover, the increasing complexity and uncertainty of GVCs, characterized by multiple and frequent cross-border trades in intermediates and foreign direct investment (FDI), have made it difficult to understand "who emits emissions for whom," thus posing great challenges to designing environmental policies (including domestic and international regulation, taxation, carbon pricing etc.) that enable countries, industries, and firms to clearly identify their climate change responsibilities.

Identifying each country's responsibility for carbon dioxide (CO_2) emissions is essential for effective international cooperation to address climate change. Countries will have little incentive to bear the costs of emissions reductions if there is no sense that they are contributing to a global movement that has the potential for achieving climate goals. And ensuring a general perception that the allocation of emission reductions across countries corresponds to responsibility for the production of emissions will be an important element in achieving international consensus on a green agenda.

This chapter presents a unified accounting framework for tracing CO_2 emissions along GVCs at country, sector, and bilateral levels, which can be used to better understand the emission responsibilities of GVC participants in various roles, such as producers, consumers, exporters, importers, investors, and investees. We then demonstrate how this framework can provide useful insights for improving environmental policy design, climate change negotiation and green GVC governance, so that those benefiting from productive activities that generate emissions can bear a more appropriate share of the costs of emissions reductions. Our main findings include 1) Since 2001, developing economies have doubled their CO_2 emissions from purely domestic value chains that serve their own final demands. These emissions are now about twice as large as those of developed economies. Given that GVCs are rooted in domestic sources, it is imperative to curb these emissions with more effective tools, such as environmental regulation, taxation, and the introduction of carbon trading schemes domestically. By greening their domestic production, developing economies can also green their exports via GVCs. 2) The carbon intensity of GVCs has decreased in both developed and developing economies between 1995 and 2021. However, creating GDP through international trade is still more carbon-intensive than doing that through purely domestic value chains. Therefore, it is important to introduce carbon pricing along GVCs to substantially raise the cost of emissions globally in the Paris Agreement era. 3) GVCs increase carbon leakage through both international trade and cross-border investment (e.g., FDI) channels. However, the current emission reduction targets do not explicitly and consistently account for the different roles and responsibilities of GVC actors, such as producers, consumers, exporters, importers, investors, and investees. This puts more burden on domestic firms than multinational enterprises (MNEs) for GVC-related emissions. Therefore, MNEs should play more active roles to fight climate change along their GVCs.

In the next section, we first provide an overview of the climate change challenges caused by the rapid increase of CO_2 emissions and show how difficult it will be to achieve carbon neutrality targets in the coming 2-3 decades. In section 3, we introduce the accounting framework according to the traditional territory-based approach for tracing both CO_2 emissions and value-added along GVCs upstream and downstream at country, sector, and bilateral levels. Based on this framework, we have developed a new methodology to identify both self- and shared emission responsibilities at the country level and applied it to the real data. In section 4, we incorporate firm heterogeneity information into our accounting framework, in which we can distinguish the roles of MNEs and domestically owned firms when they generate and induce emissions along GVCs. In section 5, we further update the territorial-based emission accounting to firm-control-based accounting by using the concept of trade in factor income. This can help to better understand the relationship between emission responsibility and firm control in terms of MNEs' FDI activities. We conclude our chapter with some policy suggestions.

5.1 Historical CO_2 Emissions and Climate Change Challenges

Climate change is one of the most pressing challenges facing humanity in the 21st century. It poses significant risks to the environment, the economy, and human wellbeing. This section first provides an intuitive image of the impacts of climate change due to increasing CO_2 emissions, using NASA's visualization figures. We then show the major economies' historical evolution of their emissions generation and how challenging it will be to achieve their carbon neutrality targets going forward.

5.2 Visible Impacts of Climate Change

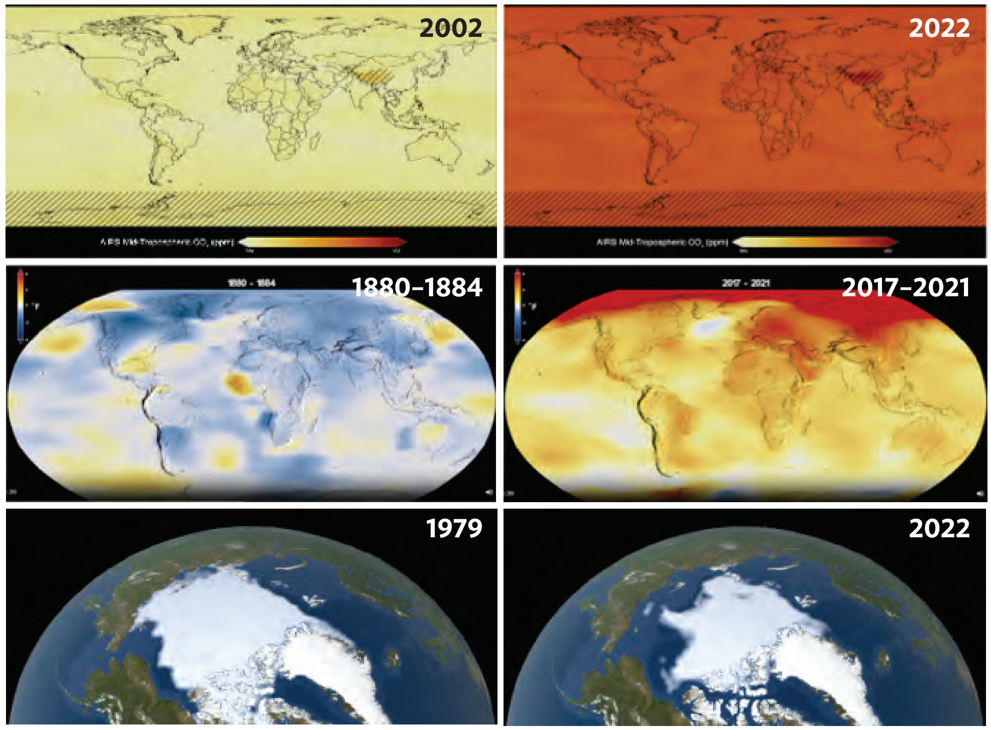
Figure 5.1 (based on the visualization tools by NASA) shows the significant and visible changes in CO_2 emissions concentration, temperature, and sea ice cover. The upper panel in this figure presents the global changes in the concentration and distribution of CO_2 emissions between 2002 and 2022 at an altitude range of 1.9 to 8 miles. The yellow-to-red regions indicate higher concentrations of CO_2 emissions, while blue-to-green areas indicate lower concentrations, measured in parts per million. A clear upward trend can be easily observed, and indeed, there's more carbon dioxide in the atmosphere now than at any other time in at least 650,000 years (Hopkin, 2005, Lüthi et al., 2008). The middle panel of the same figure (the color-coded map) shows the progression of changing global surface temperature anomalies between 1880-1884 and 2017-2021. Higher and lower than normal temperatures (normal temperatures are shown in white and are calculated over the 30-year baseline period 1951-1980) are shown in red and blue respectively. A remarkable change in color can be easily seen. In fact, the average global temperature on Earth has increased by at least 1.1° Celsius (1.9° Fahrenheit) since 1880, and the majority of the warming has occurred since 1975, at a rate of roughly 0.15 to 0.20°C per decade (GISS-NASA, 2023). In addition, significant changes have also been observed for sea ice cover. The bottom panel in Figure 5.1 shows the annual Arctic Sea ice minimum between 1979 and 2022. At the end of each summer, the sea ice cover reaches its minimum extent, leaving what is called the perennial ice cover. The area of the perennial ice has been steadily decreasing since the satellite record began in 1979, falling by 12.6 percent per decade compared to its average extent during the period from 1981 to 2010.

5.3 Historical CO_2 Emissions and Challenges Towards the Achievement of Carbon Neutrality

Using the above NASA's visualization, we can see how the impacts of climate change have progressed significantly over the years. One of the main sources of climate change is greenhouse gas emissions from fossil fuel combustion, in which CO_2 emissions account for the majority (more than 75%). Figure 5.2 shows the historical evolution of CO_2 emissions generated by both advanced and emerging large economies from 1830 to 2021, and the carbon neutrality targets announced by those countries (up to 2070).

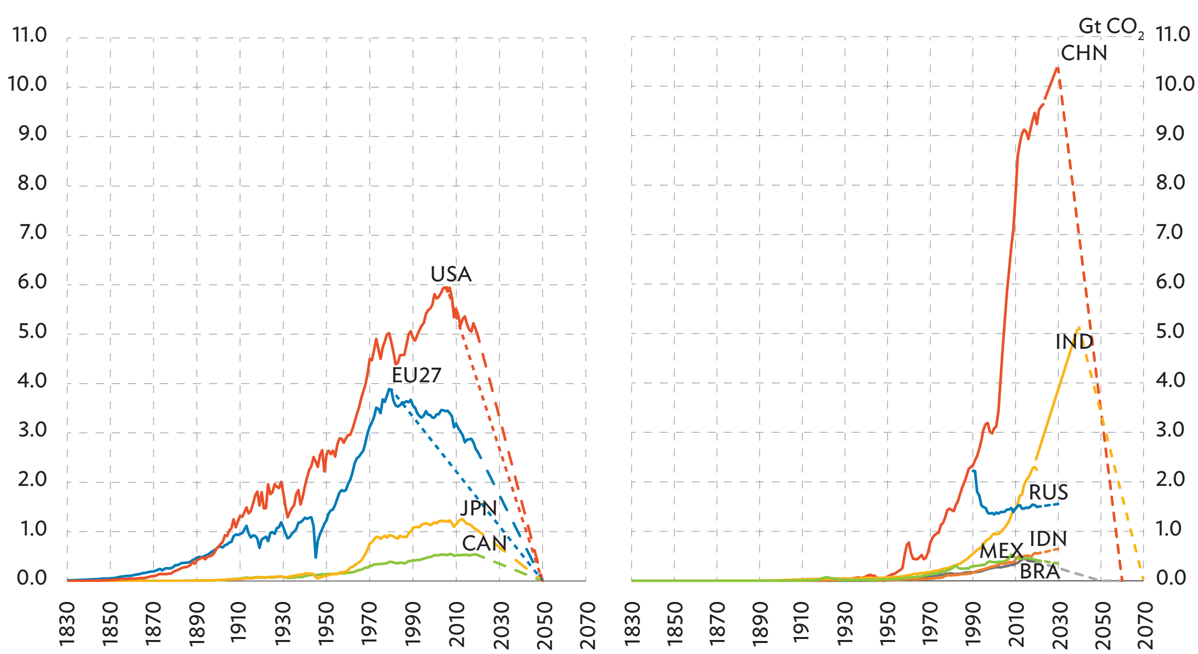
Obviously, the United States (US) is the largest emitter followed by the EU27, Japan, and Canada in the advanced economies group. Both the US and EU27 experienced a

Figure 5.1: Visualization of Climate Change Impacts



Source: NASA's Atmospheric Infrared Sounder (AIRS), GISS Surface Temperature Analysis (GISTEMP v4), and Scientific Visualization Studio (SVS)

Figure 5.2: Major Economies' Historical CO_2 Emissions from 1830 to 2021 and their Targeting Years for Carbon Neutrality

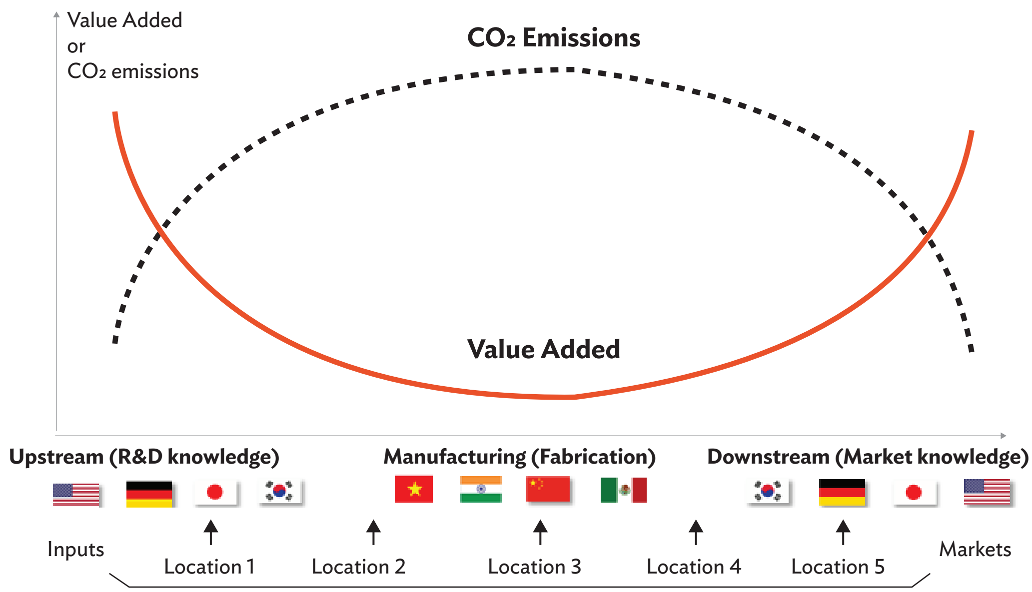


Note: The historical CO_2 emissions data is from the PRIMAP-hist national historical emissions time series (see Gütschow et al., 2016). The climate targets of countries are gathered from the Climate Action Tracker (https://climateactiontracker.org).

significant increase in their CO_2 emissions after World War II up to 1980. The main difference between the US and EU27 is that emissions by the EU27 peaked in 1980 and declined gradually afterwards, while the US' emissions continued to increase for about 25 years after 1980 and peaked at around 2008. The rapid increase in Japan's CO_2 emissions accompanied its economic takeoff between 1960 and 1970. Similar to the pattern of the US but with a relatively lower increasing tendency, Japan experienced an emission increase after 1980, and emissions peaked in 2012. From a historical perspective, the accumulated CO_2 emissions generated by the advanced economies from the Industrial Revolution to World War II account for only a small portion (about 20%) of their total accumulated emissions (more than 80% of their emissions happened after World War II). Compared to the changing pattern of advanced economies' CO_2 emissions, in the emerging economies group, the People's Republic of China (PRC) dominated the emissions with a much steeper increase after its WTO accession in 2001, followed by India which also experienced a rapid increase in emissions after 2000. The common feature of the PRC and India's rapid emission increase is that it accompanied these two countries' active participation in GVCs as important production centers and hubs of the so-called Factory Asia.

The major challenge ahead in fighting against climate change is about how to reduce CO_2 emissions. The advanced economies group in Figure 5.2 has committed to achieve carbon neutrality (net zero carbon) by the end of 2050. On the other hand, the two largest emerging countries, the PRC, and India, aim to reach carbon neutrality in 2060 and 2070 respectively. Assuming advanced economies follow a linear trend in emissions from now on to reach net carbon zero by 2050, we can observe the speed of the decline in emissions required by the slope of the dotted lines linking their current emissions level and their 2050 net zero targets. By this metric, the US is facing the most difficult challenge, followed by EU27. Japan and Canada have been relatively low-carbon societies, thus the reduction in emissions required to achieve carbon neutrality is less than in the US and EU27, marginally less effort is needed. In addition, if the US and EU27 had taken more actions much earlier starting from their peak carbon years (thinner dotted lines), their path to achieving carbon neutrality might be easier. On the other hand, for the emerging economies, especially for the PRC and India, their CO_2 emissions will keep increasing until they reach a future peak, which poses more challenges. Assuming the PRC can achieve its pledge to reach peak CO_2 emissions in 2030, reaching net zero carbon by 2060 will be a tough mission, since the slope of the dotted reduction line is very steep. Other emerging economies, such as India, will also face difficult challenges. If India follows the same increasing tendency of CO_2 emissions as the PRC has done and reaches peak emissions 10 years later than the PRC, achieving carbon neutrality by 2070 would require a very large, rapid reduction in emissions. Even if India can achieve the same level of industrialization with half the peaking level of the PRC's CO_2 emissions in 2040, for example due to the diffusion or spillover of green technologies, achieving carbon neutrality in 2070 will still require great efforts.

Figure 5.3: Smile Curve of Value-Added vs Crying Curve of CO_2 Emissions along GVCs



Source: designed by the authors based on the discussion with Yuqing Xing.

It should be noted that emissions shown in Figure 5.2 are territory-based emissions, which does not necessarily imply that the country that generates emissions should be 100 percent responsible for those emissions. This is mainly because emissions that happen in a country might be due to the production meeting other countries' final demand via complex routes of international trade and investment in the era of GVCs. In other words, given the fact that there is no commonly accepted global carbon price, the market mechanism cannot be used to solve all the problems of carbon leakage that happens via international trade and investment, as discussed by the so-called "Pollution Haven" and "Race to the Bottom"[1] hypotheses related literature (Copeland and Taylor, 1994, Taylor, 2005, Xing and Kolstad, 2002, Konisky, 2007, Bu and Wagner, 2016, Avendano et al., 2023). More importantly, as shown in Figure 5.3, the GVC strategy allows MNEs to separate headquarters and factory functions (the so-called "second unbundling" (Baldwin, 2013)), which has resulted in an asymmetric distribution of value added and carbon emissions along GVCs. Specifically, countries specializing in low value-added tasks such as manufacturing and assembling are burdened with high carbon emissions, while countries engaging in R&D and marketing capture more value added but bear less carbon emissions. For example, about 70% of Apple's total carbon footprint is generated in the manufacturing process (Apple, 2022), which is located outside of the United States, but the manufacturing process is indispensable for Apple to realize the value of its brand, software and other intangible assets, and Apple gains the largest share of the value added of the products manufactured by its foreign contract

1 The origins of the phrase race to the bottom are often traced to U.S. Supreme Court Justice Louis Brandeis in his dissenting opinion in Liggatt v Lee where he describes how firms were formed in U.S. "states where the cost was lowest and the laws least restrictive" which led to a race "not of diligence but of laxity" (Louis K. Liggett CO v. Lee, 288 U.S. 517, 1933).

makers. Developing countries participating in GVCs generally specialize in low value-added tasks with relatively high carbon emissions. To a certain extent, the increase in the carbon emissions of developing countries is attributed to the proliferation of GVCs in the last decades. A crucial issue for addressing climate change is how to help developing economies, which have been part of GVCs dominated by MNEs, and also the major generators of CO_2 emissions from now on but have relatively less advanced emissions reduction technologies and weaker regulations and face great challenges of economic development and poverty reduction, to be essentially and actively involved in the global action of emissions mitigation in the era of GVCs.

5.4 CO_2 Emissions and Their Responsibilities along Global Value Chains

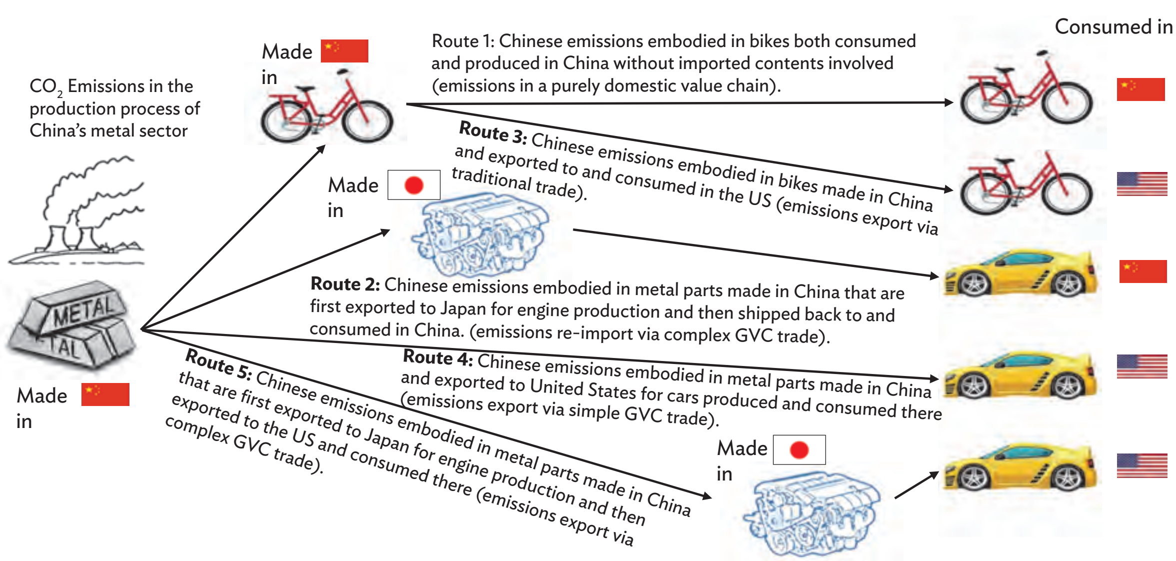
CO_2 emissions happen along GVCs, which involve both domestic and international segments of complex production networks. Before the policy-oriented discussion about emission responsibilities and how to reduce emissions along GVCs, we need to have a clear picture of the creation, transfer, and absorption of emissions along GVCs. This requires building a consistent and systematic account to trace emissions at country, sector, and bilateral levels. This section first introduces a GVC-based emission tracing system and proposes a way to share emission responsibilities between producers and consumers along GVCs.

5.5 Tracing CO_2 Emissions in Global Value Chains

Regarding the connection between international trade and emissions, a large body of literature has explored the concept of both production-based (or territory-based) and consumption-based accounting (Peters, 2008, Hoekstra and Wiedmann, 2014, Kander et al., 2016). Similar applications can be found in relation to numerous environmental issues, including climate change, energy use, air pollution, material use, land use, biomass, water quality, and biodiversity (Wiedmann, 2009, Tukker and Dietzenbacher, 2013). This accounting has considerable methodological and conceptual overlap with studies on "trade in value-added" in relation to GVCs (Johnson and Noguera, 2012, Koopman et al., 2014, Timmer et al., 2014). Using a multiregional input–output (MRIO) model, Meng et al. (2018) consistently link these two independent lines of research in the context of both climate change and GVCs. The main advantage of their accounting is that it can trace both emissions and value-added at each stage from the perspectives of production, consumption, and trade. In their accounting, international trade-related emissions are further divided into traditional trade (i.e., classical Ricardian-type trade such as "French wine in exchange for English cloth," in which there is no international production-sharing), simple GVC trade (in which factor contents cross national borders once), and complex GVC trade (in which factor contents cross national borders more than once). In addition, using this framework, we can clearly distinguish self-responsibility-based emissions (that is, emissions generated in a purely domestic value chain for domestic final use that does not involve international trade).

The accounting framework used in this Chapter mainly follows Meng et al. (2018). As illustrated in Figure 5.4, the logic behind this framework is that a country or sector's production-based emissions are both directly and indirectly embodied in all downstream countries and sectors via numerous value chain routes and are eventually absorbed by domestic or foreign final demand (tracing emissions from upstream to downstream). In turn, the production of any specific final product induces emissions of direct and indirect intermediates suppliers upstream, in this sense, emissions can also be traced from downstream to upstream in the same accounting framework (in theory, they can be defined as consumption-based emissions). To facilitate the analysis of complex trade flows, which might cross multiple borders multiple times, we divide trade into five routes, as shown in Figure 5.4.

Figure 5.4: GVC-Based Accounting Framework for Tracing Emissions



Source: Meng et al. (2023)

Emissions along Route 1 are generated through the creation of a country's gross domestic product (GDP) to satisfy the country's final demand for domestically produced goods and services (i.e., a purely domestic value chain). In this case, the country has "self-responsibility" for these emissions. Emissions along Route 2 are generated and absorbed solely within a country, but also involve international trade in which factor contents cross national borders more than once, and thus belong to the category of re-imported emissions via complex GVC trade. Emissions along Routes 3, 4, and 5 refer to emissions exports via traditional trade, simple GVC trade, and complex GVC trade, respectively. The sum of emissions along Routes 2, 3, 4, and 5 in each bilateral trade yields emissions embodied in bilateral trade (EEBT, which is consistent with the definition proposed by Peters, 2008). Therefore, our GVC-based accounting approach consistently integrates existing production-based emissions, consumption-based emissions, emissions exports, emissions imports, emissions re-imports, and EEBT under a single unified framework. Emissions from direct household combustion are not included in the above framework because they do not belong to the production process involved in the creation of GDP, but rather are simply considered part of the consuming country's self-responsibility-based emissions.

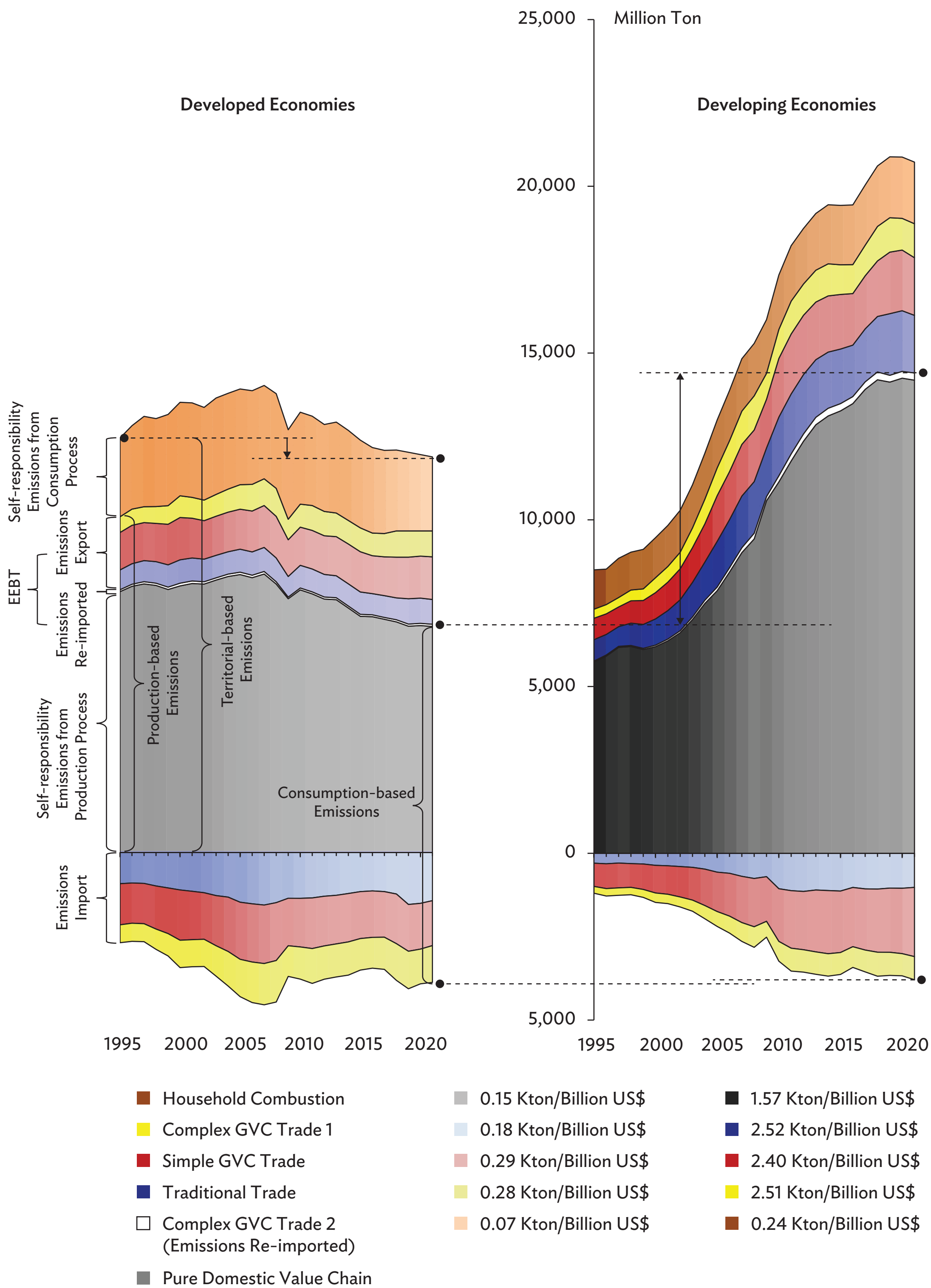
5.6 Production- vs Consumption-Based Emissions and Emissions Transfers along GVCs

By applying the above accounting framework to the long time series MRIO data (combined from the World Input–Output Database, and Asian Development Bank's Multiregional Input–Output Tables), we estimate production-based and consumption-based emissions from 1995 to 2021 for both developed and developing economies, and demonstrate how the international transfer of emissions occurs through various routes with different carbon intensities (e.g., emissions per USD of GDP created at 2015 constant prices).

Figure 5.5 shows that territorial-based CO_2 emissions by developed economies increased gradually during the period 1995–2007 (peaking in 2007), showing clear declines after 2008, and reached 11.9 Gt in 2021, which was already lower than the 1995 level of 12.4 Gt. During this period, emissions exports for the purpose of satisfying foreign final demand were the main driving force of the increasing trend from 1995 to 2007, self-responsibility-based emissions generated by the production process were the main driver leading the decreasing trend during the period 2008–2021, and self-responsibility-based emissions generated through individual household combustion were relatively stable over the entire period for both economy groups. It should be noted that developed economies' emission exports after 2018 showed a slight increasing tendency. Consumption-based emissions by developed countries increased during the period 1995–2007 as a result of rising emissions imports and decreased during the period 2008–2018, mainly because of a decrease in self-responsibility-based emissions from production processes. Developed economies' emission imports, especially via traditional trade routes rebounded again showing increasing trends after 2018. This evolution is likely due to several reasons; increased final goods imports, especially from the PRC during the COVID-19 pandemic, is one.

Developing economies showed larger increases in both self-responsibility-based emissions and emissions export and import than developed countries did. Self-responsibility-based emissions from production, production-based emissions, and territorial-based emissions by developing economies during the period 2004–2018 largely exceeded the peak levels in developed countries that occurred in 2007. Furthermore, developing economies' self-responsibility-based emissions from production processes were 2.1 times larger than those of developed countries in 2021. On a positive note, this trend shows a clear decline after 2019, but it remains to be seen whether it will continue, given the mixed factors behind this phenomenon, such

Figure 5.5: Developed and Developing Economies' CO_2 Emissions along GVCs.



Note: The colors in the figure show the emissions from different types of trade routes. Black means emissions from pure domestic value chains. Blue means emissions from traditional trade of final goods. Red means emissions from simple GVC trade, where intermediate goods cross borders once. Yellow means emissions from complex GVC trade, where intermediate goods cross borders multiple times. White means emissions from complex GVC trade that involves re-importing emissions to the country of origin. The darker the color, the higher the carbon intensity (emissions per USD of GDP at 2015 constant prices).

Source: authors' estimation based on Meng et al. (2023).

as the impacts of COVID-19 and geopolitical risks. Meanwhile, developing economies' imported emissions showed significant increasing trends and were very close to the level of developed countries in 2021. Looking at the structure of increasing emissions trade based on different GVC routes for developing economies, their emissions exports and imports increased about 3.0 and 3.3 times respectively between 1995 and 2021, with GVC trade-related emissions accounting for the majority (for emission exports, it was 63.2%, for emission imports, it was 74.5%).

The main information about carbon intensity and its evolution shown in Figure 5.5 can be summarized as follows. Carbon intensity shows a decreasing trend in both developed and developing economies via all routes between 1995 and 2021. However, the carbon intensity of developing economies in 2021 remained much higher than that of developed countries. In addition, the ever-increasing territorial-based emissions in developing economies imply that the decrease in carbon intensity in these countries did not offset the increased emissions, probably because of rapid economic and population growth (Peters et al., 2007).

5.7 Sharing CO_2 Emissions Responsibilities Across Economies along Global Value Chains

Currently, the Paris Agreement is focused on territorial-based emissions (which are easy to monitor), while consumption-based emissions are used as a reference point in designing possible transnational financial support mechanisms to enable developed countries to help developing economies reduce their emissions. Unfortunately, neither territorial- nor consumption-based accounting (both of which allocate full responsibility to either the producers or the consumers) provides sufficient incentive for countries to pursue emissions reduction efforts because of a lack of consensus regarding responsibility sharing. Although several pioneering studies have discussed the topic of producers and consumers sharing responsibility for emissions (e.g., Kondo et al., 1998, Bastianoni et al., 2004, Lenzen et al., 2007, Andrew and Forgie, 2008, Cadarso et al., 2012, Dietzenbacher et al., 2020), two problems still need to be addressed. One is how to identify a country's self-responsibility for emissions. Without an accurate measure, we are unable to even determine the amount of emissions for which responsibility should be shared among the various related parties. The other problem is how to determine the appropriate weights to enable proper distribution of responsibility for emissions among the various producers and consumers along GVCs.

As previously shown, self-responsibility-based emissions in relation to the production processes can be identified by using IO based decomposition method to separate GVCs into pure domestic and international segments, while self-responsibility-based emissions in relation to the direct household combustion processes can be directly defined. Thus, the remaining issue is how to allocate responsibility for CO_2 emissions transfers among various producers and consumers along GVCs. Here, we introduce a new method to estimate carbon leakage, which is the bilateral transfer of embodied emissions in trade (a narrow definition) from both producers' and consumers' perspectives based on the following logic. First, if a country wants to maintain its current final demand level in relation to domestically produced goods and services in monetary terms (keeping the same amount of spending of final demand in USD) under a no-trade (NT) scenario (i.e., a form of economic self-sufficiency or autarky), its emissions are defined as NT emissions. Under this NT scenario, it is self-evident that a country's production-based emissions are equal to its consumption-based emissions at the country level. Thus, the difference between the actual production-based emissions and NT emissions can be defined as production-based carbon leakage, and the difference between the actual consumption-based emissions and NT emissions can be defined as consumption-based carbon leakage. This could be a new way to measure "avoided emissions" (emissions savings that occur outside a company's value chain) based on the GHG Protocol for Project Accounting (Greenhouse Gas Protocol, 2011, Rocchi et al., 2018).

Given this narrow definition of carbon leakage from both the production and consumption sides, we can then develop two kinds of ratios to measure emissions responsibility. One is the ratio of production-based carbon leakage to total carbon leakage (production-based carbon leakage + consumption-based carbon leakage) for a specific country. This is used to measure the relative importance of a country's carbon leakage as both a producer and a consumer (i.e., a form of horizontal comparison). The other is the ratio of a country's production-based carbon leakage to global production-based carbon leakage. This is used to measure the importance of a specific country in relation to global production-based carbon leakage (i.e., a form of vertical comparison). These ratios can also be applied to consumption-based carbon leakage in the same manner. Because self-responsibility-based emissions from production processes can be measured using our accounting framework, the responsibility that should be shared from the production (or consumption) side can be defined as the difference between production-based emissions (or consumption-based emissions) and self-responsibility-based emissions. Finally, by simultaneously applying these two types of ratios (horizontally and vertically), a country's total responsibility as both a producer and a consumer can be estimated step-by-step based on our algorithm, which can be mathematically proven to be a convergent function when the steps iteratively approach infinity (conventional ways treat the importance of carbon leakage responsibilities from both the production-side and consumption-side equal, but in our method, they are considered different according to 1) the relative contribution of production-based leakage and consumption-based leakage inside a country, and 2) the relative contribution of each type of leakage compared to other countries' leakage level in the world. For detailed mathematical proof, see Meng et al., 2023).

Table 5.1 shows the results of shared global CO_2 emissions by producers and consumers for the 10 largest emitters in 2021. In the extreme case in which all responsibility for emissions transfers is assigned to producers, the PRC accounted for 32.6% of all emissions, followed by the US (13.5%). If all responsibility for emissions transfers is assigned to consumers, the PRC accounted for 29.2% of all emissions, followed by the US (16.7%). On the basis of our shared-responsibility model, the PRC accounted for 31.4% of all emissions, followed by the US (16.1%). In total, developing economies' share of responsibility for emissions has exceeded that of developed countries since 2012. Looking at the shared responsibility for emissions transfer by route, obviously GVC trade accounts for the majority (69.0%, of which 42.9% was from simple GVC trade and 26.1% was from complex GVC trade). Developed and developing economies' shares of responsibility for global emissions for the period 1995–2021 were 45.9% and 54.1%, respectively, whereas at the country level, the PRC's share of responsibility (24.9%) was greater than that of the US (19.6%), India (5.3%), Russia (5.1%), Japan (4.8%), and Germany (2.8%). The above result clearly differs from the results obtained using existing methods, which assign responsibilities based on either a linear combination of production-based and consumption-based emissions (Kondo et al. 1998), or along the demand and supply chains based on the production process (Lenzen et al., 2007) with a weight by value-added gain, or the volume of emissions that are saved globally because of trade (Dietzenbacher et al., 2020). Our purpose is in line with those of the

Table 5.1: Sharing Emission Responsibilities along GVCs

Unit: $MtCO_2$	Producers take all responsibility for emission transfer (2021)	Consumers take all responsibility for emission transfer (2021)	Shared responsibility between producers and consumers (2021)	Shared responsibility for emission transfer by three trading routes (2021)				Total responsibility on 1995-2021 cumulative global emissions
				Total trade	Traditional Trade	Simple GVCtrade	Complex GVCtrade	
PRC	9424.2 (32.6%)	8458.8 (29.2%)	9092.7 (31.4%)	1744.2 (21.9%)	540.4 (6.8%)	749 (9.4%)	454.8 (5.7%)	161885.2 (24.9%)
United States	3912.2 (13.5%)	4845.4 (16.7%)	4649.4 (16.1%)	1156.2 (14.5%)	358.2 (4.5%)	496.5 (6.2%)	301.5 (3.8%)	127559.9 (19.6%)
India	2151.1 (7.4%)	2003.8 (6.9%)	2044.1 (7.1%)	333.4 (4.2%)	103.3 (1.3%)	143.2 (1.8%)	86.9 (1.1%)	34582.3 (5.3%)
Russia	1372.4 (4.7%)	905.6 (3.1%)	1321.9 (4.6%)	535 (6.7%)	165.8 (2.1%)	229.8 (2.9%)	139.5 (1.8%)	33347.1 (5.1%)
Japan	997.8 (3.4%)	1057 (3.7%)	993.7 (3.4%)	276.6 (3.5%)	85.7 (1.1%)	118.8 (1.5%)	72.1 (0.9%)	31222 (4.8%)
Germany	554.9 (1.9%)	692.2 (2.4%)	624 (2.2%)	312 (3.9%)	96.7(1.2%)	134 (1.7%)	81.4 (1.0%)	18479.1 (2.8%)
Indonesia	482.3 (1.7%)	485.4 (1.7%)	475.5 (1.6%)	83.1(1.0%)	25.7 (0.3%)	35.7 (0.4%)	21.7(0.3%)	8919.6 (1.4%)
Mexico	340.4 (1.2%)	349.8 (1.2%)	315.3 (1.1%)	103.2 (1.3%)	32 (0.4%)	44.3 (0.6%)	26.9 (0.3%)	8616.7 (1.3%)
Brazil	310.4 (1.1%)	326.7 (1.1%)	310.3 (1.1%)	92.6 (1.2%)	28.7 (0.4%)	39.8 (0.5%)	24.1 (0.3%)	7867.8 (1.2%)
United Kingdom	266 (0.9%)	439.4 (1.5%)	394.9 (1.4%)	213.5 (2.7%)	66.2 (0.8%)	91.7 (1.2%)	55.7 (0.7%)	12077.6 (1.9%)
RoW	9131.7 (31.6%)	9379.5 (32.4%)	8721.5 (30.1%)	3121.9 (39.2%)	967.2 (12.1%)	1340.6 (16.8%)	814.1 (10.2%)	205547.9 (31.6%)
World	28943.4 (100.0%)	28943.4 (100.0%)	28943.4 (100.0%)	7971.7 (100.0%)	2469.7 (31.0%)	3423.3 (42.9%)	2078.7 (26.1%)	650105.2 (100.0%)
Developed Countries	9651.4 (33.3%)	10749.4 (37.1%)	10530.4 (36.4%)	3746.3 (47.0%)	1160.6 (14.6%)	1608.8 (20.2%)	976.9 (12.3%)	298685.8 (45.9%)
Developing Countries	19292.1 (66.7%)	18194 (62.9%)	18413.1 (63.6%)	4225.4 (53.0%)	1309.1 (16.4%)	1814.5 (22.8%)	1101.8 (13.8%)	351419.5 (54.1%)

Source: authors' estimation based on Meng et al. (2023)

above-mentioned pioneering works, but our method (idea) goes further by explicitly considering the role of GVC-based emissions accounting. The inherent innovation of our method is that we assign responsibility to producers and consumers based on their contribution (using both horizontal and vertical weights) to GVC-based carbon leakage as defined by the difference between their emissions under the NT scenario (where by definition production-based emissions are equal to consumption-based emissions at the country level) and their actual production-based and consumption-based emissions. This makes our results systematically more reasonable.

5.8 Tracing CO_2 Emissions of Multinational Enterprises in Global Value Chains

Climate change is a global issue of great concern that is significantly impacted by MNEs (Pinkse and Kolk, 2012). MNEs, as organizers of GVCs, coordinate the global production division through cross-border trade and FDI (Wang et al., 2021). MNEs account for almost 80% of global trade (WorldBank, 2020) and exert an important impact on greenhouse gas emissions at the global and national levels (Zhu et al., 2022). The Paris Agreement requires its members to submit their nationally determined contributions (NDCs) to meet the 1.5 °C target (UNFCCC, 2015). Under production-based accounting principles, countries can transfer their own emissions to other countries through FDI. This undermines the mitigation efforts of the host country. Consequently, it is crucial to clarify the CO_2 emissions behaviors of MNEs and raise their mitigation incentive via effective policy design.

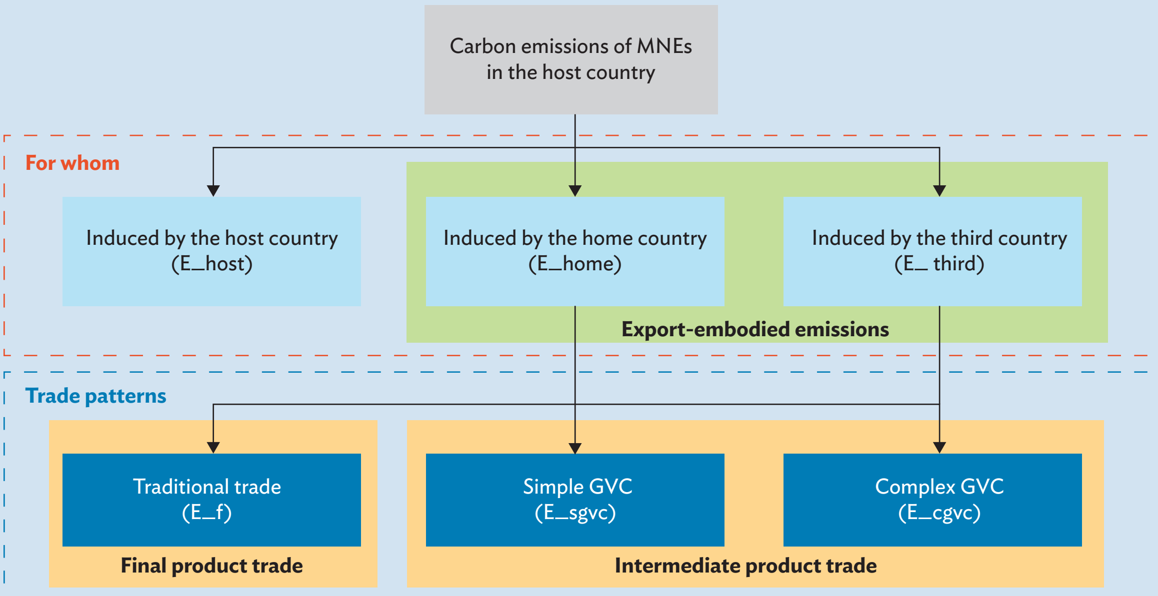
5.9 Measuring the CO_2 Emissions of MNEs in GVCs

The outward investment activities of MNEs involve not only the destination of the investment (host country) and the country of investment (home country), but the demand of third countries (countries that are neither host nor home countries) also triggers production behavior in the host country, inducing CO_2 emissions at the same time. This section therefore aims to answer the question of “MNEs emit CO_2 for whom” and to explore the reasons for the flow of MNEs’ CO_2 emissions to different destinations, especially to third countries. In addition, this section also distinguishes the CO_2 emissions of MNEs embodied in different trade patterns.

Box 5.1: Accounting for CO_2 Emissions of MNEs in Global Value Chains

The figure illustrates an accounting framework that quantifies the CO_2 emissions of MNEs in GVCs, while distinguishing the destinations of CO_2 emissions and trade patterns.

CO_2 emission Accounting Framework of MNEs (GVC Forward Linkage-based Decomposition)



Source: authors' compilation based on Wang et al. (2017) and Yan et al. (2023d).

For MNEs producing in one country, the accounting framework can decompose their total CO_2 emissions into seven routes based on the GVC forward linkage as follows:
Route 1: The emissions of MNEs induced by the host country.
Route 2: The emissions of MNEs embodied in the final products exported to MNEs' home counties.
Route 3: The emissions of MNEs embodied in the intermediate products exported to and consumed in MNEs' home counties. In this process, MNEs participate in simple GVC activities.
Route 4: The emissions of MNEs embodied in the intermediate products exported to MNEs' home counties, and the home countries use these intermediate products to produce export products. In this process, MNEs participate in complex GVC activities.
Route 5: The emissions of MNEs embodied in the final products exported to a third country.[a]
Route 6: The emissions of MNEs embodied in the intermediate products exported to and consumed in a third country. In this process, MNEs participate in simple GVC activities.
Route 7: The emissions of MNEs embodied in the intermediate products exported to a third country, and the third country uses these intermediate products to produce export products. In this process, MNEs participate in complex GVC activities.
Route 2-7 could be regarded as the CO_2 emissions induced by foreign countries, in other words, the emissions embodied in MNEs' exports. Following different trade patterns, the emissions embodied in MNEs' exports could be decomposed into two parts: the emissions embodied in the final product trade and those embodied in the intermediate product trade. When considering the number of times that intermediate products cross borders, the emissions embodied in the intermediate product trade of MNEs could be further decomposed into the emissions embodied in simple GVC activities (the intermediate products crossing borders once for production) or complex GVC activities (the intermediate products crossing borders at least twice for production) (Wang et al., 2017).

This framework is operationalized using the Organisation for Economic Co-operation and Development's Analytical Activities of Multinational Enterprises (AMNE) database (Cadestin et al., 2018), which breaks down the sectors according to the shares of domestic- or foreign-owned firms.

[a] The third country in this paper represents "countries/regions other than the host country of MNEs and the home country of MNEs".

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Wang Z, Wei S, Yu X, Zhu K. 2017. Measures of participation in global value chains and global business cycles. NBER Working Paper. No.23222.
Yan Y, Li X, Wang R, Zhou Y, Zhao Z. 2023d. Is there a "third-country effect" in global carbon emission transfer? New insights from multinational enterprises on the trade-investment nexus. GVC Development Report Background Paper.

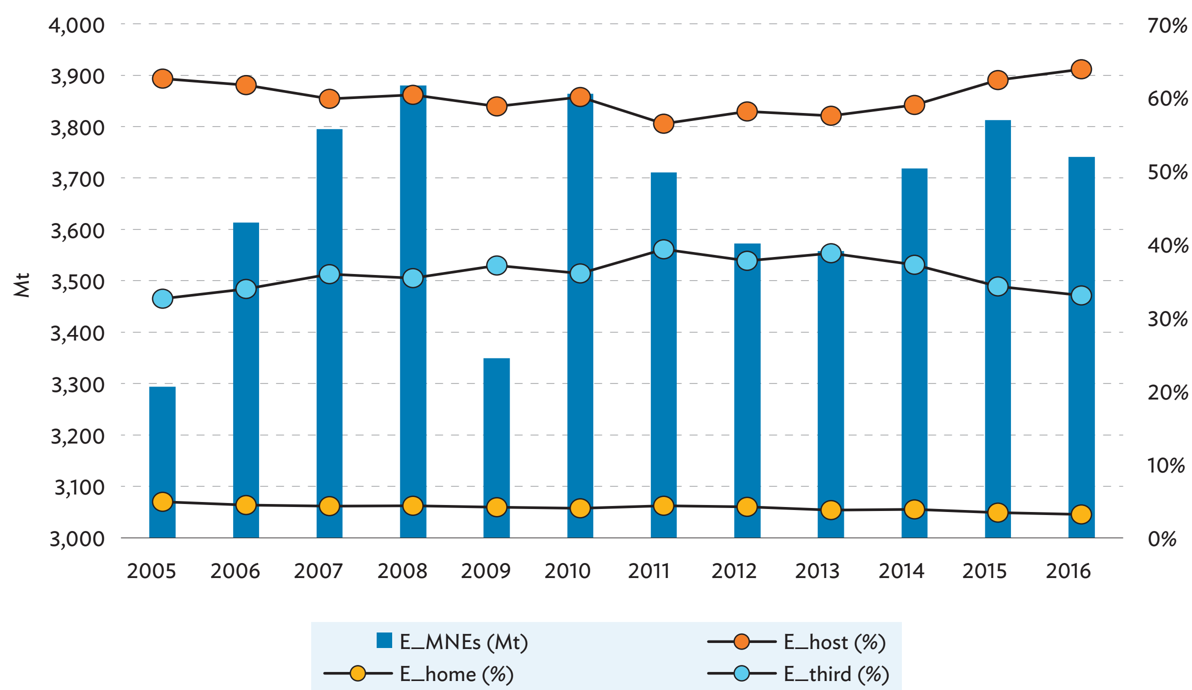
5.10 Changing Trends in MNEs' CO_2 Emissions

The MNEs' CO_2 emissions range between 3,294.0 Mt and 3,879.7 Mt (see Figure 5.6), accounting for 10% to 13% of global CO_2 emissions. MNEs' CO_2 emissions grew sharply before 2009 and decreased to a low point of 3,349.0 Mt due to the impact of the financial and economic crisis. And then further increased to a pre-crisis level of 3,868.2 Mt in 2010 but dropped again. From 2014 to 2016, MNEs' emissions rose slightly compared with the previous years with the recovery of global FDI activity but remained below their 2008 peak.

About the structure of MNEs' CO_2 emissions, it is clear that E_host (60%-70%) and E_third (30%-40%) are the two larger parts. The share of the former decreased from 62.5% to 56.4%, while the share of the latter increased from 32.6% to 39.3% during 2005 to 2011, reflecting the rapid development of global production fragmentation. After 2011, the pair exhibited an opposite trend, suggesting that the motivations for outward investments of several MNEs may have changed, and the focus gradually shifted from export-platform- and efficiency-seeking to market- and strategic asset-seeking. E_home, however, is less than 5% and declines gradually over the whole study period.

CO_2 emissions of MNEs are mainly concentrated in developed countries, such as the US, Germany, Canada, and the UK, which have the advanced technology and large consumer markets to attract a considerable volume of FDI (Figure 5.7). The US, Germany and the PRC were the top three economies in terms of CO_2 emissions by MNEs in 2016, and the

Figure 5.6: Changing Trends and Decompositions of MNEs' CO_2 Emissions (2005-2016)



Notes: E_MNEs represents MNEs' CO_2 emissions, E_host represents MNEs' emissions induced by the host country, E_home means MNEs' emissions induced by the home country, E_third indicates MNEs' emissions induced by the third country.
Source: authors' estimation using the OECD AMNE ICIO data

CO_2 emissions of these countries' MNEs increased by 49.7%, 23.0% and 23.7%, respectively, over the period 2005 to 2016. Large CO_2 emissions by MNEs reflect these economies' heavy involvement in global production fragmentation (ADB, 2021) and their essential role in inter- and intra-regional production-sharing activities.

The EU as a whole achieved an 8.3% decrease in CO_2 emissions of MNEs from 2005 to 2016, for two main reasons First, the establishment of a CO_2 emissions trading system (the European Union Emission Trading Scheme, EU-ETS), making the EU the world's most environmentally regulated region, led to the reliance on more non-fossil energy in production. For example, the share of non-fossil energy use in France increased by 10% between 2005 and 2016.[2] Second, strict environmental regulations have driven some intra-region MNEs to transfer their carbon-intensive production activities to overseas economies with lower environmental standards (usually developing economies), which has reduced emissions from EU members but induced carbon leakage to other economies (Koch and Basse Mama, 2019).

While the volume of MNEs' CO_2 emissions within developing economies is small, emissions have grown rapidly, for example from India (90.9%), Mexico (27.4%) and South Africa (40.3%). This suggests that some developed economies have shifted their production to developing economies through FDI. This allows developing economies to become involved in GVCs and provides new opportunities for them to integrate into the global economy. However, this process is accompanied by significant carbon transfers from developed to developing economies.

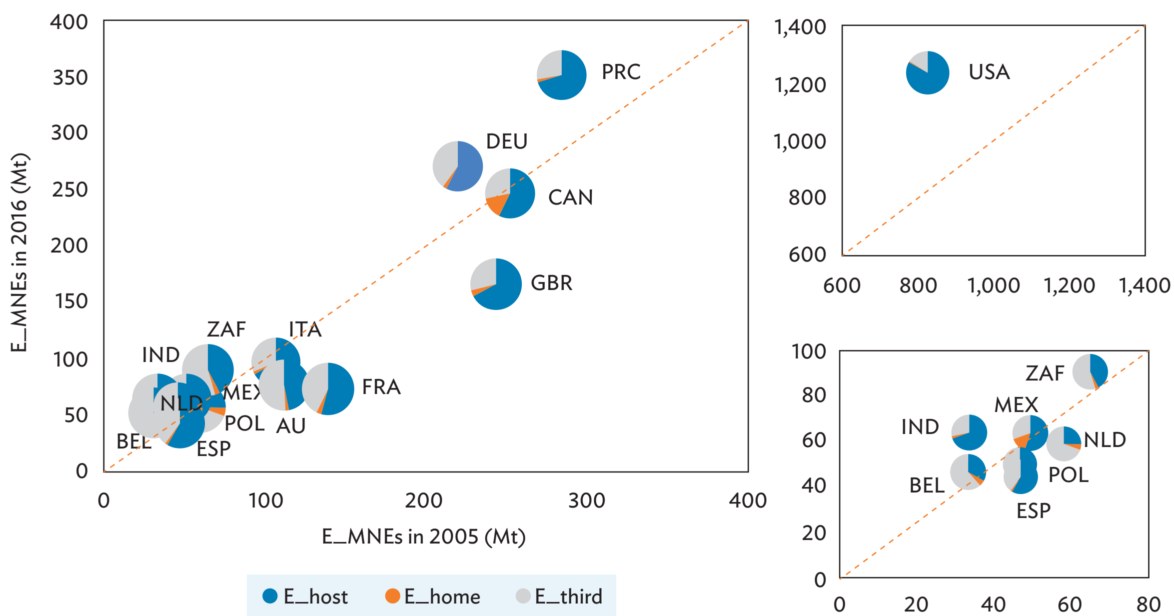
Figure 5.7 also clarifies the question "MNEs emit CO_2 emissions for whom". Differences in the motivation of MNEs to invest in an economy lead to variations in the structure of MNEs' CO_2 emissions. For "large economies", MNEs' CO_2 emissions are mainly induced by the production and consumption of host countries. E_host in the US, PRC, Germany, and the UK, for example, accounted for 83%, 71%, 58%, and 67% of MNEs' CO_2 emissions in 2016, respectively. The incentive for MNEs to invest in these countries is primarily market-seeking, i.e., to capture market share in the world's largest consumer market. As a result, the products of foreign-invested companies are mainly consumed in the domestic market.

The economies with a high E_third share include not only developing economies, such as South Africa (54%), but also some developed economies, such as the Netherlands (69%). This indicates that when MNEs invest in these economies, they not only consider the factor endowments of the host country such as low-cost labor, but also the geographical location, GVC networks and trade agreements, all of which can reduce inter-regional or intra-regional trade costs and facilitate exports to third countries. Some researchers refer to this FDI investment motivation as "third-country export-platform" FDI (Ekholm et al., 2007; Ito, 2013).

2 Data source: https://www.iea.org/data-and-statistics/data-tools/energy-statistics-data-browser, accessed 13 May 2023

There is a noticeable "US effect" on the MNEs' CO_2 emissions in Canada and Mexico. The shares of E_home in both economies are significantly higher than those in the other economies. Tracing the home countries of MNEs shows that the US induced more than 95% of E_home in these two economies. This indicates that American MNEs have established regional production networks with the US as the hub through their "home-country export-platform" FDI (Ekholm et al., 2007).

Figure 5.7: Changing Trends and Decompositions of MNEs' CO_2 Emissions in Selected Countries



Notes: Top fifteen economies with the highest CO_2 emissions of MNEs are selected in this figure. The horizontal axis of the graph represents E_MNEs in 2005, the vertical axis represents E_MNEs in 2016; The red line is the 45-degree line. The economies above the 45-degree line had higher E_MNEs in 2016 than in 2005, and the economies below the 45-degree line had lower E_MNEs in 2016 than in 2005. The colours of the circles represent the proportion of MNEs' CO_2 emissions caused by different destinations in 2016. The meaning of E_MNEs, E_host, E_home and E_third are the same as that shown in notes in Figure 5.6.

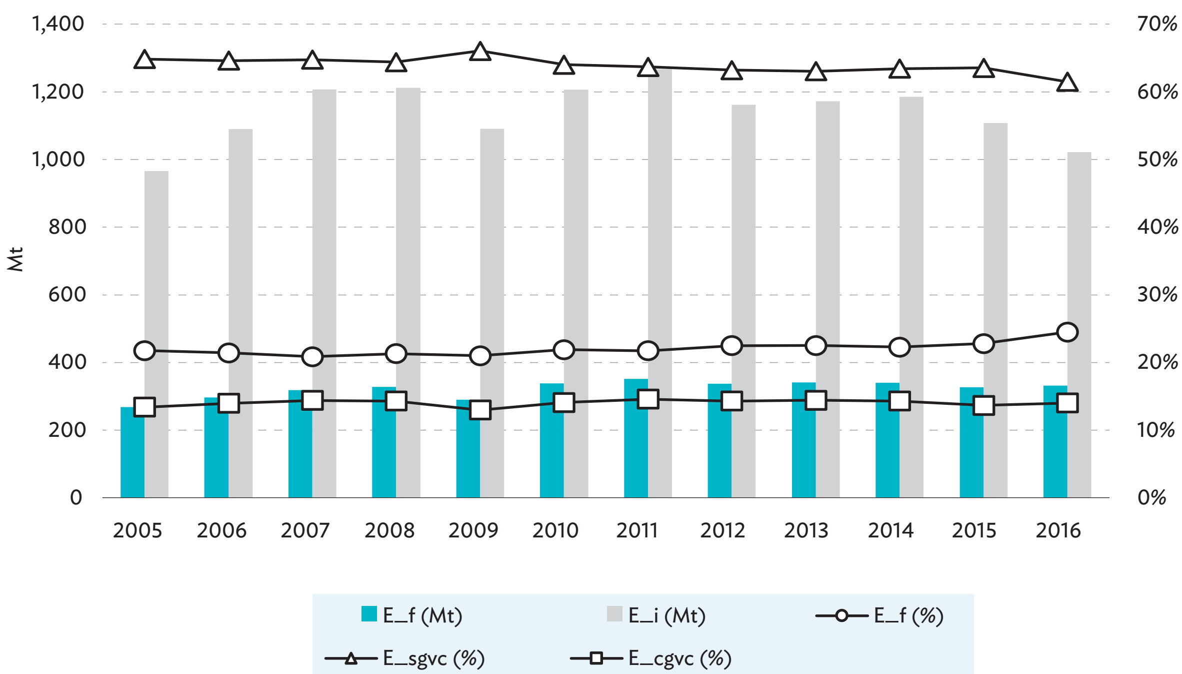
Source: authors' estimation using the OECD AMNE ICIO data.

5.11 Decomposing MNEs' CO_2 Emissions by Trade Patterns

Over 2005 to 2016, emissions embodied in intermediate product trade (E_i) were three to four times the emissions embodied in final product trade (E_f) (see Figure 5.8). This suggests that the production arrangements of GVCs drive the export activities of MNEs. Figure 5.8 also shows that E_f remained relatively stable over 2005-16, while E_i showed significant upturn and downturn. In particular, after 2011, the former showed almost no change, while the latter declined significantly. This implies that, compared with traditional international trade, intermediate product trade, which is part of international production-sharing activities, is more sensitive to global economic fluctuations and changes in the trade policies of various economies and is more vulnerable to economic shocks.

Most emissions from intermediate goods trade are associated with simple GVC activities. Emissions embodied in intermediate goods trade (E_i) can be further decomposed into two parts, emissions embodied in simple GVC activities (E_sgvc) and those embodied in complex GVC activities (E_cgvc), From 2005-2016, over 60% of total MNEs' CO_2 emissions were associated with simple GVC activities and only 15% with complex GVC activities (the remainder were emissions associated with final goods trade). Compared to the finding of Zhang et al. (2017), where emissions embodied in GVC activities account for about 55% of total global emissions without distinguishing firm heterogeneity (i.e., considering emissions generated by both domestic and foreign firms), the results here reflect that MNEs are more deeply embedded in GVC networks than domestic firms.

Figure 5.8: Decomposition of MNEs' Export-Embodied Emissions (2005-2016)



Notes: E_f indicates MNEs' emissions embodied in final product trade, E_i indicates MNEs' emissions embodied in intermediate product trade, E_sgvc represents MNEs' emissions embodied in simple GVC activities, and E_cgvc means MNEs' emissions embodied in complex GVC activities.

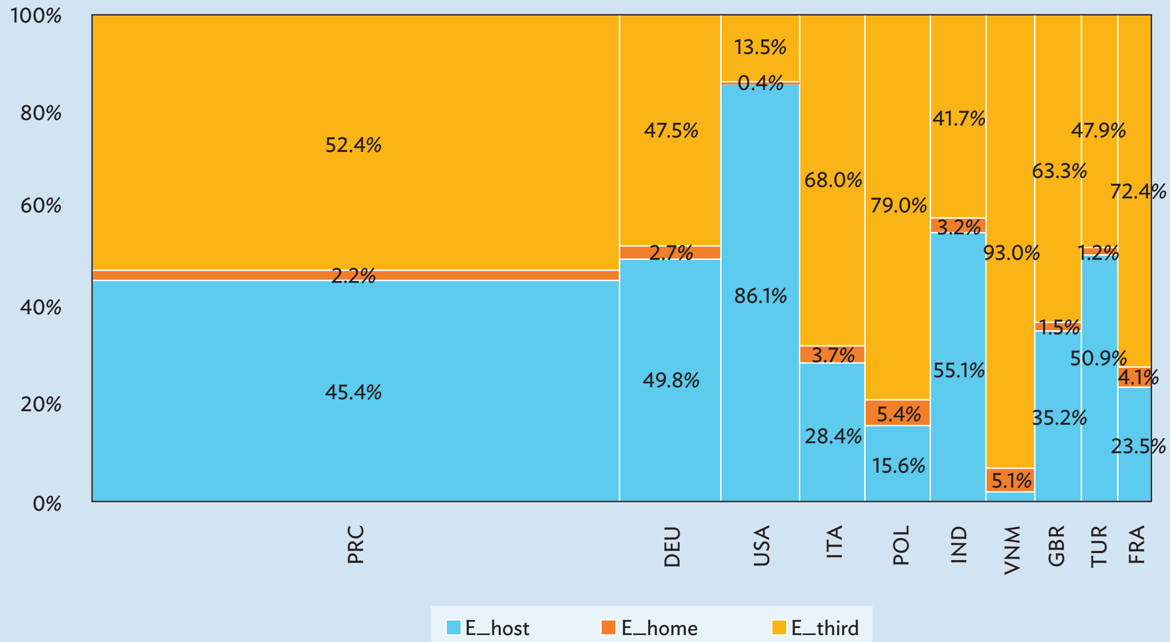
Source: Yan et al. (2023a).

The decline in MNEs' export-embodied emissions is largely driven by a decline in emissions embodied in simple GVC trade. While the share of MNEs' export-embodied emissions accounted for by simple GVC activities (E_sgvc) fell by 3.4 percentage points from 2005-2016, the share of MNEs' emissions embodied in final goods trade (E_f) increased by 2.7 percentage points and of emissions embodied in complex GVC activities (E_cgvc) remained relatively stable. These patterns reflected MNEs' efforts to integrate their cross-border production activities in the face of increasing risks of disruption to

Box 5.2: Sectoral Level Analysis: Textile Industry

Figure 5.9 shows that in the textile sector, the emissions of MNEs generated in the PRC far exceed those of other countries, accounting for about 36.4% of the total CO_2 emissions MNEs generated. From the perspective of component structure, MNEs' emissions in the US textile sector are mainly caused by domestic demand; on the contrary, these emissions in the textile sector of the UK, Italy, France, Poland and especially Viet Nam are primarily induced by third countries; and in textile sector of the PRC, India, Türkiye and Germany, the proportions of MNEs' emissions induced by domestic demand and third countries' demand are relatively close.

Figure 5.9: CO_2 Emissions of MNEs in the Textile Sector of Top 10 Economies (2016)



Notes: Top ten economies with the highest CO_2 emissions of MNEs in the textile sector are selected in this figure. The CO_2 emissions of MNEs in these economies account for more than 70% of all CO_2 emissions of MNEs in the textile sector, hence they are highly representative; the width of each bar on the horizontal axis is proportional to the share of MNEs' CO_2 emissions in the textile sector of one country in the total MNEs' CO_2 emissions in the global textile sector; the wider the bar, the greater the share.

Source: authors' estimation using the OECD AMNE ICIO data.

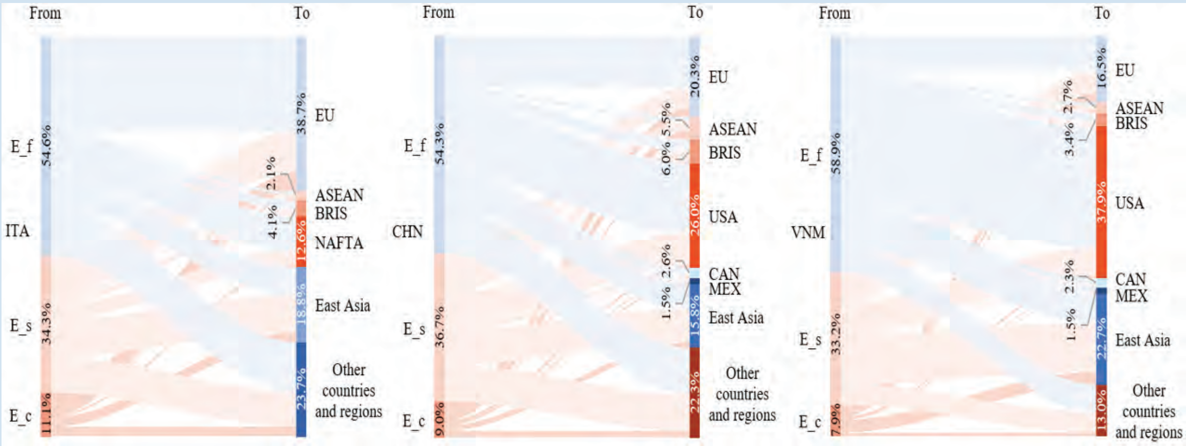
Using the PRC, Italy, and Viet Nam as examples, we can analyze the regional distributions and trade patterns of their CO_2 emissions induced by third countries (see Figure 5.10). In terms of the regional distribution of E_third, the largest share of Italy's E_third flows to the EU, and Viet Nam's and PRC's E_third flowing to the US correspond to the largest share. Furthermore, all three economies' E_third that flows to economies in East Asia and ASEAN are mainly through intermediate products trade, while their emissions flowing to the US are primarily through trade in final products. It indicates that the positions of these three economies in production-sharing activities with economies in East Asia and ASEAN are much closer to the upstream production stages, while in production-sharing activities with the US, they are closer to the downstream production stages.

Just like much literature discussed before, without considering the raw materials trade, economies located upstream of GVCs tend to export more intermediates products, in contrast, those located downstream of GVCs, tend to export more final products (Koopman et al., 2014; Meng et al., 2018; Wang et al., 2013; Zhang et al., 2017). And this finding holds for MNEs hosted by these economies as well: since the production activities of MNEs in host countries mainly use the local factors of production, the relative position of host countries in GVCs would affect the type of goods that their MNEs export.

continued on next page

Box 5.2: continued

Figure 5.10: Decomposition of Third-Country-Induced Emissions of MNEs in the Textile Sector of Selected Economies (2016)



Source: authors' estimation using the OECD AMNE ICIO data.

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global supply chains driven by the rise of trade protectionism and deglobalization since the financial crises. Such efforts involved cutting down the production length and number of times intermediate inputs cross borders to ensure the stability of their supply chains, such as production nearshoring and reshoring initiative. And this has largely involved replacing intermediate products related to simple GVCs with products generated domestically, as the former only cross borders once, it may be easier and less disruptive to find domestic substitutes than for intermediate goods traded in complex GVC activities. The production-sharing activities of complex GVC involve intermediate goods crossing borders multiple times, shaping production networks that encompass many economies. It is relatively hard for MNEs to reshape the production arrangements of complex GVCs. Thus, it is not surprising that the share of E_cgvc remained almost unchanged over the period.

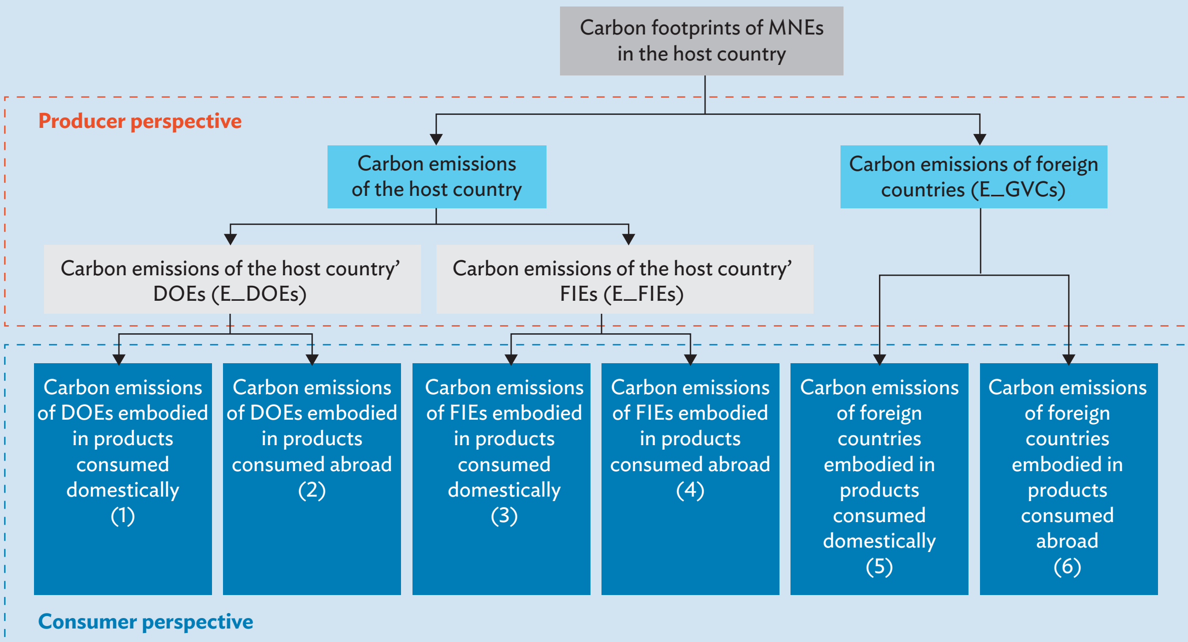
5.12 Measuring the Carbon Footprints of MNEs in GVCs

With FDI becoming an important means for MNEs to conduct globalized production, the environmental impact of MNEs, through GVCs, transcends not only these companies but also their national boundaries as they affect climate change worldwide. This part therefore aims to clarify the source of upstream inputs used by MNEs' final products production and CO_2 emissions they induce as well as the consumption destination of MNEs' final products and CO_2 emissions embodied in.

Box 5.3: Accounting for Carbon Footprints of MNEs in Global Value Chains

The figure illustrates an accounting framework proposed by Yan et al. (2023b) that quantifies the carbon footprints of MNEs in Global Value Chains, while distinguishing sources and destinations of carbon footprints.

Carbon Footprints Accounting Framework of MNEs (GVC Backward Linkage-based Decomposition)



Source: Yan et al. (2023b).

For MNEs producing in one country, the accounting framework can decompose their total carbon footprints into six routes based on the GVC backward linkage as follows:
Route 1: CO_2 emissions of the host country's DOEs (domestically owned enterprises) that are induced by MNEs' final product production (E_DOEs), and these final product productions are consumed domestically.
Route 2: CO_2 emissions of the host country's DOEs that are induced by MNEs' final product production, and these final productions are consumed abroad.
Route 3: CO_2 emissions of MNEs' foreign affiliates (i.e., the FIEs) in the host country that are induced by MNEs' final product production (E_FIEs), and these productions are consumed domestically.
Route 4: CO_2 emissions of FIEs in the host country that are induced by MNEs' final product production, and these productions are consumed abroad.
Route 5: CO_2 emissions of foreign countries that are induced by MNEs' final product production through GVCs (E_GVCs), and these productions are consumed domestically.
Route 6: CO_2 emissions of foreign countries that are induced by MNEs' final product production through GVCs, and these productions are consumed abroad.

This framework is operationalized using the Organization for Economic Co-operation and Development's Analytical Activities of Multinational Enterprises (AMNE) database (Cadestin et al., 2018), which breaks down the sectors according to the shares of domestic- or foreign-owned firms.

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5.13 Component Structure of MNEs' Carbon Footprints, A Producer Perspective

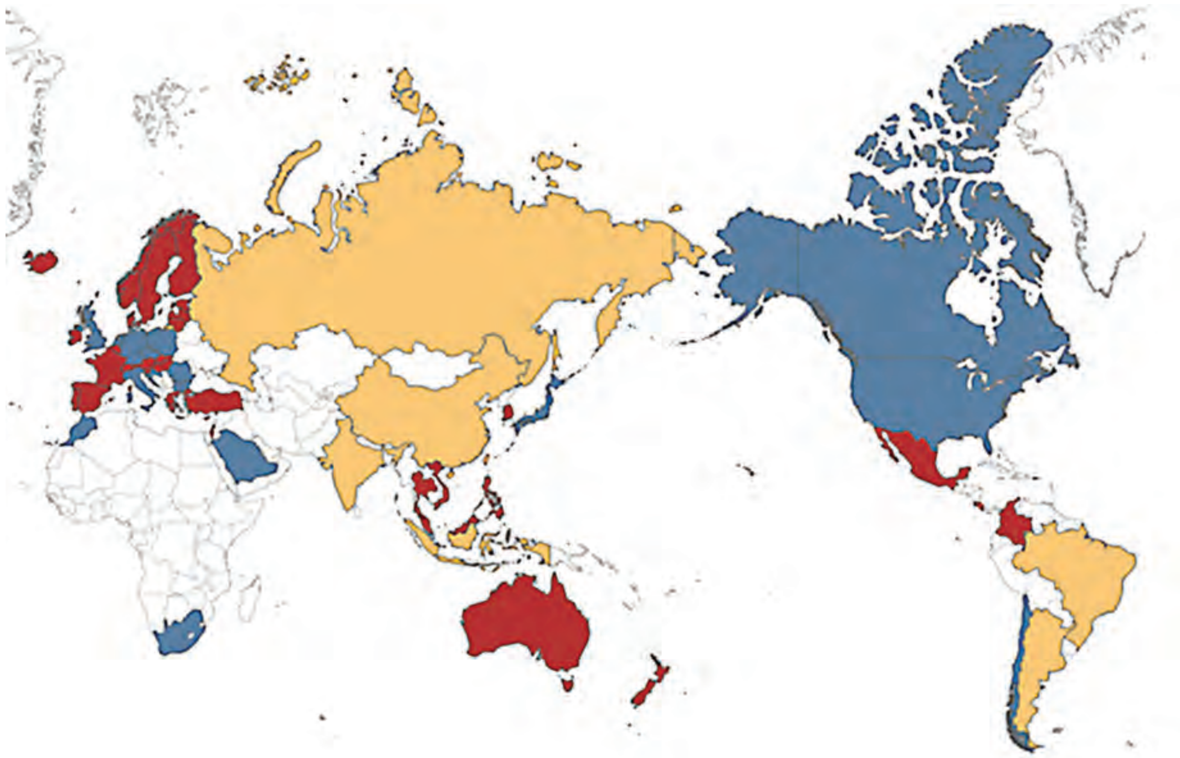
Figure. 5.11 decomposed MNEs' carbon footprints (CFs) from a producer perspective. Clearly, in major developed economies, especially G7 countries that are located upstream of GVCs and focus on innovative activities, as well as parts of economies in Europe, MNEs' CFs consist mainly of emissions generated by their affiliates; that is, the emissions of FIEs (E_FIEs). For example, in the US and Germany, E_FIEs account for between 50% and 60% of total CO_2 emissions induced by MNEs' final production. For some developing economies, particularly those BRIC countries with larger economies but that are normally located relatively downstream of GVCs, the emissions of DOEs (E_DOEs) account for the lion's share of MNEs' CFs; for instance, in the two largest emerging economies, the PRC and India, E_DOEs account for 74.0% of MNEs' total induced emissions in the former and 53.4% in the latter. This is not only because DOEs' carbon intensities in these economies are significantly higher than those of FIEs, but it is also because these domestic-owned firms are increasingly engaged in production-sharing activities with MNEs, particularly as upstream intermediate goods suppliers of MNEs (Wang et al., 2021). In the majority of countries in South and Southeast Asia, Latin America, and Europe, especially those countries with relatively small economies, the CFs of MNEs consist mainly of foreign emissions induced through GVCs (E_GVCs), typically in Singapore and Mexico. In 2016, foreign emissions induced by Singapore-hosted MNEs accounted for 78.9% of that country's total induced emissions through imports of intermediates related to GVC activities, the share in Mexico was 42.7%, showing the very open nature of these two economies' markets and their high dependence on GVCs.

5.14 Component Structure of MNEs' Carbon Footprints, A Consumer Perspective

It is also very important to analyze the MNEs' CFs along GVCs from the downstream final consumer perspective as it helps to understand how the final use could trigger the emissions embodied in the entire upstream supply chain. Figure. 5.12 decomposes MNEs' CFs from a consumer perspective.

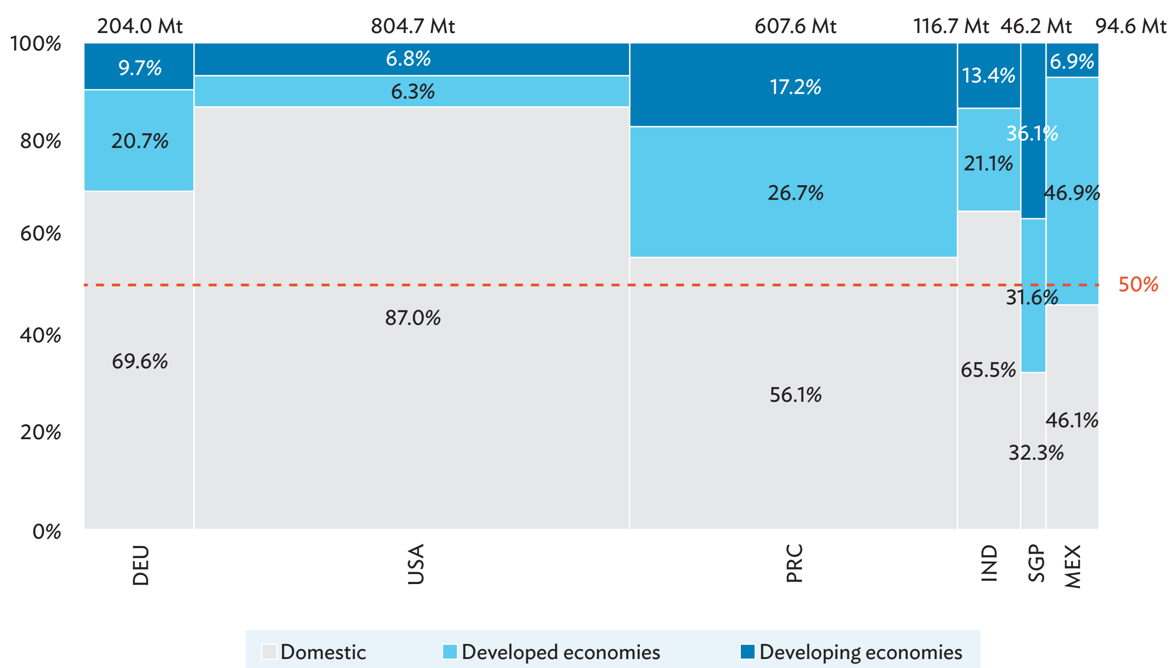
As we can see, in the US, Germany, the PRC and India, all MNEs-induced emissions are mainly embodied in products consumed domestically. Especially in the US, where emissions embodied in domestically consumed products account for 87.0%. It means that most domestic (either DOEs or FIEs) and foreign upstream suppliers' products are generated to fulfill the own demands of the US because of its huge local markets and strong domestic purchasing power. In contrast, for Singapore, 67.7% of MNEs' CFs are linked to foreign final demands. And more importantly, shares of emissions induced by developed economies as well as developing economies are relatively close. Due to its position in GVCs and its factor endowments, Singapore's economy is oriented

Figure 5.11: Component Structure of MNEs' Carbon Footprints, a Producer's Perspective (2016).



Note: Economies marked in blue represent MNEs' CFs consisting mainly of emissions generated by FIEs, and those marked in yellow and red represent MNEs' CFs consisting mainly of emissions generated by DOEs and emissions generated abroad, respectively.
Source: Yan et al. (2023b).

Figure 5.12: Component Structure of MNEs' Carbon Footprints in Selected Economies, A Consumer's Perspective (2016).



Notes: The data at the top of the chart shows the carbon footprints of MNEs hosted by each economy.
Source: Yan et al. (2023b).

toward both developed and developing economies. On the one hand, it makes up for the lack of productive capacity in developing economies by exporting high-value-added intermediate products; on the other hand, it is also closely integrated into the production networks of developed countries, becoming an essential hub in the global production network. Another interesting finding is that compared with developed economies, foreign final demands correspond to a much larger share of MNEs' CFs in the PRC, India, and Mexico, and most of these demands come from developed economies. Mexico is of particular concern since 46.9% of its MNEs' CFs are associated with the demands of developed economies, while this share of the PRC and India are 26.7% and 21.1%, respectively. And relatively lower consumption power of the domestic market and the deeper embedding of GVCs are the main reasons for this phenomenon.

5.15 Re-evaluating the Carbon Mitigation Responsibilities of MNEs in Global Value Chains: From a Factor Income Perspective

Tracing MNEs' emissions along GVCs, as the previous section does, misses a crucial aspect: redistribution of emission responsibility. Transnational investment of MNEs promotes the redistribution of environmental costs and economic benefits across countries. As pointed out by Bohn et al. (2021), "value-added generated within a country does not necessarily result in income for that country. Although a large share of the value-added is absorbed by the host country's residents in the form of wages, reinvested earnings, and profits, a substantial share of MNEs' earnings is repatriated as income to owners in the home country of the MNEs". If taking all CO_2 emissions MNEs' generated into host/ home countries' environmental costs, that would lead to an overestimation or underestimation of emissions responsibility among different countries.

In this section, we follow the study of Meng et al. (2022), not only proposing a new accounting criterion in terms of factor income for both CO_2 emissions and value-added of MNEs, the factor income-based accounting (FIBA). Such accounting can be used to show the unequal allocation of environmental costs and economic benefits between developing economies and advanced economies. We also propose an incentive fund led by MNEs of advanced economies as a complement to the Green Climate Fund (GCF), to reward emerging markets and developing economies that are aggressive in reducing emissions by providing financial support for their renewable energy projects and innovations that reduce the cost of carbon capture and storage.

Box 5.4: The Concept of Trade in Factor Income and its Relationship with Gross Trade Volume and Trade in Value-Added (using US exports to PRC as an example).

In an input–output (IO) system, value-added in relation to factor income is composed of labor compensation, net taxes, and returns on capital (including both tangible and intangible assets; in practice, i.e., gross operating surplus including capital depreciation). In gross terms, US exports (1 + 2 + 3 + 6 + 7 + 8 + *) include the domestic value-added of US- (1 + 2 + 3) and foreign-owned firms (6 + 7 + 8) in the US and foreign value-added and double-counted parts of intermediates embodied in those exports (*). In value-added terms, US exports (1 + 2 + 3 + 6 + 7 + 8) are the pure domestic value-added (1 + 2 + 3 + 6 + 7 + 8), that is, no foreign value-added or double counting is involved. In factor income terms, US exports (1 + 2 + 3 + 4 + 5 + 6 + 7) include the domestic value-added of US-owned firms (1 + 2 + 3), returns on capital of US-owned firms located in the PRC (4) and third countries (5), labor compensation for foreign-owned firms in the US (6), and net taxes on the products of foreign-owned firms located in the US (7).

Firm Location / Firm ownership	Located in the US			Located in the PRC			Located in Third Countries		
American-owned Firms	Labor Compensation 1	Net taxed on products 2	Return to Capital 3	Labor Compensation *	Net taxed on products *	Return to Capital 4 *	Labor Compensation *	Net taxed on products *	Return to Capital 5 *
Foreign-owned Firms (including Chinese-owned Firms)	Labor Compensation 6	Net taxed on products 7	Return to Capital 8	Labor Compensation *	Net taxed on products *	Return to Capital *	Labor Compensation *	Net taxed on products *	Return to Capital *

Notes: * refers to the foreign value-added and double counting embodied in US gross exports to the PRC; Net taxes refers to taxes minus subsidies on products.
US exports to PRC measured in different ways:
Gross Exports = 1 + 2 + 3 + 6 + 7 + 8 + *.
Trade in Value-Added (TiVA) = 1 + 2 + 3 + 6 + 7 + 8.
Trade in Factor Income (TiFI) = 1 + 2 + 3 + 4 + 5 + 6 + 7.

Source: Meng et al. (2022)

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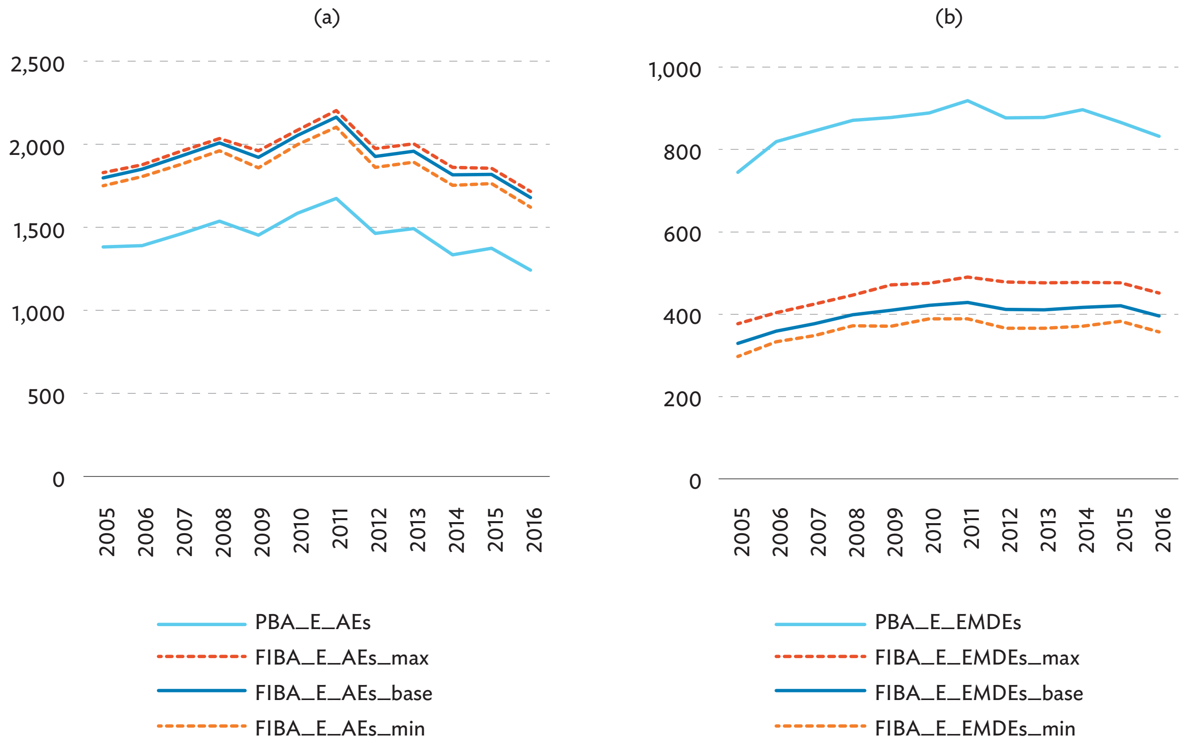
Meng B, Gao Y, Ye J, Zhang M, Xing Y. 2022. Trade in factor income and the US-PRC trade balance. China Economic Review. 73, 101792.

5.16 Environmental Costs and Economic Benefits of MNEs

Figure 5.13a and b show emissions of advanced economies as well as emerging markets and developing economies because of the production of MNEs' affiliates, as measured by production-based accounting (PBA) and FIBA. MNEs' emissions from emerging markets and developing economies measured by PBA are much higher than their emissions measured by FIBA, whereas for advanced economies, MNEs' emissions estimated by the PBA method are far lower than those estimated by the FIBA method. This suggests that emissions of emerging markets and developing economies due to inward FDI are higher than the emissions due to their outward FDI, and the advanced economies are the opposite. This result, to a certain extent, supports the pollution haven hypothesis discussed by Sapkota and Bastola (2017), Shao (2017), Shahbaz et al. (2018) and Avendano et al. (2023). That is, FDI becomes the framework for MNEs of advanced economies to transfer pollution and emissions to emerging markets and developing economies with lower environmental standards to reduce their implementation costs and carbon tax (Singhania and Saini, 2021).

Figure 5.13: CO_2 Emissions Measured by PBA and FIBA between 2005 and 2016 (Mt)

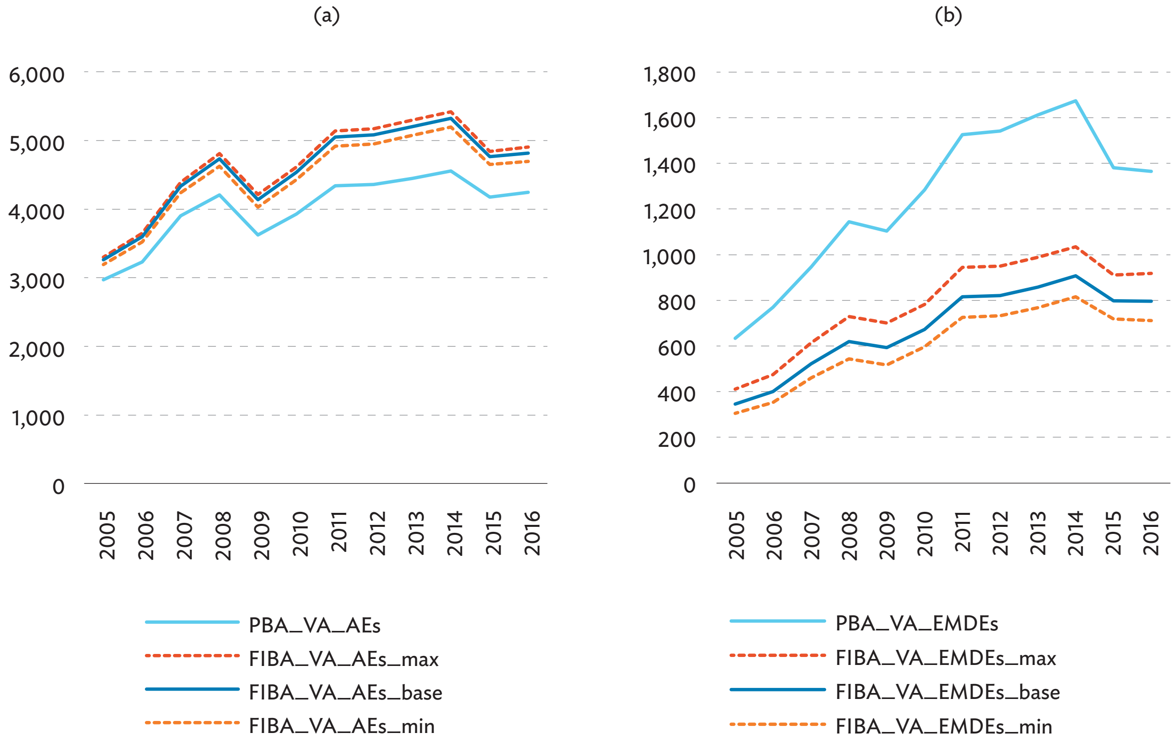


Notes: PBA_E represents CO_2 emissions that are calculated by the PBA method, FIBA_E indicates CO_2 emissions that are calculated by the FIBA method; AEs means advanced economies, EMDEs means emerging markets and developing economies; "min", "base", and "max" show the lower bound, baseline and upper bound of CO_2 emissions calculated by FIBA method (the bound setting is based on production technology assumptions).
Source: authors' estimation using the OECD AMNE ICIO data.

Now, let us turn our attention to the value-added created by MNEs' affiliates (Figure 5.14). The PBA value-added of emerging markets and developing economies is more than twice as much as their FIBA value-added. In contrast, advanced economies' PBA value-added is much lower than their FIBA value-added. Thus, advanced economies captured significant capital gains from emerging markets and developing economies through FDI activities, whereas emerging markets and developing economies experience a net outflow of factor income in terms of capital return from MNEs' activities.

Overall, flows of FDI not only lead to carbon transfers between host and home countries but also facilitate the redistribution of value-added and benefits between them. While MNEs' affiliates create a large amount of value-added in host countries, the benefits of this value-added might not entirely belong to in these countries (Bohn et al., 2021; Meng et al., 2022). However, CO_2 emissions generated in the process of creating this value-added are all accounted for (under PBA) by host countries' territorial emissions, which leads to the imbalance between benefits and environmental pollution in some economies. In global cross-border investment activities: the "real" value-added and CO_2 emissions generated through FDI in advanced economies, may be underestimated, while those in

Figure 5.14: Value-Added Calculated by PBA and FIBA between 2005 and 2016 (Billion USD)



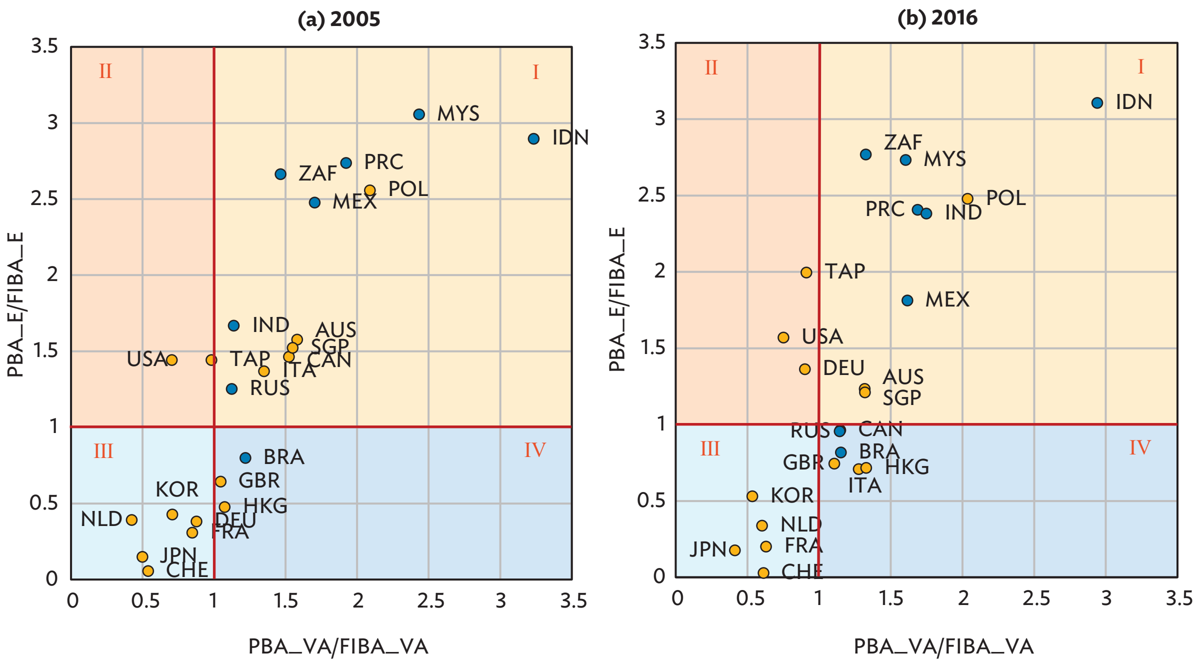
Notes: PBA_VA represents value-added that calculated by the PBA method, FIBA_VA indicates value-added that calculated by the FIBA method; AEs means advanced economies, EMDEs means emerging markets and developing economies; "min", "base", and "max" show the lower bound, baseline and upper bound of value-added calculated by FIBA method (the bound setting is based on production technology assumptions).
Source: authors' estimation using the OECD AMNE ICIO data.

emerging markets and developing economies may be overestimated. This overestimation and underestimation are masked in the traditional PBA framework. Advanced economies actually gain higher economic benefits than those of traditional statistical caliber, while the environmental costs they are allocated are far lower than their actual responsibility. Whereas emerging markets and developing economies do the exact opposite, they got a smaller factor income in terms of capital return while higher environmental costs than those of traditional statistical caliber.

At the country level, Figure 5.15 separates selected economies into four categories. Category III, the lower left quadrant, includes major FDI-outflowing countries (e.g., Republic of Korea, Japan, Netherlands, France, and Switzerland)[3] where PBA MNEs' emissions and value-added are lower than FIBA MNEs' emissions and value-added. These economies via outward FDI not only transfer a large volume of CO_2 emissions but also gain a large amount of capital gain-based factor income.

[3] In 2016, the outward FDI flows of Netherlands, Japan, Switzerland, France and the Republic of Korea ranked 3rd, 4th, 5th, 7th, and 11th respectively in the world, and their outward FDI stocks ranked 2nd, 6th, 8th, 9th and 15th respectively in the world. More details see https://data.oecd.org/fdi/fdi-flows.htm#indicator-chart.

Figure 5.15: PBA and FIBA MNEs' CO_2 Emissions and Value-Added of Selected Economies (2005 and 2016)



Notes: PBA_VA and PBA_E represent MNEs' value-added and CO_2 emissions calculated by the PBA method, FIBA_VA and FIBA_E indicate MNEs' value-added and CO_2 emissions calculated by the FIBA method; the vertical axis shows the ratio of PBA_E to FIBA_E. If PBA_E/FIBA_E>1, PBA CO_2 emissions are larger than FIBA CO_2 emissions, whereas if PBA_E/FIBA_E<1, PBA CO_2 emissions are smaller than FIBA CO_2 emissions. The horizontal axis shows PBA_VA/FIBA_VA. If PBA_VA/FIBA_VA>1, PBA value-added is larger than FIBA value-added; otherwise, PBA value-added is equal to or smaller than FIBA value-added.

Source: authors' estimation using the OECD AMNE ICIO data.

Most leading emerging markets and developing economies that receive large inward FDI such as the PRC, India, Mexico, and South Africa, fall into category I (upper right quadrant). Both PBA MNEs' emissions and value-added of these economies are far larger than their FIBA MNEs' emissions and value-added, which suggests that in the process of FDI-driven globalized production, emerging markets and developing economies paid relatively higher environmental costs (i.e., the CO_2 emission inflows via inward FDI) compared to their relatively smaller gain of factor income (i.e., the value-added outflows via inward FDI).

In category II (upper left quadrant of Figure 5.15), the US is typical. CO_2 emissions of MNEs computed by PBA are larger than those computed by FIBA, while the PBA MNEs' value-added is smaller than the FIBA MNEs' value-added, implying the US has net inflows in both CO_2 emissions and value-added under transnational investment. This phenomenon may contradict the general intuition since the US has the world's largest FDI outflows. One reason is that the US MNEs focus on services sectors which are relatively green that carbon intensive manufacturing sectors. Another possible explanation is that a large portion of US FDI flows to destination countries through tax havens, and these investments are not directly counted as US outward FDI (Coppola et al., 2021). If all these hidden investments were included in US outward FDI, then its carbon transfer and income via investment might be much larger than the values currently calculated.

For economies in category IV (lower right quadrant), CO_2 emissions of MNEs calculated by the PBA method are smaller than those calculated by the FIBA method, whereas the PBA MNEs' value-added is larger than the FIBA MNEs' value-added. Thus, while these economies transfer part of their CO_2 emissions through outward FDI activities, simultaneously, the inward FDI flowing to them also leads to a net outflow of their value-added. The UK is a prime example. Like many advanced economies, through outward FDI activities, the UK transfers a larger volume of emissions abroad and thereby expresses a net benefit in terms of the environment.

The ratios of PBA_VA/FIBA_VA and PBA_E/FIBA_E of emerging markets and developing economies, especially that of the PRC and Malaysia, declined markedly from 2005-2016. This was mainly caused by their growing outward FDI.[4] Another finding is that in both Canada and Italy, because of the decline in CO_2 emission intensities of their hosted MNEs,[5] the values of PBA_E/FIBA_E have decreased remarkably, shifting them from category I to category IV. In contrast, owing to the growing carbon coefficients as well as expanding outputs of foreign affiliates,[6] this value of Germany shows a significant upturn, which leads it to shift from category III to category II.

From the sector perspective, Figure 5.16 presents PBA and FIBA MNEs' CO_2 emissions and value-added of the basic metals sector in selected economies. More than half of MNEs' emissions were generated in emerging markets and developing economies (Figure. 5.16(a)). Among them, PBA MNEs' emissions in the PRC, other emerging markets and developing economies accounted for 34.2% and 23.9% of the total emissions generated by MNEs, respectively. In contrast, the share of PBA emissions of advanced economies in MNEs' total emissions was approximately 40%, most of which were mainly generated in the EU23 (25.6%), while only 8.4% and 7.9% were emitted in the US and other advanced economies, respectively. Notably, although MNEs emitted approximately 1/3 of their total emissions within the PRC's territory, the share of value-added they created in the PRC was only 14.1%. In contrast, these firms generated 25.6% and 7.9% of their total emissions in the EU23 and other advanced economies, respectively, whereas the shares of value-added they created were 40.7% and 15.0%, respectively. This highlights the high emissions and low value-added production characteristics of foreign affiliates in the Chinese metals industry.

Next, we consider FIBA-based MNEs' emissions. The FIBA emissions of emerging markets and developing economies, including the PRC, accounted for approximately 30% of the total global emissions generated by MNEs, whereas the share of advanced economies represented by the US and EU23 was approximately 70%. However, FIBA value-added to emerging markets and developing economies was only 18%, and

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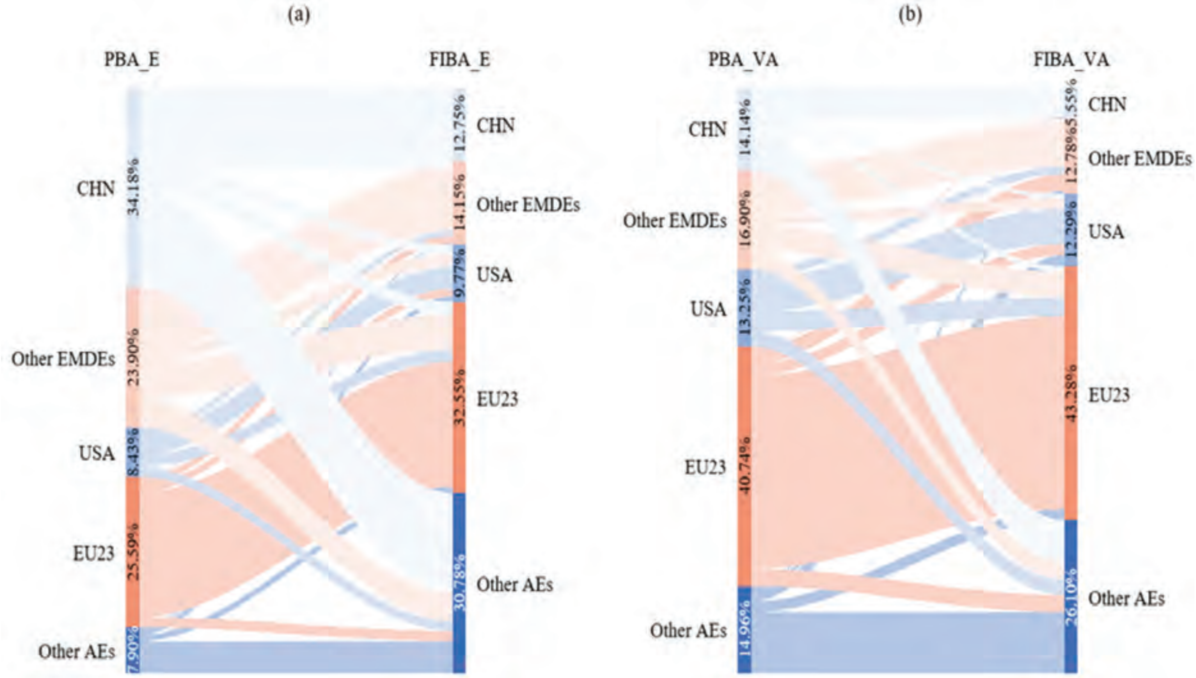
4 In 2005, the outward FDI stocks of the PRC and Malaysia are 57.2 billion USD and 22.0 billion USD, while in 2016, their outward FDI stocks grow to 1,357.4 billion USD (+2372.8%) and 126.02 billion USD (+571.9%).

5 The CO_2 emission intensities of foreign MNEs in Canada and Italy declined from 0.29kg/USD and 0.09kg/USD in 2005 to 0.16kg/USD and 0.06kg/USD in 2016.

6 The CO_2 emission intensities of Germany-hosted MNEs increased from 0.07kg/USD in 2005 to 0.17kg/USD in 2016.

Figure 5.16: PBA and FIBA MNEs' CO_2 Emissions and Value-Added of the Basic Metals Sector in Selected Economies (2016)



Notes: PBA_VA and PBA_E represent value-added and CO_2 emissions that are calculated by the PBA method, and FIBA_VA and FIBA_E indicate value-added and CO_2 emissions that are calculated by the FIBA method. EU23 indicates 23 advanced economies in the EU, other AEs represents other advanced economies, and other EMDEs means emerging markets and developing economies except for the PRC. The wavy lines show the flows of CO_2 emissions and value-added.

Source: authors' estimation using the OECD AMNE ICIO data.

approximately 82% of the value-added was acquired by MNEs controlled by advanced economies (Figure. 5.16(b)). Special attention should focus on the unbalanced environmental costs and economic benefits between other advanced economies and the PRC; the former bear approximately 7.9% of the total MNEs' emissions while gaining more than 1/4 of their factor income-based benefits via outward FDI activities, whereas the latter undertakes approximately 1/3 of the total emissions generated by MNEs, but only captures less than 6% of their factor income-based benefits.

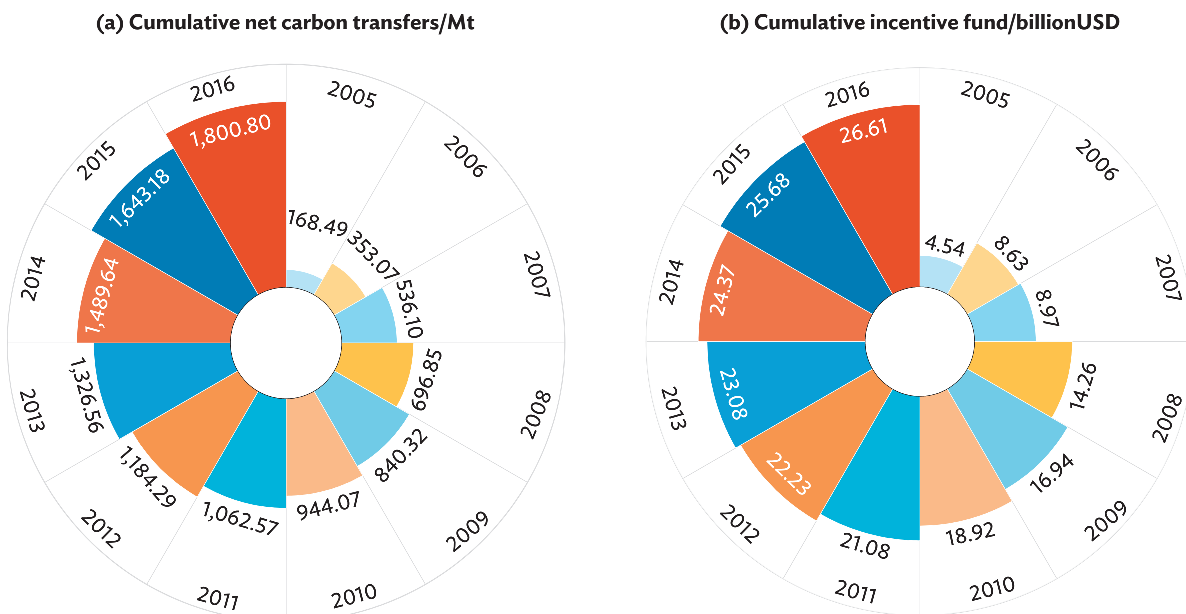
According to the composition of territorial emissions, 96.4% of the PRC's FIBA MNEs' emissions are those emitted domestically; for other emerging markets and developing economies, 74.7% of their FIBA MNEs' emissions are generated within their borders, and approximately 17% are emitted in advanced economies. However, in contrast to emerging markets and developing economies, more than 50% of the advanced economies' FIBA MNEs' emissions are generated abroad. Specifically, the US emits16.9% and 21.8% of their FIBA MNEs' emissions in the PRC as well as other emerging markets and developing economies, respectively; the EU23 generated 6.6%, 18.4%, and 6.3% of their FIBA-based MNEs' emissions in the PRC, other emerging markets and developing economies, and the US, respectively; and for other advanced economies, of all their FIBA MNEs' emissions, only 17.9% were emitted domestically, while 54.9% and 16.0% were emitted in the PRC and other emerging markets and developing economies, respectively.

5.17 Possible Incentive Fund Led by MNEs

Under the FIBA framework, the "real" emissions of advanced economies are much higher than those calculated under the PBA accounting framework used by the Intergovernmental Panel on Climate Change (IPCC). And these excess emissions are net carbon transfers from advanced economies to emerging markets and developing economies through MNEs' investment. As shown in Figure 5.17a, globally, the cumulative net carbon transfers from advanced economies to emerging markets and developing economies were as high as 1800.8 Mt as of 2016, which has significantly increased both environmental costs and emission mitigation pressures on emerging markets and developing economies, albeit under "common but differentiated responsibilities".

In light of this phenomenon, Yan et al. (2023c) proposed to build an incentive fund led by MNEs of advanced economies as a supplementary for GCF, to support the development of renewable energy projects as well as carbon capture and storage technology in emerging markets and developing economies, helping them adapt to and mitigate climate change. The funds transferred could be set equal to the cumulative net carbon transfers from advanced economies to EMDEs, multiplied by an estimate of the price of carbon. Our initial estimation uses the average carbon price[7] of the EU for each

Figure 5.17: Cumulative Net Carbon Transfer and Incentive Fund of Advanced Economies to Emerging Markets and Developing Economies through MNEs (2005-2016)



Source: authors' estimation using the OECD AMNE ICIO data.

[7] A proper way to calculate the responsibility of MNEs' cumulative net carbon transfers in monetary terms is to use the difference of carbon costs (prices) between FDI home and host countries if such data are available.

year of the 2005-16 period. This would result in a transfer of 26.6 billion USD from advanced economies' MNEs to emerging markets and developing economies. While the use of other estimates of the price of carbon and a different time period would generate different results, there is no doubt that this incentive fund would be a strong addition to the GCF if MNEs can reach a consensus on it (Figure 5.17b).

Table 5.2 further illustrates net carbon transfers from advanced economies to emerging markets and developing economies of different industries in 2016, as well as the incentive fund expected to be mobilized from MNEs owned by developed economies. It is clear that the largest carbon transfers from advanced economies to emerging markets and developing economies occur in utilities (267.6 Mt), followed by medium low-tech manufacturing (115.4 Mt). For those carbon transfers, MNEs of advanced economies would pay 1584.1 million USD and 683.3 million USD respectively, which account for 3.3% and 0.4% of the total value-added these firms obtained from emerging markets and developing economies in 2016, to establish the incentive fund, helping developing economies address climate change and carbon mitigation. It must be emphasized that, in contrast to medium low-tech manufacturing, special attention should be paid to mobilizing sufficient incentive funds from MNEs for supporting emission mitigation in utilities of emerging markets and developing economies. This sector is not only more carbon-intensive but also has a much lower labor compensation rate than other industries. In other words, MNEs of advanced economies shift more CO_2 emissions at a smaller economic cost, which undoubtedly increases the pressure on emissions reductions of emerging markets and developing economies.

Table 5.2: Net Carbon Transfer and Incentive Fund of Advanced Economies to Emerging Markets and Developing Economies in Selected Industries through MNEs (2016)

Industry	Net carbon transfer/Mt	Value-added /Million USD	Incentive fund /Million USD	Shares
Primary products	3.63	82,318.33	21.51	0.03%
Low-tech manufacturing	10.00	139,346.78	59.23	0.04%
Medium low-tech manufacturing	115.42	162,676.81	683.30	0.42%
Medium high/high-tech manufacturing	17.22	104,779.79	101.95	0.10%
Utilities	267.57	47,852.21	1,584.10	3.31%
Construction	11.60	97,121.46	68.69	0.07%
Services	9.34	469,348.87	55.32	0.01%

Notes: The 34 sectors are classified as primary products, low-tech, medium low-tech, medium high/high-tech manufacturing, utilities, construction, and services, according to the OECD industry list.
Source: authors' estimation using the OECD AMNE ICIO data.

Conclusion and discussion

Global value chains have become more prevalent in many countries, leading to a surge in CO_2 emissions from international production sharing through both trade and investment (e.g., FDI) channels. The GVC phenomenon, which involves multiple cross-border flows of intermediate goods, may complicate the implementation of the Paris Agreement, which relies on a patchwork of national policies. A persistent challenge in international climate change negotiations is how to allocate responsibility for global warming among the various participants in GVCs, such as producers, consumers, exporters, importers, investors, and investees.

This chapter presents a consistent GVC accounting framework that allows us to trace the CO_2 emissions responsibility of different country-sector-bilateral combinations through various trading routes. Our results show that the emissions from production processes in developing economies, based on their own responsibility, have accounted for a large share of global emissions growth since 2001 and reached a peak in 2019. This is worrisome because most developing economies have weaker environmental regulations and lower enforcement levels. It is imperative to curb these emissions with more effective tools, including environmental regulation, taxation, and the introduction of carbon trading schemes (ETS) domestically. Taking the PRC as an example (see Tang et al. 2020), if more balanced regulation coverage and equalized financial system for heterogeneous firms (whether they are large-scale firms or SMEs, state-owned, foreign-invested, or private firms), could be introduced, the PRC's 2030 commitment to reduce CO_2 emissions could be achieved more efficiently with less GDP loss (its green investment would be 50% lower, and its energy efficiency 84% higher than in the business-as-usual scenario in 2030). Once the PRC could get "greener" in its domestic production, its exports via GVCs will also be greener.

Although the carbon intensity of GVCs, as measured by emissions per unit of value-added, decreased in both developed and developing economies between 1995 and 2021, generating GDP through international trade is still a more carbon-intensive process than generating GDP through purely domestic value chains. Thus, introducing a Carbon Border Adjustment Mechanism (CBAM) in the context of a trade-investment-environment nexus could promote the formation of green value chains in the GVC and Paris Agreement era. However, a well-designed CBAM at the global level is crucial for getting consensus to increase carbon cost and reduce carbon leakage. For example, applying a GVC-based CGE simulation analysis to the EU's CBAM, Qian et al. (2023) show that several EU countries would experience higher GDP growth, and CO_2 emissions outside EU also would be reduced. However, the EU's CBAM will also trigger a slight increase in total CO_2 emissions within the EU due to the "rebound effects" and carbon leakage across EU countries; most countries especially the non-EU countries will suffer a relatively larger decline in consumer welfare. Therefore, an alternative may be to design the carbon border adjustment along GVCs at the country-sector-bilateral level, based on each country's share of responsibility for CO_2 emissions, rather than a simple one-way imposition like a trade tariff.

In addition to looking at responsibility at the country level, we also examine the roles of MNEs, who are the main actors in GVCs. Based on MNEs' complex production arrangements, global CO_2 emissions are transferred not only between investing countries (home countries) and producing countries (host countries), but also among other countries (third countries) in the GVC network, which adds to the complexity of global carbon transfer. From a global perspective, about 30%-40% of MNEs' CO_2 emissions are embodied in their exports to third countries, but these shares vary across different economies due to different FDI motivations and GVC production arrangements of MNEs. Nearly 80% of these third-country induced emissions are related to GVC activities, but this share varies considerably by host country (e.g., the share is only 60% in India and over 90% in Australia), and the GVC position of host countries (whether downstream or upstream in the value chain) is an important factor in this difference. At the sector level, in the textile sector, nearly 1/3 of MNEs' emissions are generated in the PRC, and 50% of them are induced by third countries, while this share is only 14% in the U.S. and more than 90% in Viet Nam.

The transnational investment of MNEs also affects the distribution of emission responsibility and economic benefits across countries. Overall, during 2005-2016, the factor income-based accounting (FIBA) value-added and CO_2 emissions of advanced economies are underestimated by 287.2 billion USD to 766.5 billion USD and 415.4 Mt to 489.6 Mt, respectively, while those of emerging markets and developing economies are overestimated. The latter bears some of the emission responsibility of the former, which partly supports the pollution haven hypothesis. From the national perspective, major FDI-outflowing advanced economies receive more factor income and incur less environmental cost, while major FDI-inflowing emerging market and developing economies receive less factor income and incur more environmental cost. As of 2016, the cumulative net carbon transfers from advanced economies to emerging markets and developing economies through MNEs' investment amounted to 1800.8 Mt. If EMDEs were compensated based on an estimation of this environmental cost, an additional 26.61 billion USD would be used to supplement the Green Climate Fund (GCF). Our research provides a useful reference point for future negotiations of carbon responsibility sharing across countries and offers a feasible way for financing the GCF, which will facilitate the achievement of the net-zero emission target consistent with the Paris Agreement.

Although there is a general agreement on the principle of "common but differentiated responsibilities" (CBDR) among the international community, many challenges remain in implementing it effectively. Given the increasing difficulty of limiting global warming to 1.5°C and the fact that most developing economies have no absolute emissions reduction targets and relatively weak environmental regulations, it is crucial to help these countries set appropriate and ambitious targets for reducing emissions and/or achieving carbon neutrality, which could help curb the current rapid rise in global CO_2 emissions. The Paris Agreement allows countries to start from different points and pursue different ambitions toward their own carbon neutrality goal, and uses production-based accounting to measure their emissions (e.g., the original idea of carbon neutrality at the individual country level means taking full responsibility for all direct and indirect emissions), without explicitly considering the responsibility sharing of carbon leakage caused directly and indirectly by international trade and investment.

This implies that a net carbon exporting country and a net FDI inflow country might bear more responsibility in achieving its own carbon neutrality goal, while a net carbon importing country and a net FDI outflow country might bear less responsibility than needed. In this sense, negotiating about responsibility sharing for carbon leakage across countries is inevitable if we want to achieve the global goal of net-zero emissions. Therefore, our GVC-based sharing approach provides a useful reference point for future negotiations.

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