



# Emissions intensity comparisons and consumption-based CO<sub>2</sub> accounting of transportation services

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## Abstract

As the international division of labour becomes more entrenched, the distance goods travel before they reach the final consumer increases; at least this was the case before the outbreak of the COVID-19 pandemic. International trade and cross-border cargo movements generate significant carbon emissions. Despite theoretical advances, empirical studies frequently draw contradictory conclusions and the influence of international trade on a country's decarbonization efforts is inconclusive. This study examines the carbon emissions caused by countries' transportation services on global value chains. The input–output (IO) model and the 2015 multi-regional environmental input–output table from the UNCTAD-Eora database are employed. The input–output approach was used to determine the carbon emissions generated by the transport sector, along global value chains, in 190 countries. Environmentally extended IO analysis then reallocates emissions responsibilities of the transport sector from production to consumption. The study identifies which country's transport sectors add more value or emit more CO<sub>2</sub>. Our findings indicated that: (1) the transportation industry of a country may have a detrimental effect on the environment while generating minimal economic benefit; and (2) a country's transport industry may be tightly related to global value chain operations, but does not create considerable environmental impact. Given the significant differences in emissions intensity, we propose not only calculating the production-based accounting (PBA) of CO<sub>2</sub> emissions, but also the consumption-based accounting (CBA). If CBA emissions are lower than PBA emissions, a country's transport sector is in carbon-leakage credit. The top three countries with the highest carbon-leakage credit for the transport sector were China, Russia and USA. If carbon emissions are taken into consideration, some nations may cease to possess a comparative advantage in manufacturing and trade.

**Keywords** Carbon emissions · Input–output model (IO model) · Global value chains (GVCs) · Consumption-based accounting (CBA) · Production-based accounting (PBA)

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## 1 Introduction

As trade barriers including information flows and logistics costs, have significantly decreased, international interactions have become more frequent, resulting in the formation of global value chains (GVCs). GVCs account for more than two-thirds of global trade (World Bank 2019). GVCs refer to the people and activities associated with the manufacturing of goods or the provision of services, as well as supply, transportation, distribution, and after-sales activities. Services and finished products are provided through raw material acquisition, design, production, manufacturing, distribution and sales in different countries. The value added to the products in each phase of the process, the role each country plays in supply chains and the interaction they have with each other form GVCs. The French economist Perroux believed that economic growth occurs around a single pole rather than uniformly across an area (or cluster) (Higgins and Savoie 2017). This pole is typically characterized by core sectors that spawn ancillary businesses, primarily due to direct and indirect effects. Direct effects suggest that the core industry either supplies its clients with goods and services or purchases them from its suppliers (upstream related industries) (downstream linked industries). Thus, core industries and connected industries may engage as suppliers or customers. By purchasing goods and services, workers in the primary and related industries, which support the growth and expansion of economic activities such as retail and real estate, may have indirect consequences. The expansion of the core industry entails an increase in output, employment, and investments, in addition to the introduction of new technologies and industrial sectors. Regional development is unbalanced as a result of the magnitude and economics of agglomeration at the growth pole. In such a process, transportation, namely transportation terminals, may be crucial. This relationship is more prevalent and robust the more dependent or associated an activity is with transportation (Olivier et al. 2007).

The resulting need for maritime transport has shifted from a demand for the possession of products to a demand for the possession of added value, timely, dependable, and cost-effective goods (Panayides 2006). Given the deepening of the international division of labor, goods have to be processed in and out of countries multiple times before reaching end consumers. Developed countries have moved manufacturing offshore, enabling businesses to take advantage of relatively lower labor costs, economies of scale, access to specialized inputs (Abraham and Taylor 1996) and new markets and specialized investment opportunities in less developed countries (Cadarsó et al. 2010). Businesses and countries tend to ignore the external effects of long-distance transport, while benefiting from value chains. Meanwhile, several studies quantitatively analyze the emissions of alternative routes and scenarios for transportation services to provide important information regarding policy benefits for shipping or air-transport businesses (McKinnon 2014; Van den Berg and De Langen 2017).

Figure 1 illustrates the import and export values of international trade in US Dollars between 2001 and 2019, during which period the trade value tripled. Multinational corporations and their mother countries have benefitted from the



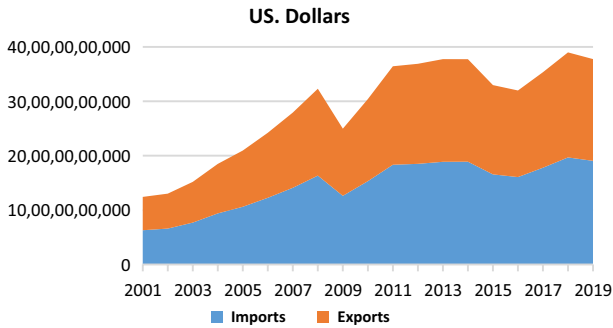


Fig. 1 Import and export values in the period 2001–2019

operation of GVCs. Intermediate products are transported into and out of several nations multiple times in order to be processed. The length of a value chain corresponds to the average number of production stages that a generic product has to undergo along it (Muradov 2016). The composition of a value chain can become intricate. Carbon emissions are generated from two sources of international trade: from the production of goods and their transportation between trading partners. International transportation accounts for 33% of global trade-related carbon emissions (Cristea et al. 2013).

National CO<sub>2</sub> emission inventories can be based on consumption-based accounting (CBA) or production-based accounting (PBA) (Franzen and Mader 2018). Due to the international reallocation of energy-intensive manufacturing, carbon dioxide emissions, known as *carbon leakage*, may increase in countries without emission reduction commitments (Kuik and Gerlagh 2003; Zhang and Fang 2019). Moreover, carbon leakage through the global production outsourcing may undermine the efforts of countries with strict pollution regulations to control their own domestic emissions (Sherafati et al. 2020). Carbon leakage may occur if, for reasons of costs related to climate policies, businesses transfer production to other countries with laxer emission constraints (Babiker 2005; EU ETS 2016). Here, we define carbon leakage as the difference between the amount of consumption-side CO<sub>2</sub> emission and the amount of production-side CO<sub>2</sub> emission. A carbon-leakage debt country means it consumes more carbon than its production produces. A carbon-leakage credit country means it produces more carbon than it actually consumes.

A country can reduce its carbon emissions by replacing domestic production with imported carbon-intensive commodities, thereby separating the country that ultimately consumes goods from the country that produces pollution. Should the emissions of international logistics and offshoring be attributed to producers or consumers (Cadarsó et al. 2010)? Addressing this question is crucial because it helps determine who is primarily responsible for emissions and who should be held accountable for their reduction. How should production be redistributed by international trade between countries with different emission intensities (Wakeland et al. 2012)? In a global manufacturing context, emissions from cross-border transport logistics are easily ignored and their allocation is difficult to identify (Nakamichi



**Table 1** ISIC of transport sectors. *Source* International Standard Industrial Classification of All Economic Activities (Third Revision, 2012)

Group	Class	Description
Division	60	Land transport; transport via pipelines
601	6010	Transport via railways
602		Other land transport
	6021	Other scheduled passenger land transport
	6022	Other non-scheduled passenger land transport
	6023	Freight transport by road
603	6030	Transport via pipelines
Division	61	Water transport
611	6110	Sea and coastal water transport
612	6120	Inland water transport
Division	62	Air transport
621	6210	Scheduled air transport
622	6220	Non-scheduled air transport
Division	63	Supporting and auxiliary transport activities Activities of travel agencies
630		Activities of travel agencies
	6301	Cargo handling
	6302	Storage and warehousing
	6303	Other supporting transport activities
	6304	Activities of travel agencies and tour operators; tourist assistance activities n.e.c
	6309	Activities of other transport agencies

et al. 2016). Is the pollution and emissions division between trading partners “beggar thy neighbour”? This study focuses on the correlation between transportation and the environmental burden of the globalized economy. The study quantifies the carbon emissions of transport sectors for individual countries in the global economy. As shown in Table 1, based on the third revision of the International Standard Industrial Classification (ISIC) of All Economic Activities, transport sectors consist of ISIC-type classification codes 60 (land transport via road, rail, pipelines), 61 (water transport), 62 (air transport), and 63 (supporting and auxiliary transport services) (United Nations Statistical Division 2008; Lenzen et al. 2013). The rest of this paper is structured as follows: Sect. 2 reviews the literature on GVCs, value-added trade and carbon emissions along value chains. Model development details for calculating carbon emissions are presented in Sect. 3. Section 4 details the model results and conclusions and recommendations for future research are offered in the final section.

## 2 Literature review

The literature review first outlines the development history and driving factors of GVCs, and then discusses value-added trade and the literature related to carbon emissions along value chains.



## 2.1 Global value chains (GVCs)

The value chain is defined as the wide spectrum of operations carried out by businesses and employees to make a product from its creation to end use and beyond. This covers tasks such as designing, manufacturing, distribution, delivery and final customer service (Gereffi and Fernandez-Stark 2011). In 1977 Terrence Hopkins and Immanuel Wallerstein (Hopkins and Wallerstein 1977) introduced the words ‘commodity chain’ to monitor the input of all final consumables and track a series of production transformation processes. Later on, the idea of a global commodity chain was presented in Gary Gereffi’s work (1994), to, for example, define an apparel distribution chain from raw materials (such as cotton, wool or synthetic fibers) to the finished product (apparel). The terminology changed from global commodity chains to global value chains (GVCs) in the 2000s, arising from the study of trade and manufacturing organizations as value-added chains (Porter 1985). The value chain concept is similar to that of the product chain, but more optimistic from the viewpoint of trying to understand the determinants of global industrial organizations. A significant distinction illustrated in the literature is producer-driven or buyer-driven chains. Producer-driven GVCs are found in high-tech fields such as semiconductor or pharmaceutical industries. Since these industries depend on technology and R&D, leading companies are positioned upstream and manage product design, while most of the assembling is delegated to downstream countries. Retailers and brand marketers manage production in a buyer-oriented chain, outsource production, and concentrate on marketing and sales. As observed in clothing product chains (Gereffi 1994), GVCs with low capital requirements and less skilled employees are typically structured in this way.

Over the past 20 years, globalization has dominated the world economy. As a result of economies of scale in ocean shipping, physical distance is no longer relevant in trade models, replaced by ‘economic distance’, as this is proxied by ocean freight rates (Haralambides 2017). Products are manufactured in low-wage countries and transported thousands of miles to their destination. However, in the US, since supply chains are often too long, prices of international shipping are high and emerging market costs are rising sharply. More important to this, however, is the *unreliability* of supply chains, and the ensuing costs of higher inventories, particularly since the COVID19 pandemic. As a result, there have been voices arguing for shorter supply chains and *nearshoring*. The concept argues for more investment and employment, sustained wages, and bringing goods and services back home. This helps businesses move corporate thinking away from “cheaper FOB costs” by lowering the overall cost of their products. The Boston Consultancy Group (Sirkin et al. 2011) forecast in 2011 that the U.S. would begin an industrial revival within 5 years and thereby encourage industry and customer convergence, the relocation of producers, and restructuring of the supply chain to form stronger links.

## 2.2 Length of value chains

In order to better account for the internationalization and fragmentation of production, new trade statistics have been developed that can identify the value added by



each country to GVCs. The OECD Trade in Value-Added (TiVA) initiative considers the value added by each country in the production of goods and services that are consumed worldwide. TiVA indicators are designed to better inform policy makers by providing new insights into the commercial relations between nations. Conventional trade statistics compute the overall value of a country's exports, including the value of imported raw materials. However, this means that intermediate goods flowing through several borders are repeatedly overestimated in import and export trade statistics. At the same time, the total sum cannot represent the source of demand for the commodity and the intermediate input, or flow direction and usage of the processed goods. The TiVA initiative focuses mainly on the value created by domestic production activities. The deduction of raw materials can properly represent the relationship between export trade and domestic jobs and other development activities, as well as the contribution of countries' involvement in trade activities to the economy and to the competitiveness of countries. In addition, it is possible to isolate countries in the global value chain by measuring TiVA. The location of the middle and lower reaches of the chain links the chains of trade of different countries, showing the degree of interdependence between countries.

Figure 2 presents the calculated length of value chains of 26 industrial sectors based on the UNCTAD-Eora database (Casella et al. 2019). The length refers to the total number of processing stages of a product along its value chain and is split into upstream and downstream lengths. Assuming that the length of each sector is specified as 1, Fig. 2 shows the average value chain length of each industry sector in the world in 2015. The larger the sum of upstream and downstream lengths, the more complicated the division of labor along the value chains. An industry with a shorter upstream value chain length implies that it is closer to the initial inputs and is located on the upstream of the global value chain. Oppositely, an industry with a shorter downstream value chain length implies that it is closer to the end user and in the downstream position on the global value chain. Figure 2 indicates that the "Metal Products" industry, which includes the manufacture of basic metals and fabricated metal products, except machinery and equipment, is the value chain that has undergone most stages of production. The "Private Household" industry, which includes the activities of private households as employers of domestic staff, has the shortest value chain.

The nature of GVC participation by services and manufacturing sectors is markedly different, with services exhibiting more forward linkages. Figure 2 shows that the 'Transport Equipment Sector' tends to have higher values in the upstream index (distance to final consumer) than the downstream index (steps embodied in production). On the other hand, the 'Transport Sector' tends to have a higher downstream index than upstream index (Fig. 2).

According to the Law of Comparative Advantage, a multinational corporation chooses to produce products and provide services with lower opportunity cost (Krugman 1993). These firms make use of their competitive edge, such as abundant funding, advanced technology, marketing and management, to enjoy the advantages that offshoring brings. Countries that specialize in producing competitive products can offer relatively low-cost goods and services and trade with one another. Both parties are supposed to benefit from the operation of GVCs. Because of the different



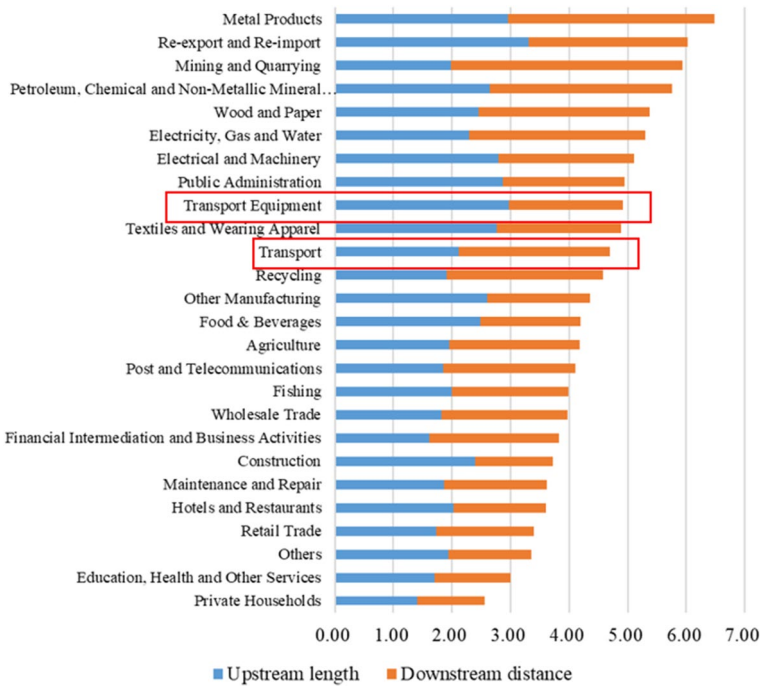


Fig. 2 Length of GVCs

emission reduction standards of countries, developed countries transfer high-polluting industries to countries with low environmental restrictions, and then import the goods and services needed through international trade, thereby reducing their own production emissions to meet standards or cost considerations (Mabey and McNally 1999). Since the 1990s, the positive and negative effects of trade liberalization on the climate have given rise to heated debates. Wakeland et al. (2012) examined how trade redistributes production between countries with different emission intensities. The attribution of emissions from international freight and offshoring was examined by Kuik and Gerlagh (2003) and a number of hypotheses, including the environmental curve of Kuznets (EKC), the pollution paradise hypothesis, and the “underlying race” outcome have been discussed. Despite theoretical advances, empirical studies frequently draw contradictory conclusions and International trade’s influence on national decarbonization outcomes is inconclusive (Fan et al. 2019; Chen et al. 2021).

There are three ways to measure the value added by each country to GVCs. The first is a case study of selected products to track the value created by the product at all stages along its supply chain. It is difficult to provide a comprehensive picture of an economy’s participation in cross-border production chains. The second is the use of current trade Statistics, which deducts all imported intermediate products directly from the gross export value, calculates the portion of the exporting country’s domestic value added, but faces the fact that some goods cannot be clearly distinguished



between intermediate or final products. The third way is to use Input–Output (IO) tables, which combines countries’ statistics such as trade, national income and industry association tables, to indirectly estimate the added value created by countries’ trade. However, the level of detail must be produced through certain assumptions. IO analysis is currently the most commonly used method to measure value-added trade internationally.

The principle of general interdependence between the different components of an economic system has been the cornerstone of economic analysis (Leontief 1936). As the IO model is inherently linear in nature, it is designed to easily quantify and flexibly measure the effects of shifts in demand. Input–output models can also be used to examine interregional trading results in various regions. Additional columns can be added to conduct environmentally extended input–output analysis (EEIOA). Such a model extension has enabled researchers to investigate how a sector induces itself and other economies to pollute in order to meet its own end demand.

### 3 Research method

This section first introduces the IO model, and then uses the IO data to calculate carbon emissions along value chains for individual countries.

#### 3.1 The input–output model and research data

The Eora global supply chain database, based on a multi-region input–output table (MRIO) model, generates a time series of high-resolution input–output tables (IO tables) with corresponding environmental and social satellite accounts for 190 countries. The Eora MRIO includes a balanced global MRIO table that details inter-sectoral transfers across 190 countries, as well as 2720 line item environmental indicators covering greenhouse-gas (GHG) emissions, labor inputs, air pollution, energy consumption, water requirements, and land occupation. We employ a streamlined version (Eora26) with a 26-sector harmonized classification focusing on the Transport sector.

An input–output model is a quantitative economic model reflecting interdependencies between different national economic sectors or regional economies. The model demonstrates inter-industry ties within an economy and shows how one sector’s production can be an input to another sector. Considering the economic activity in a single country, the basic IO table shown as Table 2, contains the intermediate demand ( $T$ ), the final demand block ( $Y$ ), the total output ( $X$ ) and the value added block ( $VA$ ).

Referring to Table 2, the IO table can be split into inputs and outputs, where inputs contain intermediate and initial Inputs, and the outputs are composed of intermediate and end demands. Based on general equilibrium economics, the total input of an economy will be equal to its total output. Equations (1) and (2) show the outputs and inputs of sector  $i$  (transport), respectively. Then, in Eq. (3), the outputs are equal to the inputs.





**Table 2** IO Table for a single country

Output sector		Intermediate demand (T)						Final demand (Y)	Gross output (X)	
		Sector								
		1	2	...	<i>j</i>	...	<i>n</i>			
Input sector										
Intermediate input	Sector	1	$t_{11}$	$t_{12}$	...	$t_{1j}$	...	$t_{1n}$	$y_1$	$x_1$
		2	$t_{21}$	$t_{22}$	...	$t_{2j}$	...	$t_{2n}$	$y_2$	$x_2$
		⋮			⋮				⋮	⋮
		<i>i</i>	$t_{i1}$	$t_{i2}$	...	$t_{ij}$	...	$t_{in}$	$y_i$	$x_i$
		⋮			⋮				⋮	⋮
		<i>n</i>	$t_{n1}$	$t_{n2}$	...	$t_{nj}$	...	$t_{nn}$	$y_n$	$x_n$
Value added (VA)			$va_1$	$va_2$	...	$va_i$	...	$va_n$		
Total input (X)			$x_1$	$x_2$	...	$x_i$	...	$x_n$		

$$\sum_{j=1}^n t_{ij} + y_i = x_{i,out} \quad (1)$$

$$\sum_{i=1}^n t_{ij} + va_i = x_{i,in} \quad (2)$$

$$x_{i,out} = \sum_{j=1}^n t_{ij} + y_i = \sum_{i=1}^n t_{ij} + va_i = x_{i,in} \quad (3)$$

Each element in the matrix  $T[t_{ij}]_{n \times n}$  is further divided by the total outputs of the sector to obtain the input coefficient matrix  $A[a_{ij}]_{n \times n}$ , where element  $a_{ij}$  is the input coefficient, representing the input proportion of sector  $i$  (transport) required to produce one unit product of sector  $j$ .  $X=AX+Y$  and is shown as Eq. (4), where  $\hat{X}$  is the diagonal matrix converted from the column matrix of total outputs  $X$ .

$$A=TX^{-1} \quad (4)$$

$$X=LY \quad (5)$$

The Leontief Inverse Matrix  $L[l_{ij}]_{n \times n}$  depicts the coefficients (economic multipliers) that quantify the subsequent effects on the economy of an initial increase in production in a particular economic activity, and the element  $l_{ij}$  represents the total (direct and indirect) inputs required by sector  $j$  due to one more unit of final demand of sector  $i$ . The output matrix is shown as Eq. (6):

$$B = \hat{X}^{-1}T \quad (6)$$



$X = VA + XB$  and let  $(I - B)^{-1} = G$ , where  $G[g_{ij}]_{n \times n}$  is the Ghosh Inverse matrix and the element  $g_{ij}$  is the total (direct and indirect) inputs required by sector  $i$  to a satisfied one unit of demand of sector  $j$ .

### 3.2 Carbon emissions generated along global value chains

This study examined production-based and consumption-based carbon emissions from transport sectors along global value chains. This section applies the multi-regional Environmental Extended Input–Output (EEIO) model to calculate carbon emissions and carbon multiplier (intensity) (Kitzes 2013). The EEIO model is a generalized IO table with indicators of the environmental impact of production activities by industry sectors, including greenhouse gas emissions, energy consumption, and land used. Direct emissions from production in a country's industrial sectors are the production-based accounting (PBA), where the Eora database directly delivers the PBA emissions for each sector by country. For subsequent calculations, direct emissions from country  $k$ 's transport sector  $i$  are represented by  $p_i^k$ , and the PBA emissions of  $n$  sectors in  $G$  countries are represented as a column matrix  $P[p_i^k]$  with dimension  $1 \times Gn$ . By dividing the direct emissions of country  $k$ 's transport sector  $i$  by its total output ( $x_i$ ), the direct emissions multiplier  $f_i^k$ , is the direct emission for one unit of production of country  $k$ 's transport sector  $i$  and is the sector's direct emission intensity, calculated as in Eq. (7). The matrix of direct emission multipliers of  $n$  sectors in  $G$  countries is represented as a column matrix  $F[f_i^k]_{1 \times Gn}$  with dimension  $1 \times Gn$ .

$$f_i^k = \frac{p_i^k}{x_i} \quad (7)$$

The total emission multiplier matrix  $M[m_i^k]_{1 \times Gn}$  is obtained by multiplying the direct emission multiplier matrix  $F$  by the Leontief inverse matrix  $L$ , as shown in Eq. (8). The elements of matrix  $(m_i^k)$  represent the total emissions directly (and indirectly) from the upstream sector(s) for one more unit of country  $k$ 's transport sector  $i$ , which is the total emission intensity of the sector's production.

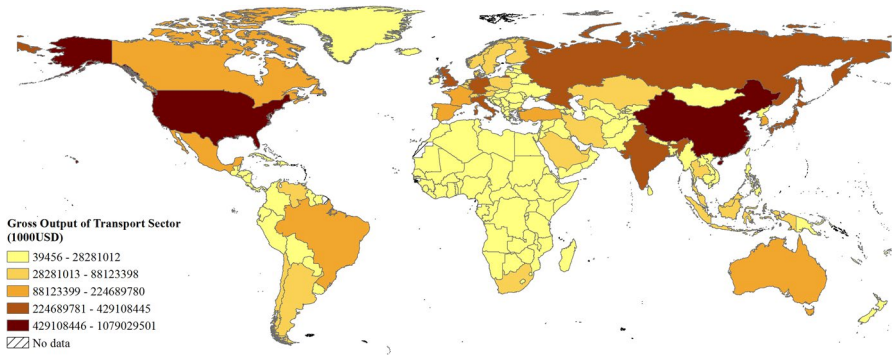
$$M = FL \quad (8)$$

The CBA of a sector is the sum of all emissions upstream of its value chain, caused by the consumption of that sector. The calculation consists of multiplying the total emissions multiplier of individual sectors for each country  $(m_i^k)$  by its end demand ( $y_i^k$ ), as shown in Eq. (9),  $c_i^k$  representing the CBA emissions of country  $k$ 's transport sector  $i$ .

$$c_i^k = m_i^k \times y_i^k \quad (9)$$

EEIO analysis can be defined as the process of reallocating total emissions within an economy, reallocating emission responsibilities from production-based to consumption-based requirements, and comparing emission transfers on both sides. The reallocation aimed to provide more precise measurements of environmental impacts





**Fig. 3** Gross Output of the Transport Sector in 2018

resulting from the production and consumption of goods and services. This helps to determine who is primarily responsible for emissions and who should be held accountable for their reduction.

## 4 Results

This section details the output, demand, production-based and consumption-based carbon emissions of the transport sector along global value chains in 190 countries.

### 4.1 Carbon emissions generated by the transport sector along global value chains

The transport sector breakdown includes land transport, pipeline transport, water transport, air transport, travel and ancillary. Figures 3, 4, 5, 6, 7 and 8 depict the gross output in US\$1000 (\$K) of the transport sector, end demand (\$K) of the transport sector, PBA carbon emission in gigagrams (Ggs), CBA carbon emission in Ggs, the direct emission intensity (Ggs/\$K), and the total emission intensity (Ggs/\$K). Direct emission intensity refers to actual emissions in order to provide \$1000 worth of transportation services. Total emission intensity refers to the emissions generated in the upstream of the value chain, driven by each additional US\$1000 of end demand in the transport sector.

According to PBA emissions, China's transport sector emitted 432,000 Ggs of CO<sub>2</sub> in 2015 with a direct emission intensity of 0.00040036 Ggs CO<sub>2</sub>/\$K, thereby indicating that for China's transport sector to provide an additional thousand US dollars services, it would emit 0.00040036 Ggs of CO<sub>2</sub>. According to the CBA emissions, to fulfill the end demand of China's transportation services, total CO<sub>2</sub> emissions from the upstream of the value chain were 151,307 Ggs of CO<sub>2</sub>. Total emission intensity of China's Transport sector was 0.00086515 Ggs CO<sub>2</sub>/\$K, indicating that to meet every additional thousand US dollars in China's end demand of transportation sectors, the world would generate 0.00086515 Ggs of CO<sub>2</sub> (Table 3).



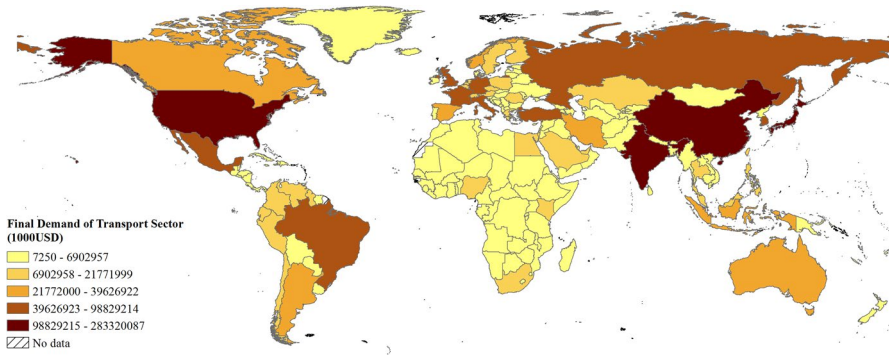


Fig. 4 End Demand of the Transport Sector in 2018

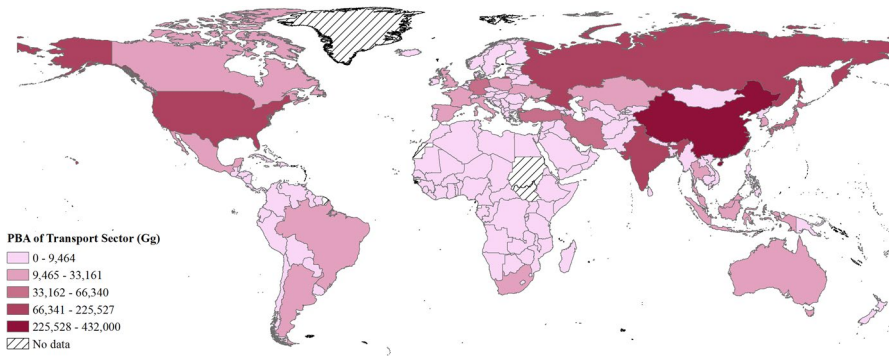


Fig. 5 PBA emissions of the Transport Sector in 2015

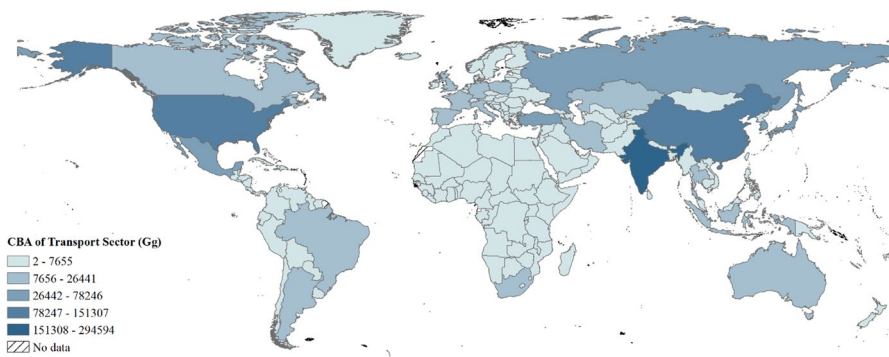


Fig. 6 CBA emissions of the Transport Sector in 2015



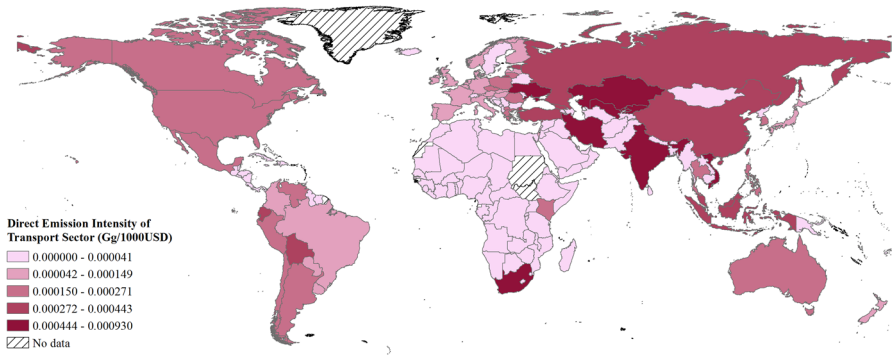


Fig. 7 Direct Emission Intensity of the Transport Sector in 2015

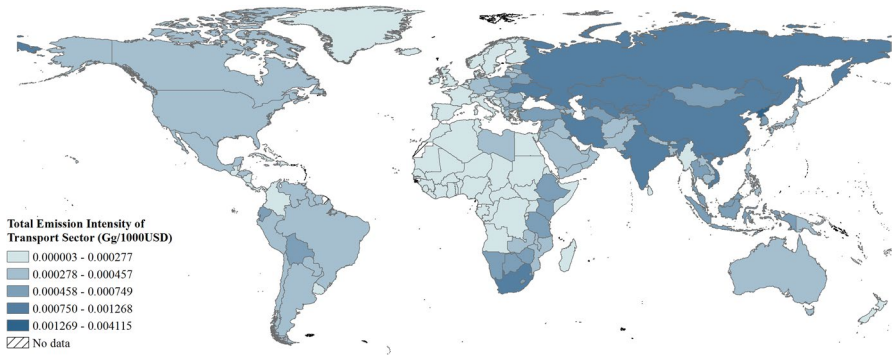


Fig. 8 Total Emission Intensity of the Transport Sector in 2015

CBA emissions minus PBA emissions in the transport sector in 2015 are shown in Fig. 9. China's result was -208,693 Ggs of CO<sub>2</sub>, indicating that the country had achieved carbon-leakage credit in the transport sector, and its actual production of transportation services resulted in higher emissions than its consumption of such services. In order to support the end demand of various industrial sectors around the world, China has produced an additional 208,693 Ggs of CO<sub>2</sub> in the transport sector. For China's consumption in the transport sector alone, it would have only needed to emit 151,307 Ggs of CO<sub>2</sub> to meet its end demand.

The top ten countries with the greatest absolute CBA-PBA values in the transportation industry are shown in Figs. 10 and 11. PBA emissions reflect a country's real emissions when it comes to providing transportation services, whereas CBA emissions indicate the emissions that a country should produce when it comes to consuming transportation services. If CBA emissions are greater than PBA emissions, a country's transportation sector is in carbon-leakage debt. If CBA emissions are less



**Table 3** Carbon emissions data for China's transport sector

	Direct emission intensity (GgsCO <sub>2</sub> /\$K)	Total emission intensity (GgsCO <sub>2</sub> /\$K)	PBA (GgsCO <sub>2</sub> )	CBA (GgsCO <sub>2</sub> )
China	0.00040036	0.00086515	432,000	151,307



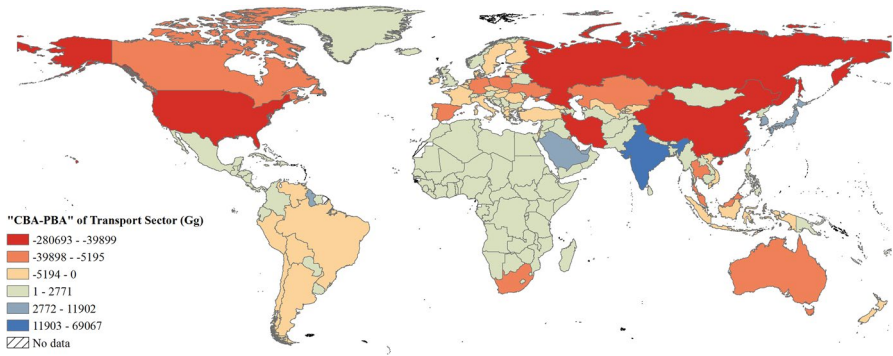


Fig. 9 “CBA-PBA” of the Transport Sector in 2015

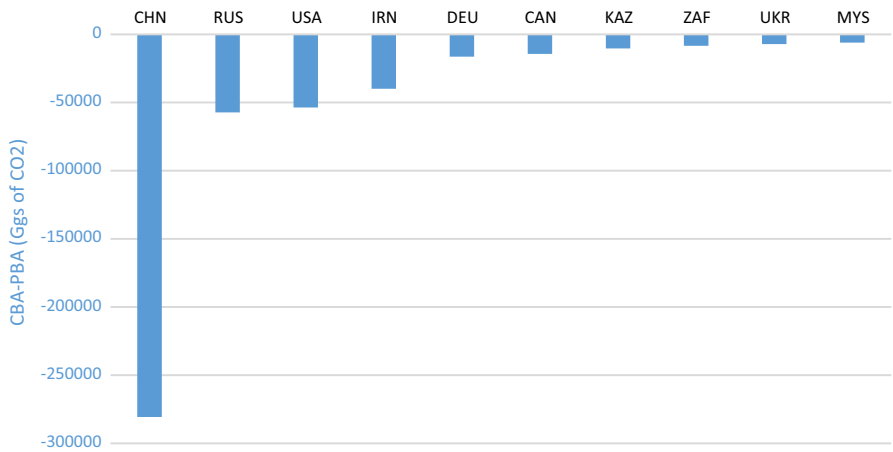


Fig. 10 Top 10 countries with the highest carbon-leakage credit for the transport sector

than PBA emissions, a country’s transport sector is in carbon-leakage credit. If PBA emissions are close to CBA<sup>1</sup> emissions, a country’s carbon<sup>2</sup> emissions are neutral.

Figure 12 shows the top 20 countries that released the most carbon dioxide by their transportation industry in 2015, as well as their relative direct emission intensity in that industry. Although China had the greatest PBA emissions in terms of providing transportation services, its direct emission intensity was comparatively low when compared to that of Iran (IRN) and Kazakhstan (KAZ), implying that China’s

<sup>1</sup> CHN (China), RUS (Russian Federation), USA (United States of America), IRN (Iran), DEU (Germany), CAN (Canada), KAZ (Kazakhstan), ZAF (South Africa), UKR (Ukraine), and MYS (Malaysia).

<sup>2</sup> IND (India), KOR (Korea), JPN (Japan), HKG (Hong Kong), SAU (Saudi Arabia), GUY (Guyana), ARE (United Arab Emirates), GBR (United Kingdom of Great Britain), EGY (Egypt), and PAK (Pakistan).



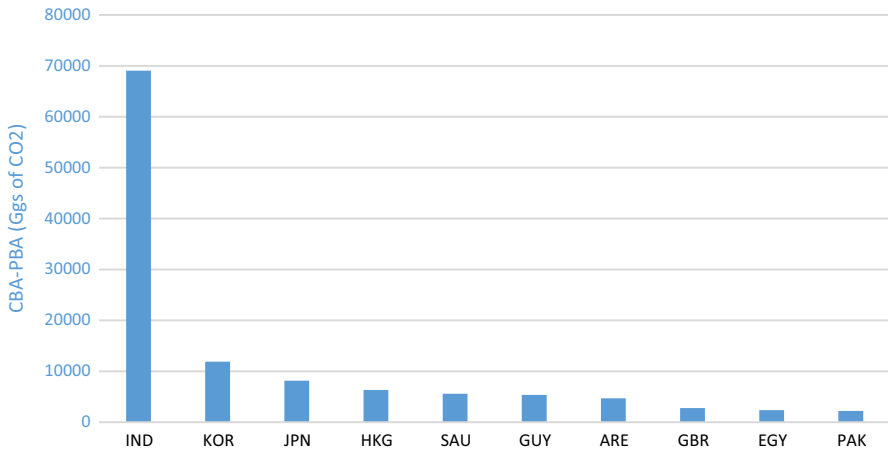


Fig. 11 Top 10 countries with the highest carbon-leakage debit for the transport sector

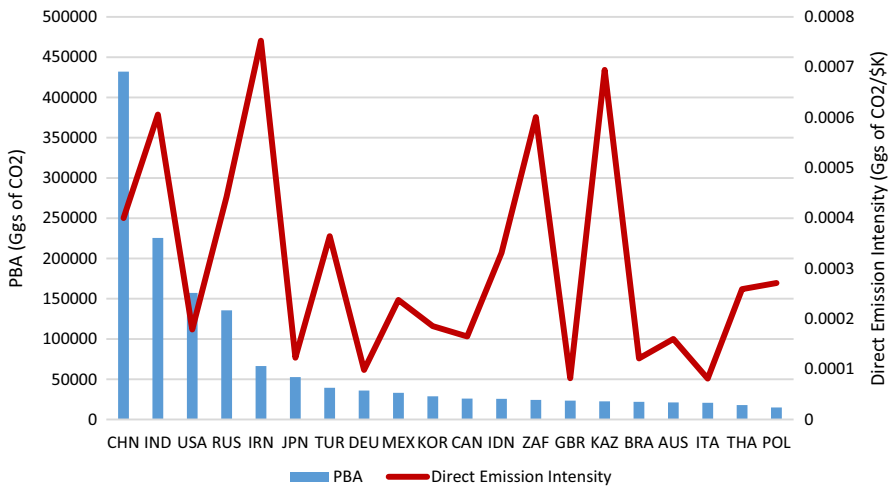


Fig. 12 Top 20 countries with the highest PBA emissions for the transport sector and their direct emission intensity

transportation industry had a high gross output. China’s actual emissions were lower than those produced by Iran (IRN) and Kazakhstan (KAZ) in order to provide \$1000 worth of transportation services. Countries with lower direct emission intensity, such as Germany (DEU), the United Kingdom (GBR), and Italy (ITA), generated low real emissions per \$1000 of transportation services, making them more suited to providing transportation services in terms of carbon emissions.<sup>3</sup>

<sup>3</sup> CHN (China), IND (India), USA (United States of America), RUS (Russian Federation), IRN (Iran), JPN (Japan), TUR (Turkey), DEU (Germany), MEX (Mexico), KOR (Korea), CAN (Canada), IDN





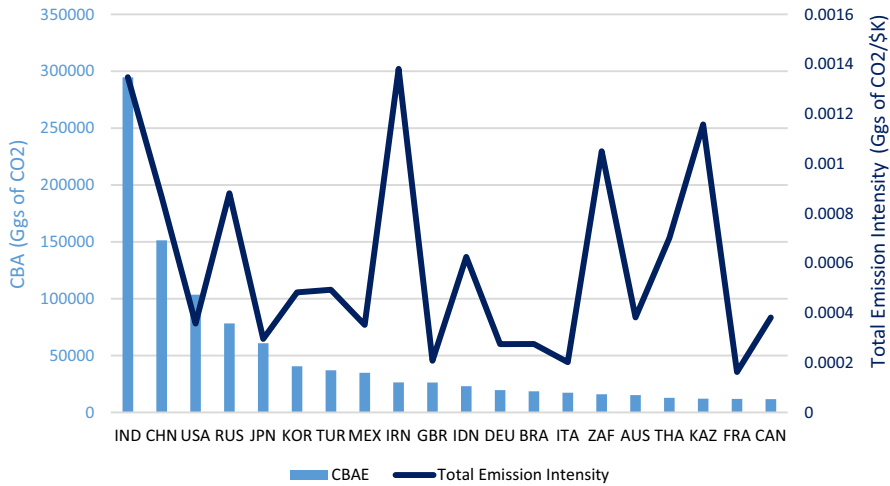


Fig. 13 Top 20 countries with the highest CBA emissions for the transport sector and their total emission intensity

Figure 13 shows the top 20 countries with the highest CBA emissions in the transport sector in 2015, compared to their total emission intensity. India had the highest CBA emissions as a result of its high-end demand for transportation services. Despite the fact that India had the highest CBA emissions in terms of transportation services' consumption, its total emission intensity was still lower than that of Iran (IRN), indicating that India's transport sector had extremely high-end demand. Emissions generated upstream of the value chain, driven by each additional US\$1000 of end demand in India's transport sector were lower than those of Iran's<sup>4</sup> transport sector.

## 5 Conclusions

As a result of the significant reduction in trade barriers in recent years, the development of global value chains has led to increasingly frequent international interactions. According to the Law of Comparative Advantage, multinationals choose to manufacture products in regions with lower opportunity costs, countries choose to specialize in their more advantageous products, and global value chains enable local production of relatively low-priced goods and services. However, the deepening

Footnote 3 (continued)

(Indonesia), ZAF (South Africa), GBR (United Kingdom of Great Britain), KAZ (Kazakhstan), BRA (Brazil), AUS (Australia), ITA (Italy), THA (Thailand), and POL (Poland).

<sup>4</sup> IND (India), CHN (China), USA (United States of America), RUS (Russian Federation), JPN (Japan), KOR (Korea), TUR (Turkey), MEX (Mexico), IRN (Iran), GBR (United Kingdom of Great Britain), IDN (Indonesia), DEU (Germany), BRA (Brazil), ITA (Italy), ZAF (South Africa), AUS (Australia), THA (Thailand), KAZ (Kazakhstan), FRA (France), and CAN (Canada).



division of production globally, makes the value chains of goods longer before reaching the final consumer, and value chain carbon emissions are having a negative impact on the environment.

This study explored the relationship between value chain positioning and carbon emissions in the transport sector of the global economy. It found that: (1) the transportation industry of a country may have a detrimental effect on the environment while generating minimal economic benefit. The majority of transportation services continue to rely on fossil fuels or other pollutant sources. Excessive reliance on this type of transportation increases air and water pollution, including other negative environmental effects. Inefficient transportation systems of limited capacity, high maintenance costs and outdated technology, generate significant pollution while providing little economic benefit; (2) a country's transport industry is tightly embedded in global value chains, but it does not create considerable environmental impact. Countries with strong transport infrastructure and efficient logistics networks stand to gain significantly from the increased trade flows generated by global value chains, as they are able to provide businesses with transport solutions that are efficient and cost-effective. This can lead to increased profits for transport companies and increased economic activity throughout the country. In addition, the study presented an emission intensity perspective to help countries and businesses develop strategies for improving the economy and the environment. Countries and corporations should identify the areas of economic activity where they possess a comparative advantage, capitalize on their strengths, and identify and address their weaknesses. When taking into consideration carbon emissions, some countries may no longer hold a comparative advantage in manufacturing and trade. As climate change becomes a more urgent concern, governments all over the world are implementing regulations to cut their carbon emissions. This may result in an increase in manufacturing costs in certain countries, as they migrate to greener practices.

This study does a cross-sectional analysis of 2015 data. The EORA database provides global multi-country IO tables, although it mixes product and industry dimensions across countries only every 5 years. Future research could explore the mixed effect on emissions in the transport sector globally due to the recent supply chain disruptions. On the one hand, disruptions have led to a fall in automobile, road, and air traffic, which has the potential to reduce emissions from these transportation modes. On the other hand, however, supply chain disruptions may have raised emissions due to the longer distances that commodities have to travel to reach their final destination. The impact of COVID-19 pandemic on the length of the value chain distance and carbon emissions is worth exploring further (Notteboom et al. 2021). The study year, on the other hand, can be extended in order to perform timing column analysis and detect changes in the operations of long-term global value chains. On the other hand, the study year may be extended to run time series analysis and discover changes in the functioning of long-term global value chains.

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## References

- Abraham, K.G., and S.K. Taylor. 1996. Firms' use of outside contractors: Theory and evidence. *Journal of Labor Economics* 14 (3): 394–424.
- Babiker, M.H. 2005. Climate change policy, market structure, and carbon leakage. *Journal of International Economics* 65 (2): 421–445.
- Cadarso, M.-Á., L.-A. López, N. Gómez, and M.-Á. Tobarra. 2010. CO<sub>2</sub> emissions of international freight transport and offshoring: Measurement and allocation. *Ecological Economics* 69 (8): 1682–1694.
- Casella, B., R. Bolwijn, D. Moran, and K. Kanemoto. 2019. Improving the analysis of global value chains: The UNCTAD-Eora Database. *Transnational Corporations* 26 (3): 115–142.
- Chen, S., K. Akimoto, Y. Sun, M. Kagatsume, and N. Wang. 2021. The sustainability of regional decarbonization through the global value chain analytical framework: A case study of Germany. *Journal of Cleaner Production* 317: 128335.
- Cristea, A., D. Hummels, L. Puzello, and M. Avetisyan. 2013. Trade and the greenhouse gas emissions from international freight transport. *Journal of Environmental Economics and Management* 65 (1): 153–173.
- EU ETS. 2016. Carbon leakage. Climate Action—European Commission. [https://ec.europa.eu/clima/policies/ets/allowances/leakage\\_en](https://ec.europa.eu/clima/policies/ets/allowances/leakage_en)
- Fan, B., Y. Zhang, X. Li, and X. Miao. 2019. Trade openness and carbon leakage: Empirical evidence from China's industrial sector. *Energies* 12 (6): 1101.
- Franzen, A., and S. Mader. 2018. Consumption-based versus production-based accounting of CO<sub>2</sub> emissions: Is there evidence for carbon leakage? *Environmental Science & Policy* 84: 34–40.
- Gereffi, G. 1994. The organization of buyer-driven global commodity chains: how US retailers shape overseas production networks. *Contributions in Economics and Economic History* 95–95.
- Gereffi, G., and K. Fernandez-Stark. (2011). *Global value chain analysis: a primer*. Durham: Center on Globalization, Governance & Competitiveness (CGGC), Duke University
- Haralambides, H. 2017. Globalization, public sector reform, and the role of ports in international supply chains. *Maritime Economics & Logistics* 19 (1): 1–51.
- Higgins, B., and D.J. Savoie. 2017. *Regional economic development: essays in honour of François Perroux*. Routledge.
- Hopkins, T.K., and I. Wallerstein. 1977. Patterns of development of the modern world-system. *Review (Fernand Braudel Center)* 111–145.
- Kitzes, J. 2013. An introduction to Environmentally-Extended Input-Output Analysis. *Resources*, 2(4): 489–503.
- Krugman, P.R. 1993. What do undergrads need to know about trade? *American Economic Review* 83 (2): 23–26.
- Kuik, O., and R. Gerlagh. 2003. Trade liberalization and carbon leakage. *The Energy Journal* 97–120.
- Lenzen, M., D. Moran, K. Kanemoto, and A. Geschke. 2013. Building Eora: A global multi-region input–output database at high country and sector resolution. *Economic Systems Research* 25 (1): 20–49.
- Leontief, W.W. 1936. Quantitative input and output relations in the economic systems of the United States. *The Review of Economic Statistics* 105–125.
- Mabey, N., and R. McNally. 1999. Foreign direct investment and the environment: from pollution havens to sustainable development. WWF-UK Report.
- McKinnon, A. 2014. The possible influence of the shipper on carbon emissions from deep-sea container supply chains: An empirical analysis. *Maritime Economics & Logistics* 16 (1): 1–19.
- Muradov, K. 2016. Structure and length of value chains. Available at SSRN: <https://ssrn.com/abstract=3054155> or <https://doi.org/10.2139/ssrn.3054155>.
- Nakamichi, K., S. Hanaoka, and Y. Kawahara. 2016. Estimation of cost and CO<sub>2</sub> emissions with a sustainable cross-border supply chain in the automobile industry: A case study of Thailand and neighboring countries. *Transportation Research Part D: Transport and Environment* 43: 158–168.



- Notteboom, T., T. Pallis, and J.P. Rodrigue. 2021. Disruptions and resilience in global container shipping and ports: The COVID-19 pandemic versus the 2008–2009 financial crisis. *Maritime Economics & Logistics* 23 (2): 179–210.
- Olivier, D., F. Parola, B. Slack, and J.J. Wang. 2007. The time scale of internationalisation: The case of the container port industry. *Maritime Economics & Logistics* 9 (1): 1–34.
- Panayides, P.M. 2006. Maritime logistics and global supply chains: Towards a research agenda. *Maritime Economics & Logistics* 8 (1): 3–18.
- Porter, M.E. 1985. Creating and sustaining superior performance. *Competitive Advantage* 167.
- Sherafati, M., M. Bashiri, R. Tavakkoli-Moghaddam, and M.S. Pishvae. 2020. Achieving sustainable development of supply chain by incorporating various carbon regulatory mechanisms. *Transportation Research Part d: Transport and Environment* 81: 102253.
- Sirkin, H., M. Zinser, and D. Hohner. 2011. Made in America, Again: Why manufacturing will return to the U.S. Boston Consulting Group.
- United Nations. Statistical Division. 2008. International Standard Industrial Classification of all Economic Activities (ISIC) (No. 4). United Nations Publications.
- Van den Berg, R., and P.W. De Langen. 2017. Environmental sustainability in container transport: The attitudes of shippers and forwarders. *International Journal of Logistics Research and Applications* 20 (2): 146–162.
- Wakeland, W., S. Cholette, and K. Venkat. 2012. *Food transportation issues and reducing carbon footprint Green technologies in food production and processing*, 211–236. New York: Springer.
- World Bank. 2019. Global Value Chain Development Report 2019: Technological Innovation, Supply Chain Trade and Workers in a Globalized World. <https://www.worldbank.org/en/topic/trade/publication/global-value-chain-development-report-2019>
- Zhang, Q., and K. Fang. 2019. Comment on “Consumption-based versus production-based accounting of CO<sub>2</sub> emissions: Is there evidence for carbon leakage?” *Environmental Science & Policy* 101: 94–96.

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