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Measuring carbon emissions of foreign direct investment in host economies

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Abstract

This paper presents a statistical framework for estimating the effect of foreign direct investment (FDI) on carbon emissions in host economies through capital formation funded by FDI and the production of foreign-owned firms. In addition to providing empirical evidence on the impact of FDI on carbon emissions in host economies, it begins to untangle the relationship between the offshoring of multinational enterprises (MNEs) and global carbon emissions. The framework is also used to develop comparable estimates of carbon emissions in the host economy from operations of non-FDI enterprises. The methodology used is underpinned by the OECD Inter Country Input Output tables (ICIOT) linked to carbon emissions, FDI statistics by industry from the OECD, and the OECD Analytical AMNE Database. The empirical evidence shows that the carbon intensity of gross fixed capital formation (GFCF) financed by FDI has fallen over time, driven in most countries by reduction in the carbon intensity of the electricity, gas and water industry. Results also show that the carbon emissions from the ongoing operations of foreign-controlled firms (henceforth MNEs) are larger than those associated with their capital formation. At industry-level, manufacturing; wholesale and retail trade; and electricity, gas and water had the highest overall emissions and emission intensities among MNEs. A comparison between MNEs and Domestic Owned Enterprises (DOEs) showed that although DOEs accounted for the largest share in total emissions and carbon intensities, there were cases in low carbon intensive countries were MNEs had higher carbon intensities. Findings on MNEs trade links to emissions indicated strong links between high emissions in the mining industries; transport and storage; and manufacturing industries with exports. Given the important role shown by the results of FDI companies in global carbon emissions, policies by home and host economies could play an important role in reducing global carbon emissions. For home countries, policies that incentivize their domestic direct investors to meet high environmental and emissions standards in host economy operations could be an impotant tool in addition to host economy policies. Addressing data limitations would improve the quality of the estimates. Improvements could come from developing statistics that identify the FDI flows that are used to expand capacity in the host

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economy and carbon emissions by MNEs. Finally, expanding country coverage would enable a more comprehensive analysis of the impact of offshoring of MNEs on global carbon emissions.

Keywords: Carbon emissions, foreign direct investment, input-output tables

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ACRONYMS

AMNEs	Activity of Multinational Enterprises
DOEs	Domestic Owned Enterprises
FDI	Foreign Direct Investment
GFCF	Gross Fixed Capital Formation
ICIO	Inter-Country Input-Output
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
ISIC	International Standard Industrial Classification
M&As	Mergers and Acquisitions
MNEs	Multinational Enterprises
OECD	Organization for Economic Cooperation and Development
SPEs	Special Purpose Entities
Rev	Revision
US	United States
WIOD	World Input-Output Database

I.   INTRODUCTION

The effects of foreign direct investment (FDI) on host economies are complex as has been recognized by many authors. For instance, FDI has been associated in host economies with rising wages (Rippy, (1976); Harrison, (1995); Lipsey, (2004); and Hill, (1990)); higher productivity (Okamoto & Sjholm, (2000); Kokko, Zejan, & Tansini, (2001); and Kathuria, (2000)), productivity and knowledge spillovers to domestic firms (Smarzynska, (2004); and Aitken & Harrison, (1991)); exports diversification and introduction of new industries (Lipsey, (2000); and Wendy & Chia, (2004)) and increasing growth (Romer, (1993); Blomstrom, Lipsey, & Zejan, (1994); Lipsey, (2000); and De Mello, (1999)). In relation to environment and sustainability, the effects of FDI are unclear as FDI can affect carbon emissions through multiple channels, including by increasing the scale of economic activity, by contributing to demand for addressing climate change, and by diffusing low-carbon knowledge and technology across borders.

One view is that if demand for environmental quality increases as incomes rise, then eventually environmental damage will begin to fall (the environmental Kuznets curve argument), and, thus, as FDI increases incomes, it will contribute to this increased environmental demand in host economies. Another view is that FDI is usually associated with higher carbon emissions especially in low-income countries (Zhu, Duan, Guo, & Yu, (2016); Lee, (2013); Shahbaz, Balsalobre-Lorente, & Sinha, (2019); Mabey & McNally, (1999); Seker, Ertugrul, & Cetin, (2015); and Shao, (2018)). The main argument is that countries with low incomes tend to set low pollution standards to be able to attract resource seeking as well as pollution intensive FDI (also referred to as the 'pollution havens' hypothesis). Proponents of this view recommend, in addition to consumer or financial sector-driven initiatives to improve companies' behavior, the use of mandatory environmental conduct requirements to prevent the best firms being undermined by unscrupulous competitors. A third view is that FDI is cleaner than domestic investment because it deploys new technologies that are cleaner than domestic producers, thus supporting improvements in the environment of the host country (Blackman & Wu, (1999); and Zarsky, (1999)). This view also referred to as the "pollution halos" argument focuses environmental related outcomes of FDI on the associated positive effects of better management, adherence to higher standards, and use of better technology. Those higher standards could include both those set in the home country of the MNE or other host economies, which could result in positive spillovers to the home and host countries.

In this paper, we do not take or attempt to test any particular view, but rather focus on contributing to the ongoing debate on the effect of FDI on the environment by developing a framework for estimating its contributions to carbon emissions. The framework relies on industry level information on production, trade, investment, carbon emissions, and distinction between Activities of MNEs (AMNE) and DOEs to produce estimates of the carbon emissions

from FDI and the operations of foreign-owned firms. The data used for the analysis makes it possible to derive estmates of carbon emissions directly from the investment and production activities of MNEs as well as the indirect emissions from, for example, their use of electricity generated within the host economy. These estimates are an attempt to quantify the outcomes of the three main potential effects cited n the literature as discussed above. Thus, this paper aims at providing a simple and replicable framework that can be useful for answering the following three key questions about FDI and emissions for a given country:

i.   What is the effect of greenfield investment and capacity extension resulting from foreign direct investment on emissions in host economies?
ii. What is the effect of the operations of foreign owned enterprises on emissions in host economies?
iii. What effect does international trade activity of foreign owned enterprises have on emissions in host economies?

The first set of indicators that are developed focuses on addressing the first question by examining the financing role of FDI. FDI flows are often used for new investments (greenfield investments) and/or for extension of capacity of existing enterprises. Each of these investment activities results in gross fixed capital formation (GFCF) in the host economy, which is associated with carbon emissions in the industries that supply the respective products that go into GFCF. The second set of indicators aims to address the second question by providing estimates of emissions from the ongoing operations of MNEs in the host economy. In addressing the second question, we also develop comparable estimates of carbon emissions in the host economy from operations of DOEs. The third set of indicators aims to assess the effect of MNEs on emissions in the host economies through their international trade activities (mainly exports). As already highlighted, FDI may serve as a channel for some countries to offshore production of pollution intensive products that have high demand in home economies of the FDI that have more strict environmental regulations. In such cases, FDI may increase emissions in the host economy from the actual production as well as emissions associated with domestic and international transportation associated with imported inputs and exports of final goods.

This rest of the paper is organized as follows: Section 2 presents the methodology and data used for developing the estimates and also discusses some of the methodological and data limitations. In Section 3, we present and discuss some key results, and Section 4 concludes by discussing some policy implications and highlighting potential areas of further research.

II. METHODOLOGY AND DATA USED
A. Estimating the investment effect of FDI on carbon emissions

One of the benefits of FDI to host economies is expanded production capacity through greenfield investments as well as new investments in existing operations, such as new buildings,

infrastructure, machinery, and equipment. When FDI resources are received, they can be used for GFCF which is measured as the total value of a producer's acquisitions, less disposals, of fixed assets during the accounting period, plus certain specified expenditures on services that add to the value of non-produced assets. However, the process of creating fixed and non-produced assets that are part of GFCF generates carbon emissions by the production units involved in their creation. The main objective of these indicators is to estimate the total amount of carbon emissions that result from the creation of the fixed and non-produced assets by the respective production units that are located in the host economy. We refer to this set of indicators as carbon emissions in supply to GFCF of FDI.

The methodology that was used for estimating the carbon emissions arising from the supply to GFCF funded by FDI involved, first, determining the carbon emissions in supply to GFCF, using the central equation system of input-output analysis and then apportioning the emissions between those funded by FDI and those funded from other sources. To determine the carbon emissions embodied in supplies to gross fixed capital formation, we multiplied estimates of total carbon emissions that include both direct and indirect carbon emissions per unit of output of each supplying industry by its respective output used for GFCF. Direct emissions were based on International Energy Agency (IEA) estimates of CO2 emissions from fuel combustion during production based on calculations using the IEA energy data and the default methods and emission factors from the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories[2] (IEA, 2020). The direct emissions relate to carbon emitted from fuel combustion during the production process while indirect emissions relate to carbon emissions embodied in inputs, for example emissions generated to produce cement used as an input for the construction of buildings. These estimates were then multiplied by the estimated amount of GFCF financed by FDI to derive the carbon emissions of capital formation of FDI. The steps followed and source data used were as follows:

Step 1:
Obtaining information on the total emissions emitted during production for each industry for each country.
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Step 2:
Estimating the coefficient for the direct emissions (C^{direct}) during production for each industry. This was estimated by dividing total emissions for each industry by its output.

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Step 3:
Estimating total carbon emission coefficients for the direct and indirect emissions from various industries using estimates of direct carbon emission coefficients and respective domestic input coefficients obtained from input–output tables. The following formula was used:

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[2] The IEA uses the simplest (Tier 1) methodology to estimate CO2 emissions from fuel combustion based on the 2006 guidelines. The computation follows the concept of conservation of carbon, from the fuel combusted into CO2. Generally, the Tier 1 estimation of CO2 emissions from fuel combustion for a given fuel can be summarized as the product of fuel consumed and an emission factor. Emissions are then summed across all fuels consumed for each industry.

$$C^{total} = (I - A)^{-1} \cdot C^{direct} \qquad \textbf{(1)}$$

where C^{total} denotes an $(n \times 1)$ vector of total emission coefficients of direct and indirect emissions, C^{direct} is an $(n \times 1)$ vector of direct emission coefficients, A is the input coefficient matrix of the input–output table, I is the $(n \times n)$ identity matrix, and n is the number of industries. Thus, $(I - A)^{-1}$ is the Leontief inverse matrix.

Step 4:
Estimating total carbon emissions associated with GFCF by adapting the central equation system of input-output analysis through multiplying total carbon emission coefficients derived for each industry by its respective supply for final use in GFCF.

$$Carbon\ emissions\ of\ GFCF = C^{total} \times final\ use\ in\ GFCF \qquad \textbf{(2)}$$

Step 5:
Apportioning the total emissions associated with GFCF to FDI by multiplying the share of FDI in GFCF by the total emissions derived in 2.

$$Carbon\ emissions\ of\ GFCF\ of\ FDI = C^{total} \times final\ use\ in\ GFCF \times {FDI}/{GFCF} \qquad \textbf{(3)}$$

To enable meaningful comparability between industries and across countries, industry level estimates of carbon emissions in supply to GFCF of FDI were divided by the respective industry level final demand for domestic products, which were derived from the input-output tables.

B. Estimating the effect of ongoing operations of foreign owned enterprises on carbon emissions

FDI can increase the scale of economic activity in the host economy, can increase export diversification and can lead to structural changes in the economy through the introduction of new industries. However, the production activities of the foreign-owned enterprises also generates carbon emissions in the host economy. It is not possible to isolate the operations of all FDI enterprises in the host economy. Nonetheless, data on the activities of MNEs makes it possible to establish operations of a subset of FDI enterprises where direct investors have control. We used the OECD Analytical AMNE Database to track production activity of these foreign-owned firms (henceforth referred to as MNEs) and domestically owned enterprises (DOEs) over time for individual industries and to derive respective estimates of emissions associated with their production activity as follows:

First, we estimated the total carbon emission coefficient of direct and indirect emissions using the Leontief inverse matrix of the ICIOTs requirement matrix as shown in (4), This Leontief inverse matrix produces direct and indirect output multipliers of countries, MNEs and DOEs by

industry, under the assumption that a single matrix merging MNEs and DOEs reflects relationship within MNEs and DOEs and between MNEs and DOEs.

$$C_{MNEs\ \&\ DOEs}^{total} = (I - A_{MNEs\ \&\ DOEs})^{-1} \cdot C_{MNEs\ \&\ DOEs}^{Direct} \qquad \textbf{(4)}$$

where $C_{MNEs\ \&\ DOEs}^{total}$ denotes an $(n \times 1)$ vector of total (direct and indirect) emission coefficients, A is the requirement matrix estimated from the ICIOTs, I is the $(n \times n)$ identity matrix, $(I - A_{MNEs\ \&\ DOEs})^{-1}$ is the Leontief inverse matrix for MNEs and DOEs, and n is the product of the number of countries and the combined number of industries for MNEs and DOEs. Approximation method for matrix inversion is implemented to overcome challenges posed by size of ICIOT (the matrix is 4080 rows and 4080 columns) relative to computer memory and entries near 0. An analytic solution of $(I - A)^{-1} = \frac{1}{|I-A|} C^T$, is used where $|I - A|$ denotes the determinant of $(I - A)$ and C^T denotes the adjugate matrix, which is the transpose of the matrix of cofactors of $(I - A)$. The matrix of cofactors is obtained by replacing each element of $(I - A)$ by its cofactor (see illustration in the annex). This recursive method proposed by Cramer is inefficient for large matrices. Further, entries near 0 can cause large $\frac{1}{|I-A|}$. The approximation method used in this paper is the Neumann series combined with a threshold to ensure convergence ((Climent, Thome, & Wei, 2001) and (Moulinec, Suquet, & Milton, 2018)). The Neumann series of a matrix A is $(I - A)^{-1} = \sum_{k=0}^{\infty} A^k$, where $A^0 = I$[3]. The threshold to stop the matrix multiplication $A^k = AA^{k-1}$ is at $(I - A)_n^{-1} \cdot Final\ demand\ vector = Output\ vector$. For this, the convergence is met for n after approximatively 40 iterations.

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[3] We can show that the Neuman series $\sum_{k=0}^{n} A^k$ converges for the requirement matrix A. We know that $\sum_{k=0}^{n} A^k = (I - A)^{-1}$ is the inverse of $(I - A)$ if $(I - A)^{-1} \cdot (I - A) = I$. This can be proven in two steps. At the first step, it is easy to show that $\sum_{k=0}^{n} A^k \cdot (I - A) = I + A^n$. At the second step, it is easy to show that $\lim_{n\to\infty} \sum_{k=0}^{n} A^k \cdot (I - A) = I + \lim_{n\to\infty} A^n$. $\lim_{n\to\infty} A^n = 0$ if the operator norm of A is less than 1 ($\|A\| < 1$). This condition is fulfilled because we can consider Tchebycheff norm ($A_\infty - norm$) ((Ben-Israel & Greville, 2003). $\|A\| = \max_{1\le j\le n} \sum_{i}^{n} |a_{ij}|$ (which is less than one because $a_{ij} = \frac{Intermediate\ consumption_{ij}}{Output_j}$ and it comes that $\sum_{i,j}^{n} a_{ij} < 1$. A will have the Hilbert-Schmidt norm $\|A\| = \langle A, A \rangle = \sum_{i,j}^{n} a_{ij}^2$ only if $\sum_{i,j}^{n} a_{ij} < 1/n$. The requirement that $|a_{ij}| < 1$ is challenged by presence of negative value in ICIOTs and scarcity of data. For instance, technical coefficient is 1 for foreign Saudi Arabi Motor vehicles, trailers and semi-trailers industry (SAU_F_C29) in the use of foreign Japan construction (JPN_F_F).

$C_{MNEs \& DOEs}^{total}$ was further split into, C_{MNEs}^{total} and C_{DOEs}^{total} for each country and industry. This breakdown allowed the estimation of carbon emissions in MNEs and DOEs output for final demand (FD) of various countries industries as follows:

$$Carbon\ emissions\ in\ MNEs\ Output\ for\ FD = C_{MNEs}^{total} \times MNEs\ Output\ for\ FD$$
$$(5)$$

$$Carbon\ emissions\ in\ DOEs\ Output\ for\ FD = C_{DOEs}^{total} \times DOEs\ Output\ for\ FD \qquad (6)$$

C. Estimating the effect of international trade of MNEs on emissions

MNEs tend to have higher export intensities than DOEs for a number of reasons, including their role in the creation and management of global value chains and that they tend to be more productive and innovative. The production of exports, like other production, contributes to carbon emissions in the host economy although such emissions are embodied in products that satisfy foreign rather than domestic demand. We estimated the emissions associated with exports of MNEs using reported data on the exports of host countries and industries. We also estimated emissions associated with exports of DOEs for comparison purposes. The estimates are based on the equations shown in (7) and (8).

$$Carbon\ emissions\ of\ Exports\ of\ MNEs = C_{MNEs}^{total} \times Exports\ of\ MNEs \qquad (7)$$

$$Carbon\ emissions\ of\ Exports\ of\ DOEs = C_{DOEs}^{total} \times Exports\ of\ DOEs \qquad (8)$$

The data that was used in the equations is summarized in the Table 1.

Table 1. Data sources		
Data	**Source**	**Period**
Carbon emissions	IEA production-based emissions	2005-15
Output	OECD National Accounts Database	2005-15
Input coefficients	OECD Input Output Database	2005-15
GFCF	OECD National Accounts Database	2005-15
Inward FDI of non-SPEs	OECD FDI financial flows database	2005-15
Final demand	OECD Input Output Database	2005-15
MNEs and DOEs final demand	OECD Analytical AMNE database	2005-15
MNEs and DOEs exports	OECD Analytical AMNE database	2005-15
MNEs and DOEs input coefficients	OECD Intercountry Input Output Tables from the Analytical AMNE database	2005-15
Source: Authors.		

D. Use of the ICIO of AMNEs

The Inter-Country Input-Output (ICIO) tables provide a matrix of the transactions of domestic-owned and foreign-owned firms in 59 countries plus the rest of the world in the host country[4] (Cadestin, et al., 2018). The matrix covers 34 unique industrial sectors over the period 2005-2016. There are four main elements in the ICIO table: the intermediate consumption matrix, the final demand matrix, the value-added vector and the gross output vector. Figure 1 is a compressed extract which for illustration purposes shows the intermediate consumption matrix in the shaded parts. Cells in columns correspond to a country/sector's inputs by ownership; cells in rows correspond to the output of a country/sector by ownership. Gross output of each country is equal to the sum of rows and final demand or the sum of columns and value added. The shaded part shows how each cell of the intermediate consumption matrix for each sector is divided into four cells corresponding to the inputs used by domestic-owned firms from domestic and foreign owned firms and inputs used by foreign-owned firms from domestic and foreign owned firms. The final demand matrix is split across rows to reflect the final demand of products from domestic-owned and foreign-owned firms. The value-added and gross output vectors are split across columns to indicate the value-added and gross output of domestic-owned and foreign-owned firms in each country and sector.

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[4] https://www.oecd.org/sti/ind/analytical-AMNE-database.htm#database

Figure 1: Structure of the ICIO tables for each year

			Ctry 1				Ctry 2				Ctry 1	Ctry 2
			Sector 1		Sector 2		Sector 1		Sector 2		Final Demand	Final Demand
			Dom.	For.	Dom.	For.	Dom.	For.	Dom.	For.		
Ctry 1	Sector 1	Dom.										
		For.										
	Sector 2	Dom.										
		For.										
Ctry 2	Sector 1	Dom.										
		For.										
	Sector 2	Dom.										
		For.										
Value added												
Gross output												

E. Data and methodological limitations

In the case of carbon emissions from GFCF of FDI, the main data limitation was the absence of FDI data that distinctly finances GFCF. Available estimates for total FDI include funding that could be used for other expenditures besides GFCF. For instance, FDI could be used to finance changes in ownership of existing capital such as with mergers and acquisitions (M&As) or could be used as transit capital through special purpose entities (SPEs). FDI could also be used to acquire financial assets. To address the data limitation related to transit capital, we excluded estimates for countries with large well-known offshore financial centers (Luxemburg, Netherlands and Ireland). Comparative estimates based on operating entities (excluding special purpose entities) showed similar trends but are not discussed here due to their unavailability for some of the countries in the sample. Further improvements to the estimates could be made if updates to the international statistical standards and, in particular the balance of payments statistical standards, make possible to obtain a decomposition of FDI by use in the host country.

For estimates associated with the operations of MNEs, the main data limitation was the absence of separate direct carbon emissions data for MNEs and DOEs which meant that the direct emissions of MNEs and DOEs in the same industry were assumed to be the similar. This assumption could be eased with more information on the direct emissions of MNEs; such information would be helpful, for example, in clarifying the impact on emissions of MNEs and DOEs explained fully by differences in their respective production functions and technologies. The overall variation in the total emissions for both MNEs and DOEs that could subsequently be reflected in the estimates we made is mainly due to differences in their industry distribution and sourcing patterns especially between domestic and imported inputs, as reflected by the differences in the respective input coefficients.

Other limitations to the estimates include geographical bias to only OECD countries and limitations of the analysis to the period between 2005 and 2015, due to data availability. Further, the central equation system of input-output analysis fails to reflect dynamic interactions between the respective variables. For instance, the timing of the deployment of FDI funds for GFCF could occur with lags, but in the estimation, we assume that there are no lags. Other related caveats of IOTs pertain to lack of constraints on the factors of production and on the supply side, a fixed input structure and fixed ratios for production for each industry, lack of budget constraints that might prevent households or producers to purchase all additional output, and assumption that households consume goods and services in exact proportion to their initial budget shares. Finally, the IEA estimates of CO_2 emissions from fuel combustion are derived using the Tier 1 method, but countries may be using a more sophisticated Tier 2 or Tier 3 method that considers detailed available country-specific information (e.g., on different technologies or processes).

III. RESULTS
A. Carbon emissions associated with the investment effect of FDI

The results on carbon emissions associated with the investment effect of FDI provide insights into the main sources of emissions in host economies from final use of domestic products for GFCF financed by FDI. They also allow us to undertake a comparison of emissions by industry in a country and between countries. The estimates are in metric tons of emissions and metric tons of emission per 1 million US dollars of output generated to meet final demand. Coverage is for 29[5] countries during the period 2005 to 2015 and 36 industries based on the International Standard Industrial Classification (ISIC) Revision 4 classification. However, for more meaningful comparison between and within countries and industries, we present results for 14 countries which have more consistent annual and industry estimates. We also exclude estimates for 2005 in the comparison across countries and industries because it had the highest number of omissions. The results also highlight the 10 largest industries with the remaining 26 industries summed up into a tenth category labeled other for ease of comparison. Figure 2 presents 3 different charts of estimates of carbon emissions of GFCF of FDI in metric tons per 1 million US dollars of final demand of domestic output.

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[5] The 29 countries whose estimates are available include Australia, Belgium, Canada, Chile, Czech, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Mexico, New Zealand, Norway, Poland, Portugal, Slovak, Slovenia, Spain, Sweden, Switzerland, United Kingdom, and United States.

Figure 2. CO2 emissions in related to GFCF of FDI (metric tons per 1 million US dollars of final demand), 2006-15
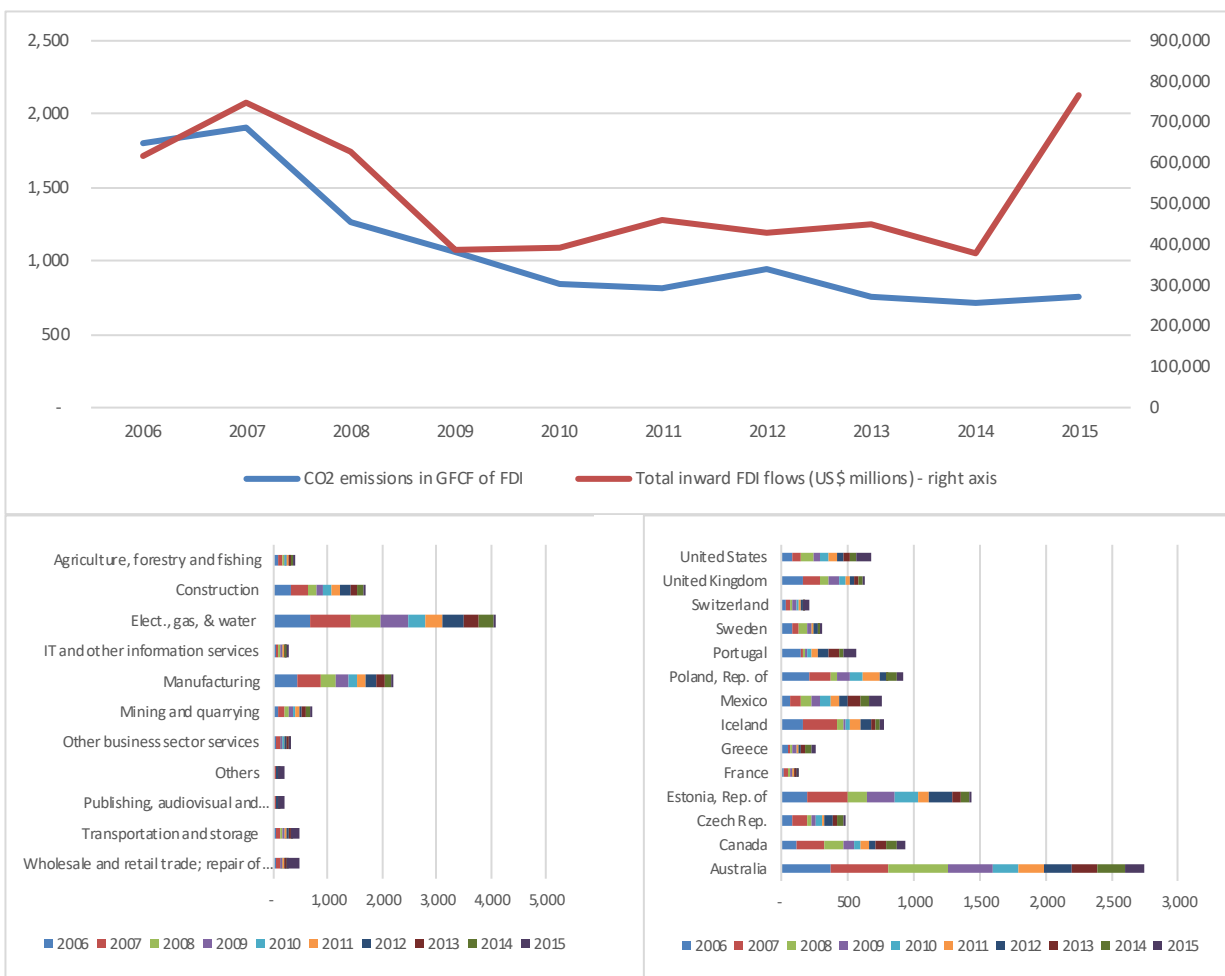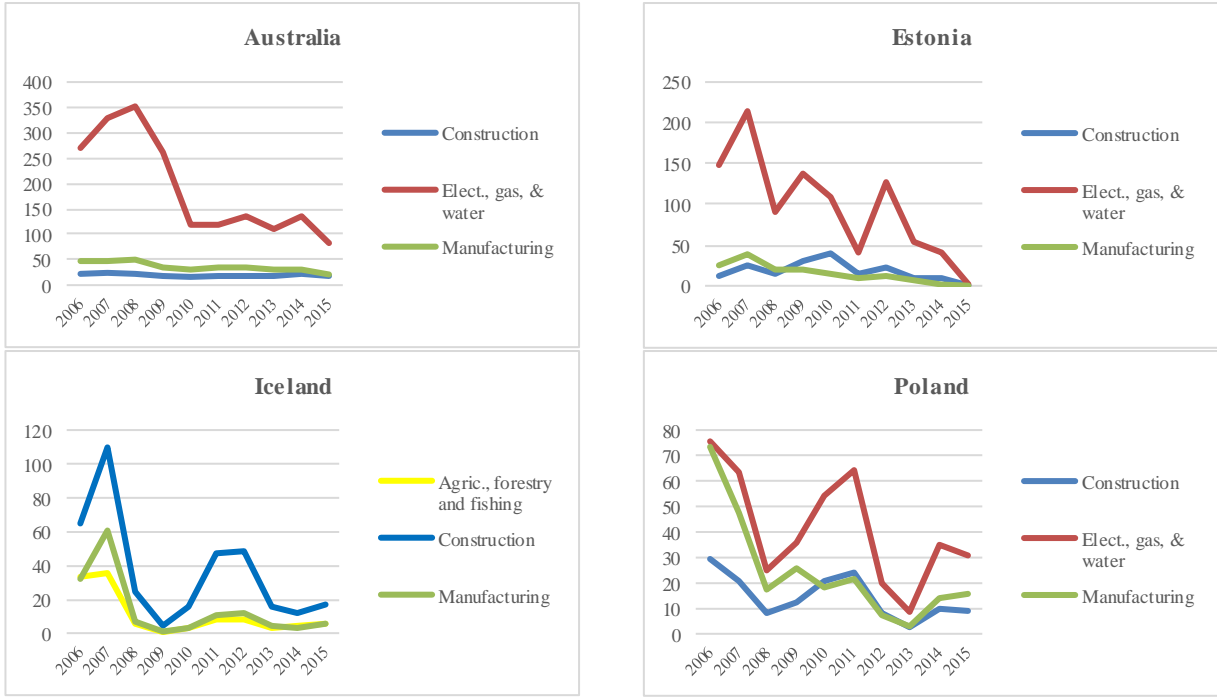
Source: Authors' calculations from OECD data.

The chart in the top panel shows a comparison of trends in total carbon emissions of GFCF funded by FDI per US$ 1 million of final demand and the total for inward FDI flows for countries covered. The estimates show emissions associated with GFCF financed by FDI fell during the period. In addition, trends in emissions and FDI between 2006 and 2009 were similar. However, while the fall in FDI inflows bottomed out in 2010 and recovered between 2014 and 2015, emissions continued to fall, albeit at a slower pace, in the later years of the period. The trend in emissions suggests that FDI in the later years of the period of analysis had a lower overall effect on emissions.

The bottom left panel of Figure 2 presents the cumulative emissions over the period by industry. The industry with the highest emissions relative to domestic demand was electricity, gas, and water whose emissions were almost twice those of manufacturing, which were the second highest. In terms of shares to total emissions, the electricity, gas, and water industry had an average share of 39 percent of total emissions, followed by manufacturing at 21 percent and construction at 16 percent. The high contribution of the electricity, gas, and water industry

emissions was linked to countries in the sample that relied on fossil fuels for their energy requirements. The estimates also showed that construction industry emissions, which were the third highest, were most significant in countries with large investment projects in the oil and gas industry, while manufacturing industry emissions were evenly spread across most countries. The cumulative emissions by country during the ten-year period from 2006 to 2015 are shown in the bottom right panel of Figure 2. As shown, the highest emissions during the period were from Australia, followed by Estonia, Canada, Poland, and Iceland. The least emissions were in France, Switzerland, Greece, and Sweden.

Further disaggregation of the industry composition by country shows varying patterns across countries, In Figure 3, estimates for the top 3 industries by size of emissions in each country are presented for Australia, Estonia, Iceland, and Poland. In all of four countries, an overall downward trend in emissions is observed. For Australia, Estonia, and Poland, the downward trend was mainly driven by the decline in emissions from the electricity, gas, and water industry. In Iceland, the leading industry which also explains most of the decline during the period was construction. In Iceland, the estimates also show agriculture, forestry and fishing featuring among the top 3 main sources of emissions while electricity, gas and water industry, which is common to the other 3 countries, is not among the top 3 major sources of emissions in Iceland.

Figure 3. Top 3 industries by country of CO2 emissions related to GFCF of FDI (metric tons per 1 million US dollars of final demand), 2006-15

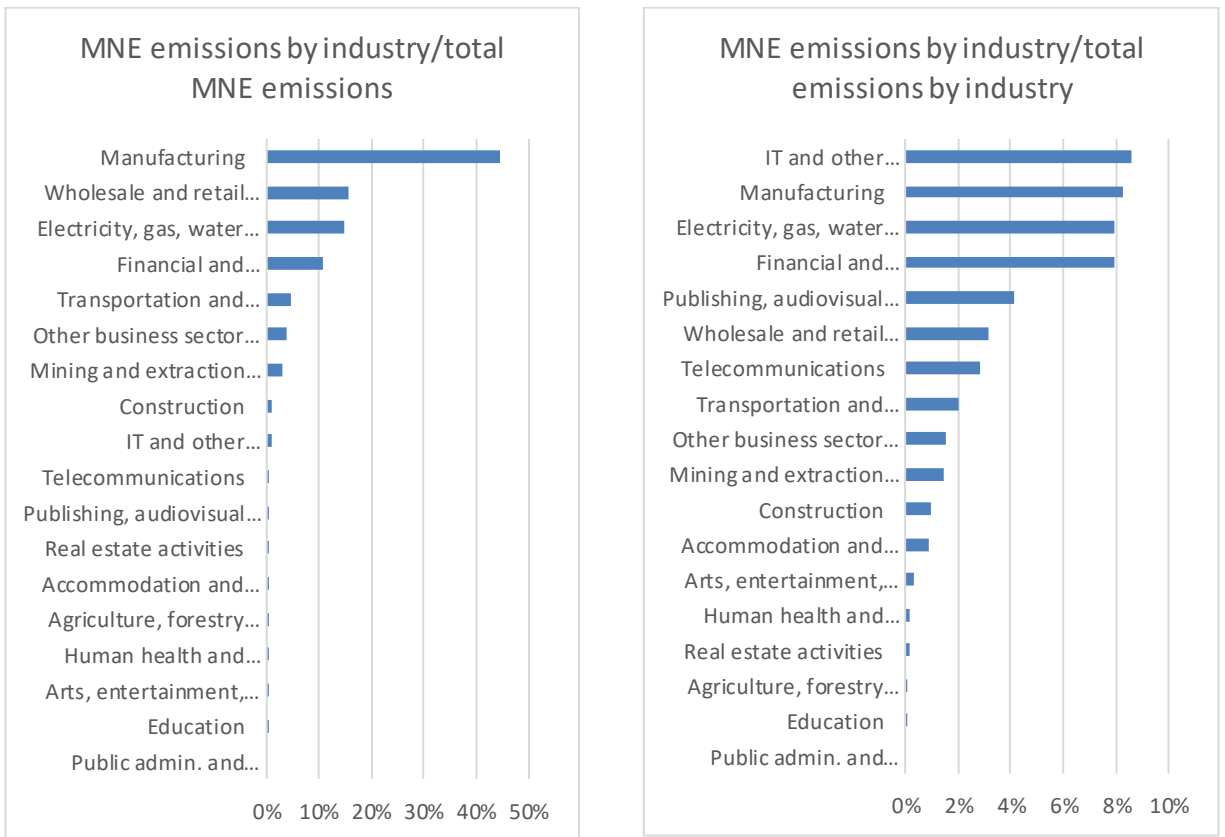Source: Authors' calculations form OECD data.

B. Carbon emissions of ongoing operations of MNEs

Estimates of carbon emissions from the ongoing operations of MNEs were based on activities of foreign owned MNEs operating in 59 countries[6] during 2005 to 2015 in 34 industries based on ISIC rev 4. The estimates show in the left panel of Figure 4 total direct and indirect carbon emissions (hereafter referred to as carbon emissions) in the output of MNEs used for final demand by industry. Manufacturing had the largest contribution to emissions of MNEs equivalent to 44 percent total emissions of MNEs followed by wholesale and retail trade at 16 percent and electricity, gas and water at 15 percent. Estimates for the share of carbon emissions of MNEs within each industry are shown in the right panel of Figure 4. According to the estimates, IT, Manufacturing, electricity, gas and water and Financial and Insurance activities of MNEs had the largest contributions in the respective industries. Although some industries like IT and Financial and Insurance activities had large contributions within their respective industries, their overall contribution to total emissions is small as shown by the chart in the left panel.

Estimates of the direct and indirect carbon intensity (hereafter referred to as carbon intensity) of final demand for products produced by MNEs compared to DOEs are shown in Figure 5 measured in thousands of metric tons of emissions per 1 million US dollars of output. The chart in the left panel of Figure 5 presents the industry distribution, which shows that mining; electricity; manufacture of basic metals; wholesale and retail trade and manufacture of chemicals and pharmaceuticals had the highest carbon intensities. The estimates also show that the carbon intensity of MNEs was lower than that of DOEs in all industries.

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[6] The countries whose estimates are available are Morocco, Argentina, Australia, Austria, Belgium, Bulgaria, Brazil, Canada, Switzerland, Chile, China, Colombia, Costa Rica, Cyprus, Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, United Kingdom, Greece, Hong Kong, Croatia, Hungary, Indonesia, India, Ireland, Iceland, Israel, Italy, Japan, Korea, Lithuania, Luxembourg, Latvia, Mexico, Malta, Malaysia, Netherlands, Norway, New Zealand, Philippines, Poland, Portugal, Romania, Russian Federation, Saudi Arabia, Singapore, Slovak Republic, Slovenia, Sweden, Thailand, Turkey, Chinese Taipei, United States, Viet Nam, South Africa

Figure 4. Carbon emissions in MNEs output, 2005-15 average

MNE emissions by industry/total MNE emissions

Industry	
Manufacturing	
Wholesale and retail…	
Electricity, gas, water…	
Financial and…	
Transportation and…	
Other business sector…	
Mining and extraction…	
Construction	
IT and other…	
Telecommunications	
Publishing, audiovisual…	
Real estate activities	
Accommodation and…	
Agriculture, forestry…	
Human health and…	
Arts, entertainment,…	
Education	
Public admin. and…	

MNE emissions by industry/total emissions by industry

Industry	
IT and other…	
Manufacturing	
Electricity, gas, water…	
Financial and…	
Publishing, audiovisual…	
Wholesale and retail…	
Telecommunications	
Transportation and…	
Other business sector…	
Mining and extraction…	
Construction	
Accommodation and…	
Arts, entertainment,…	
Human health and…	
Real estate activities	
Agriculture, forestry…	
Education	
Public admin. and…	

Source: Authors' calculations from OECD data.

In the panel on the right side of Figure 5, estimates are presented for the carbon intensity of MNEs and DOEs by country. Saudi Arabia had MNEs with the highest carbon intensity followed by South Africa, Singapore and the United States. MNEs in Iceland, Costa Rica, Finland, Denmark, and Slovenia had the lowest average intensities. DOEs in almost all countries had higher carbon intensities than MNEs except for Malta, Luxemburg, Norway, Hong Kong, Switzerland, and Ireland. The largest differences between carbon intensities of MNEs and DOEs was in Russia, China, India, US, Japan and Saudi Arabia where the carbon intensities of DOEs were about 5.4, 2.6, 3.4, 2.1, 4.8 and 1.6 times higher than the carbon intensities of MNEs respectively.

Figure 5. Carbon intensities of output (000's of metric tons per 1 million USD), 2005-15 average
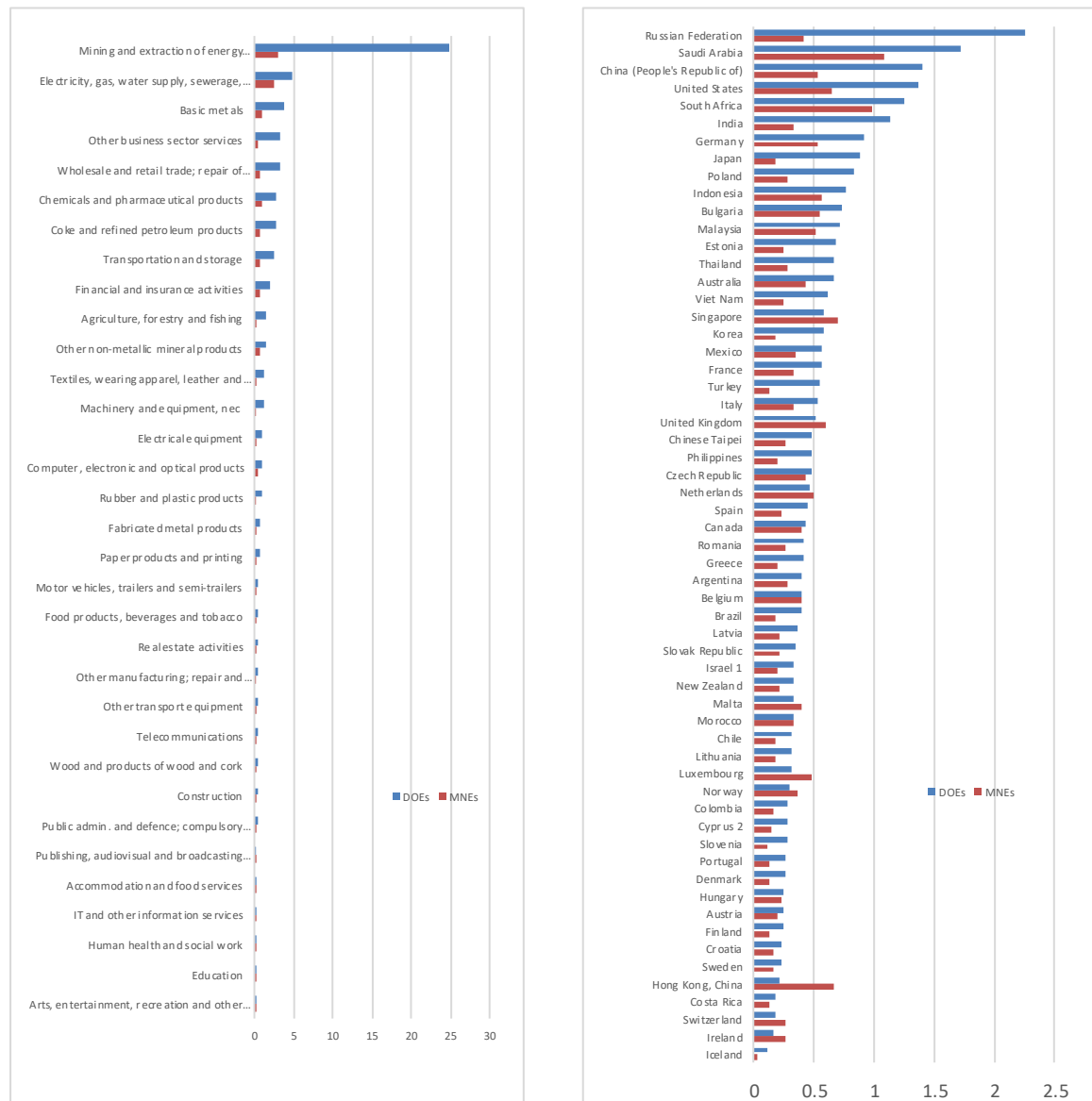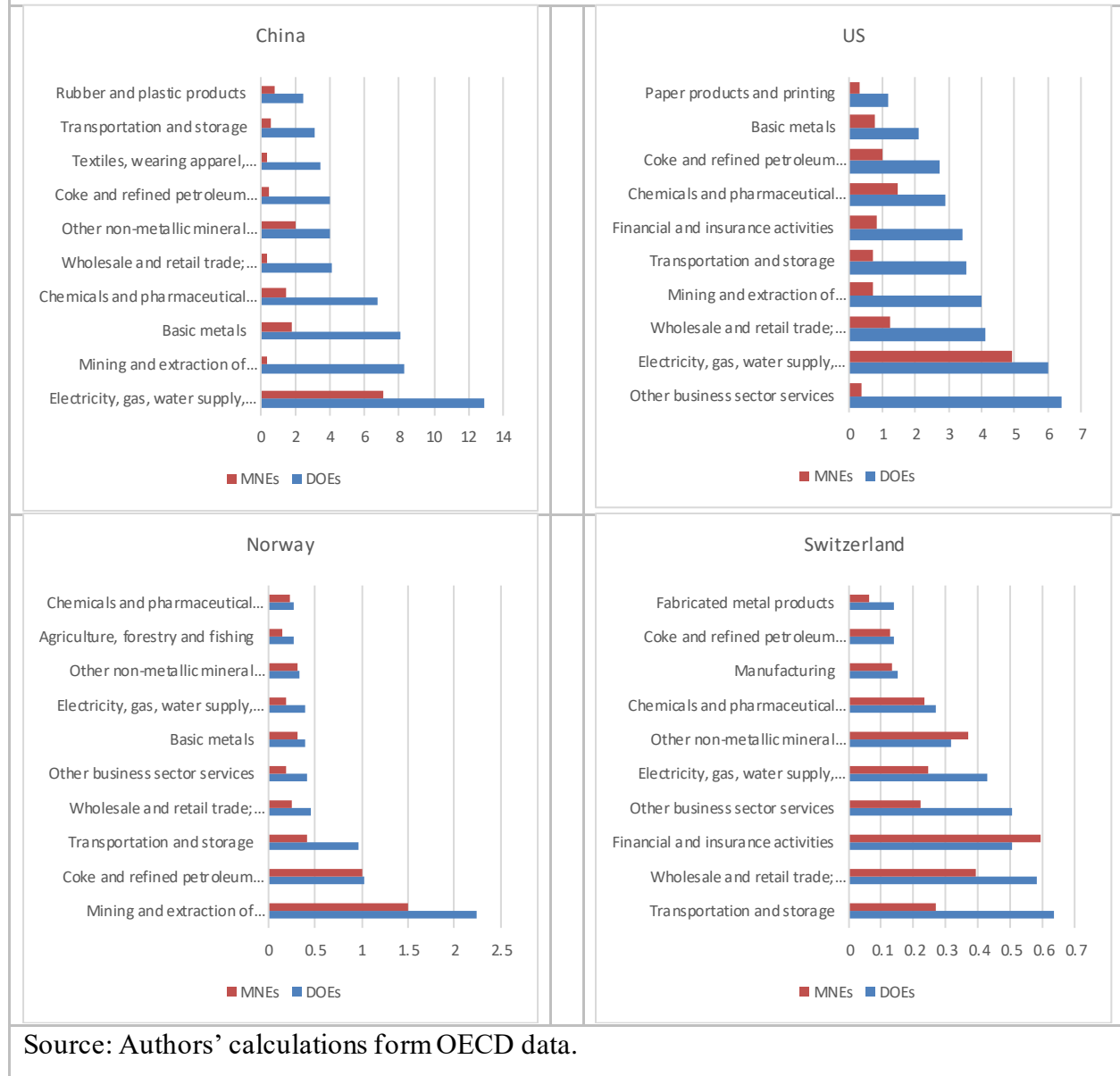

Source: Authors' calculations from OECD data.

A comparison of the industry-level carbon intensities between selected large and developed economies with overall high carbon intensities (China and US) and small and developed economies with overall low carbon intensities (Norway and Switzerland) showed varying patterns in the industry distribution of emissions. In China, electricity gas and water had the highest intensity; in the US other business services; in Norway, Mining; and in Switzerland Transport and storage. The carbon intensity of MNEs in high carbon intensive industries was quite small compared to DOEs with the exception of the electricity, gas and water sector for the large, developed economies. However, for the smaller developed economies, although the carbon

intensity of MNEs was lower compared to DOEs in the different industries, the difference was much smaller.

Figure 6. Carbon intensities of output (000's of metric tons per 1 million USD), 2005–15 average
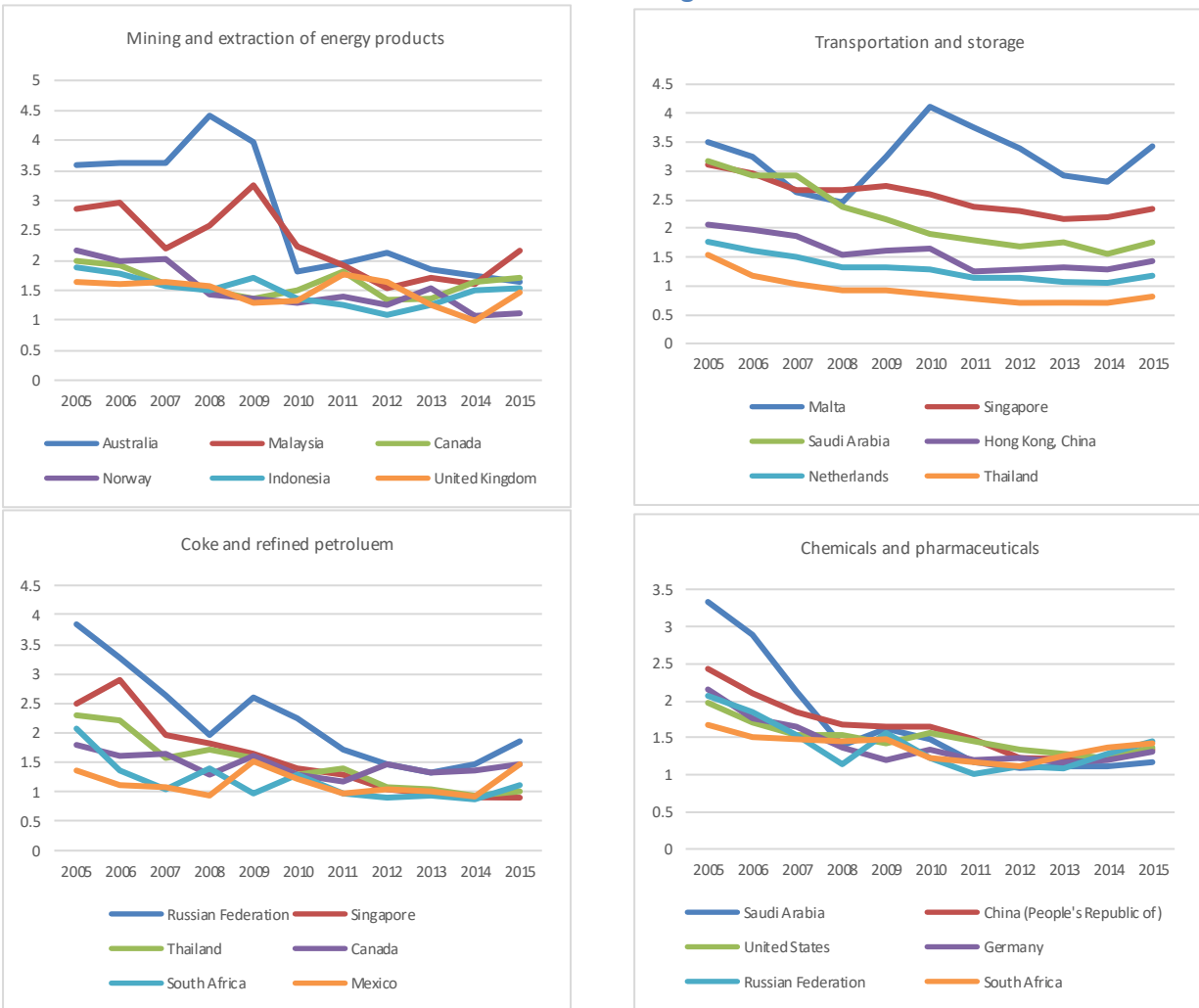
Source: Authors' calculations form OECD data.

Estimates of trends in the carbon intensities of MNEs between 2005 and 2015 for selected industries with large carbon intensities (mining, transport, manufacture of coke and refined petroleum and manufacture of chemicals and pharmaceuticals) for six countries with the highest carbon intensities in each industry are shown in Figure 6. In mining, MNEs in Australia, had the highest intensities followed by Malaysia, Canada, Norway, Indonesia and United Kingdom. In transport, MNEs in Malta, Singapore, Saudi Arabia, Hongkong, Netherlands and Thailand had the highest intensities while in manufacturing of coke and refined petroleum, Russia, Singapore,

Thailand, Canada, South Africa and Mexico had the highest intensities. In the manufacture of chemicals and pharmaceuticals, Saudi Arabia, US, Germany, Russia and South Africa had the largest carbon intensities. The trends in annual carbon intensities in mining and manufacturing were generally downward, while in transport, the decline noted during the middle of the period had ceased with the latter period showing a rebound.

Figure 7. Trends in carbon intensities of MNEs output (000's of metric tons per 1 million USD), 2005-15 average

Source: Authors' calculations from OECD data.

C. Carbon emissions in Exports of MNEs

In this subsection, we examine emissions associated with exports to determine the effect of external demand on emissions among MNEs and DOEs. In in the top panel of Figure 8, we plot a scatter diagram of industry carbon intensities of MNEs against their corresponding industry shares of emissions in exports to emissions in total output of MNEs. In the lower panel, a scatter

diagram is plotted of country carbon intensities of MNEs against respective country shares of emissions in exports to total emissions in output of MNEs.

Figure 8. MNE carbon and export intensities, 2005–15 average[7]
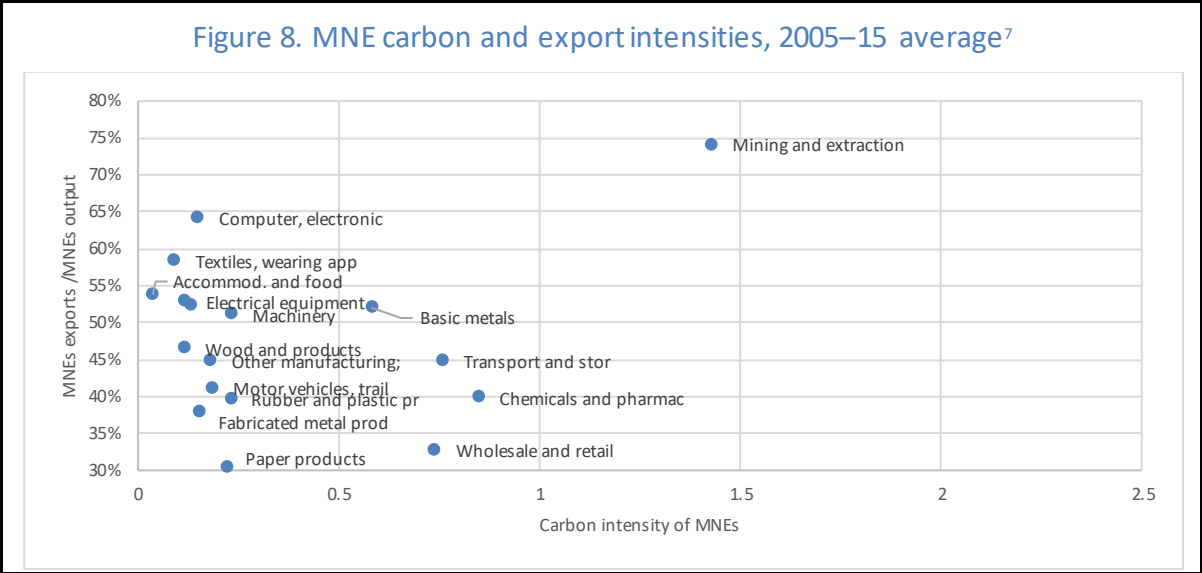
[7] Sectors with export shares of less than 30 percent of total output are not shown on the sector chart. They include IT and other information services; Coke and refined petroleum products; Other business sector services; Food products, beverages and tobacco; Other non-metallic mineral products; Agriculture, forestry and fishing; Financial and insurance activities; Publishing, audiovisual and broadcasting activities; Telecommunications; Arts, entertainment, recreation and other service activities; Education; Electricity, gas, water supply, sewerage, waste and remediation services; Real estate activities; Construction; Human health and social work; and Public admin. and defence; compulsory social security. In addition, countries with export shares of total output of less than 45 percent are not showed in the country chart. They include Bulgaria, Poland, Lithuania, Portugal, Norway, Hong Kong, India, France, South Africa, Germany, Colombia, Russian Federation, United Kingdom, Turkey, Latvia, Spain, Australia, Romania, Greece, Croatia, Italy, Argentina, New Zealand, Japan, United States, and Brazil.
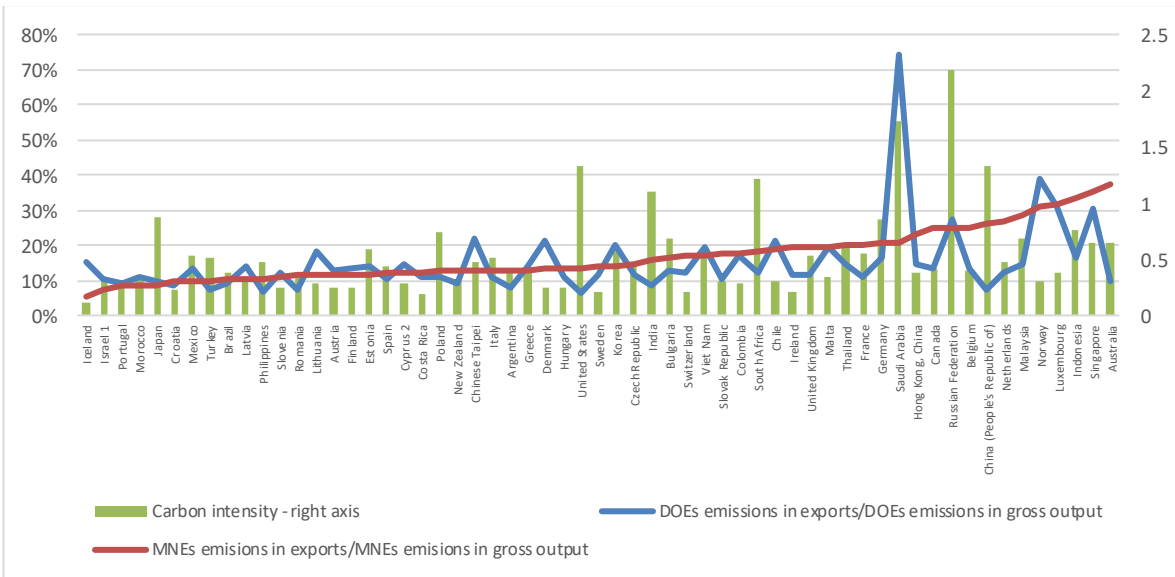
Source: Authors' calculations from OECD data.
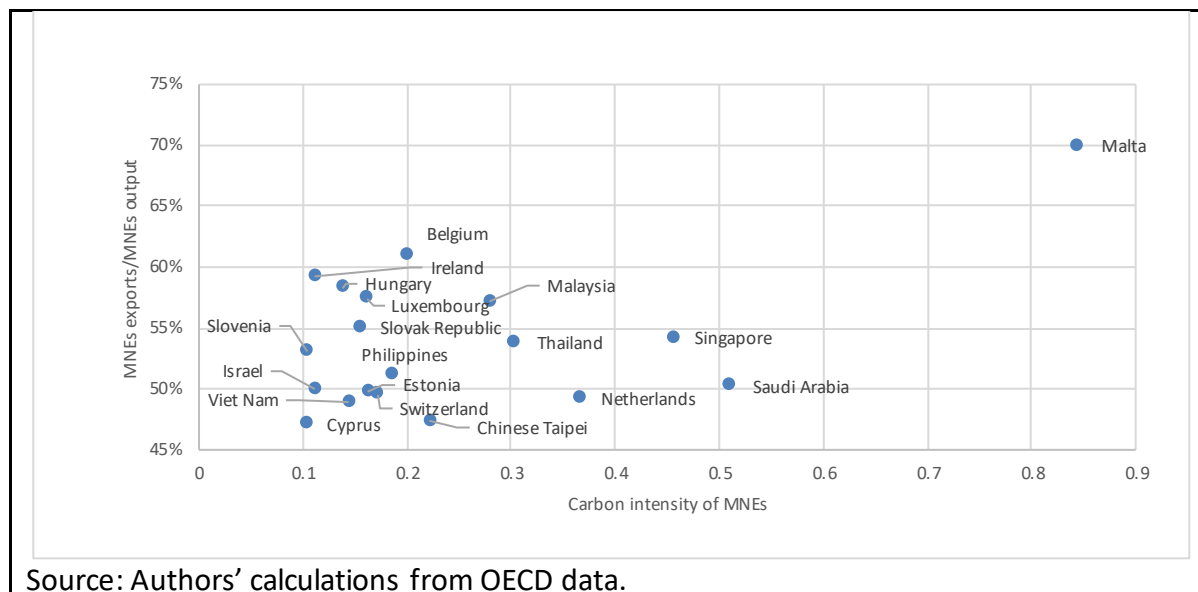
In the industry chart in the top panel, we note that most industries with high carbon intensities among MNEs (transport, manufacturing, wholesale and retail trade) have export intensities of 30 percent to 45 percent suggesting that a significant share of the emissions in high carbon intensity industries is driven by foreign demand. An exception is in the case of mining which has a large share of its output exported and also has a high carbon intensity. On the other hand, several low carbon intensity industries (accommodation, manufacture of textiles, manufacture of electrical equipment, manufacture of machinery, and manufacture of computer and electronic products) have most of their output exported, which makes their combined effect on domestic emissions by MNEs to meet foreign demand significant.

In the country chart in the lower panel, a similar observation is made, as countries with fairly low carbon intensities have large shares of their output exported. The implication is that a sizeable share of the emissions in the low carbon intensity countries is driven by foreign demand. For instance, the chart shows that although MNEs in countries like Belgium, Hungary, Luxemburg, Malaysia, Slovak, Slovenia, Switzerland and Philippines have relatively low emission intensities, more than half of their output is exported. A notable exception is Malta which has both high carbon intensities and export shares to output.

In Figure 9, we compare the share of MNEs emissions in exports to respective emissions in their output against corresponding estimates for DOEs by country and superimpose a bar chart for the carbon intensity. We note that export related emissions shares are higher for MNEs compared to DOEs in a majority of the countries. Exceptions include Norway, Saudi Arabia, Chile, Korea, Denmark, Cyprus, Lithuania, Latvia, Mexico, Israel and Iceland. In addition, export related emissions are for the most part higher for MNEs compared to DOEs in countries with low carbon intensities.

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Figure 9.Carbon intensities and shares of export emissions to output emissions, 2005 – 15 average

Source: Authors' calculations from OECD data.

IV. CONCLUSION AND POLICY IMPLICATIONS

This paper presented an experimental approach for estimating the effect of foreign direct investment on carbon emissions in host economies through their investment, production, and exports related activities. The novel contribution of the approach is two-fold – first it makes use of already available data, and second it is intuitive, and easy to follow and replicate for many countries as data becomes available. The estimates obtained were comparable within and between industries and countries. More importantly, the estimates were used to answer important policy questions on the effect of FDI on emissions. The estimates showed that emissions from the investment activity of FDI have generally fallen between 2005 and 2015. In addition, they are concentrated in electricity, construction and manufacturing industries. We also found that compared to emissions from operations of FDI companies, emissions from investment activity funded by FDI were much smaller.

For ongoing operations of FDI companies, high carbon emission estimates for MNEs were mainly in manufacturing; wholesale and retail trade; and electricity, gas and water industries. The same industries also had the highest carbon intensities. The construction industry, which had a large effect on emissions for FDI funded GFCF, was not a major contributor to emissions from the ongoing operations of MNEs. Further, MNEs were found to have lower contributions to overall emissions and carbon intensities in all sectors compared to DOEs. However, within individual industries in some countries, there were cases were MNEs had higher carbon intensities compared to DOEs especially in countries with low overall carbon intensities. The results also showed that MNEs in industries with high carbon intensities were median contributors to exports while MNEs in industries with low intensities had significant

contributions to exports. In addition, we noted that MNEs in countries with the highest export intensities had generally low carbon intensities.

The work has shown the important role that firms operating in one economy but owned by investors in another economy have in global carbon emissions. This suggests that policies by home and host economies could play an important role in reducing global carbon emissions. For home countries, policies that incentivize their domestic direct investors to meet high environmental and emissions standards not only in their operations in the home economy but also at their foreign operations could be important to reducing emissions globally and not just domestically. Such policies could not only reduce emissions by inducing these firms to use lower carbon production functions and technology at home and abroad but also by inducing them to demand lower carbon infrastructure and transportation in the host economies. If firms were also encouraged to reduce emissions along their supply chains, it could lead them to demand that their suppliers reduce their carbon emissions. For host economies, it is important to remove barriers to investment in environmental goods and services industries as well as in low carbon technologies to promote positive spillovers and knowledge and technology transfer to the domestic economy. In addition, host economies should include an analysis of the impact on carbon emissions as part of their FDI attraction strategies. Finally, developing a standard for companies to disclose their carbon emissions will provide valuable information that can help us better understand the role of all enterprises, both MNEs and DOEs, in carbon emissions.

▪ There are, however, some methodological limitations of the framework as well as data limitations to its implementation. In the future, work could aim to improve the framework by addressing some of these limitations. Possible interesting areas of future work include FDI estimates that distinguish between the use of FDI resources for acquisition of assets versus for capacity extension, including greenfield investment, expanded information on the role of MNEs in carbon emissions, and integrating the use of models for estimating outcomes from the main relationships reflected in the equations used to capture dynamic interactions. Some sensitivity analysis on the differences in direct emissions between MNEs and DOESs is another important area that could provide additional policy implications.

REFERENCES

Aitken, B., & Harrison, A. (1991). Are there spillovers from foreign direct investment? Evidence from panel data for Venezuela. *World Bank, Washington, DC Mimeo*.

Ben-Israel, A., & Greville, T. N. (2003). Generalized inverses: theory and applications. *Vol. 15. Springer Science & Business Media*.

Blackman, A., & Wu, X. (1999). Foreign direct investment in China's power sector: trends, benefits and barriers. *Energy policy*.

Blomstrom, M., Lipsey, R. E., & Zejan, M. (1994). What explains the growth of developing countries? *Convergence of productivity: Cross-national studies and historical evidence*.

Cadestin, C., De Backer, K., Desnoyers-James, I., Miroudot, S., Rigo, D., & Ye, M. (2018). Multinational enterprises and global value chains: the OECD analytical AMNE database.

Climent, J.-J., Thome, N., & Wei, Y. (2001). A geometrical approach on generalized inverses by Neumann-type series. *Linear algebra and its applications*.

De Mello, L. R. (1999). Foreign direct investment-led growth: evidence from time series and panel data. *Oxford economic papers*.

Harrison, A. (1995). Determinants and effects of direct foreign investment in Cote d'Ivoire, Morocco, and Venezuela.

Hill, H. (1990). Indonesia's industrial transformation part II. *Bulletin of Indonesian Economic Studies*.

IEA. (2020). Emissions from fuel combustion 2020 Edition.

Kathuria, V. (2000). Productivity spillovers from technology transfer to Indian manufacturing firms. *Journal of International Development*.

Kokko, A., Zejan, M., & Tansini, R. (2001). Trade regimes and spillover effects of FDI: Evidence from Uruguay. *Weltwirtschaftliches Archiv*.

Lee, J. W. (2013). The contribution of foreign direct investment to clean energy use, carbon emissions and economic growth. *Energy Policy*.

Lipsey, R. E. (2000). Affiliates of US and Japanese Multinationals in Production and Trade. *NBER-EASE*.

Lipsey, R. E. (2004). *Home-and host-country effects of foreign direct investment. In Challenges to globalization: Analyzing the economics.* University of Chicago Press.

Mabey, N., & McNally, R. (1999). Foreign direct investment and the environment: From pollution havens to sustainable development. *World Wide Fund for Nature United Kingdom, Surrey*.

Moulinec, H., Suquet, P., & Milton, G. W. (2018). Convergence of iterative methods based on Neumann series for composite materials: Theory and practice. *International Journal for Numerical Methods in Engineering*.

Okamoto, Y., & Sjholm, F. (2000). *FDI and the dynamics of productivity: Microeconomic evidence.* APEC Study Centre, Graduate School of International Development, Nagoya.

Rippy, J. F. (1976). *The capitalists and Colombia.* Ayer Company Pub.

Romer, P. (1993). Idea gaps and object gaps in economic development. *Journal of monetary economics*.

Seker, F., Ertugrul, H. M., & Cetin, M. (2015). The impact of foreign direct investment on environmental quality: a bounds testing and causality analysis for Turkey. *Renewable and Sustainable Energy Reviews*.

Shahbaz, M., Balsalobre-Lorente, D., & Sinha, A. (2019). Foreign direct Investment--CO2 emissions nexus in Middle East and North African countries: Importance of biomass energy consumption. *Journal of cleaner production*.

Shao, Y. (2018). Does FDI affect carbon intensity? New evidence from dynamic panel analysis. *International Journal of Climate Change Strategies and Management*.

Smarzynska, J. B. (2004). Does foreign direct investment increase the productivity of domestic firms? In search of spillovers through backward linkages. *American economic review*.

Wendy, D., & Chia, S. Y. (2004). Multinationals and East Asian Integration. International Development Research Center, Canada.

Zarsky, L. (1999). Havens, halos and spaghetti: untangling the evidence about foreign direct investment and the environment. *Foreign direct Investment and the Environment*.

Zhu, H., Duan, L., Guo, Y., & Yu, K. (2016). The effects of FDI, economic growth and energy consumption on carbon emissions in ASEAN-5: evidence from panel quantile regression. *Economic Modelling*.

Annex 1: Working example on computing emission estimates

Emissions

	Agriculture	Manufacturing	Services	Total
	480	440	160	1080

Input-Output tables

To (Columns) / From (Rows)	Agriculture	Manufacturing	Services	Households (HFCE)	Exports	Total Output	Final use
Agriculture	100	500	400	500	100	1600	600
Manufacturing	200	500	500	500	500	2200	1000
Service	400	400	300	400	100	1600	500
Value Added (COE, GOS, GMI)	800	600	300				1700
Imports	100	200	100				1600
Total Inputs	1600	2200	1600	1400	600	5400	
Total Domestic Intermediate	700	1400	1200			5400	

Check		
	Supply	Use
	1600	1600
	2200	2200
	1600	1600

Requirements Matrix (A)

To (Columns) / From (Rows)	Agriculture	Manufacturing	Services
Agriculture	0.06	0.23	0.25
Manufacturing	0.13	0.23	0.31
Service	0.25	0.18	0.19

Identity Matrix (I)		
1	0	0
0	1	0
0	0	1

(I-A)

0.94	-0.23	-0.25
-0.13	0.77	-0.31
-0.25	-0.18	0.81

Check: $(I-A)^{-1} \times Y = X$

1600
2200
1600

Leontif Inverse (Multipliers)

	Agriculture	Manufacturing	Services	Total
Agriculture	1.30	0.52	0.60	2.42
Manufacturing	0.41	1.59	0.74	2.73
Service	0.49	0.52	1.58	2.59
Total	2.19	2.63	2.92	

Direct emissions coefficients	0.30	0.2	0.1

Direct and indirect emissions coefficients (emissions multipliers)			
Total	0.519	0.526	0.485
Rearrangement for CO2 content in final use	0.519	0.000	0.000
	0.000	0.526	0.000
	0.000	0.000	0.485

HFCE diagonal				
Agriculture	500	0.00	0	
Manufacturing	0	500.00	0	
Services	0	0.00	400	
Embodied emissions - HFCE	259.7339782	262.8778718	194.050786	716.663

Exports diagonal				
Agriculture	100	0	0	
Manufacturing	0	500	0	
Services	0	0	100	
Embodied emissions - exports	51.94679565	262.8778718	48.51269649	363.337
Total embodied emissions				1080

Output Industry	Contributing Industry	Multiplier	Total direct emissions	Partial direct and indirect emissions	Total direct and indirect emissions
Agriculture	Agriculture	1.30	0.3	0.389	
Agriculture	Manufacturing	0.41	0.2	0.082	
Agriculture	Services	0.49	0.1	0.049	0.519
Manufacturing	Agriculture	0.52	0.3	0.157	
Manufacturing	Manufacturing	1.59	0.2	0.317	
Manufacturing	Services	0.52	0.1	0.052	0.526
Services	Agriculture	0.60	0.3	0.180	
Services	Manufacturing	0.74	0.2	0.147	
Services	Services	1.58	0.1	0.158	0.485

	Households	exports	
Agriculture	259.73	51.95	312
Manufacturing	262.88	262.88	526
Services	194.05	48.51	243
total	716.66	363.34	1080

Annex 2: Illustration on the computation of the Output multiplier

Suppose $(I - A) = \begin{bmatrix} 0 & 2 & 9 \\ 1 & 4 & 6 \\ 3 & 7 & 8 \end{bmatrix}$, then matrix of cofactor is

$$C = \begin{bmatrix} (-1)^{1+1}\begin{vmatrix} 4 & 6 \\ 7 & 8 \end{vmatrix} & (-1)^{1+2}\begin{vmatrix} 1 & 6 \\ 3 & 8 \end{vmatrix} & (-1)^{1+3}\begin{vmatrix} 1 & 4 \\ 3 & 7 \end{vmatrix} \\ (-1)^{2+1}\begin{vmatrix} 2 & 9 \\ 7 & 8 \end{vmatrix} & (-1)^{2+2}\begin{vmatrix} 0 & 9 \\ 3 & 8 \end{vmatrix} & (-1)^{2+3}\begin{vmatrix} 0 & 2 \\ 3 & 7 \end{vmatrix} \\ (-1)^{3+1}\begin{vmatrix} 2 & 9 \\ 4 & 6 \end{vmatrix} & (-1)^{3+2}\begin{vmatrix} 0 & 9 \\ 1 & 6 \end{vmatrix} & (-1)^{3+3}\begin{vmatrix} 0 & 2 \\ 1 & 4 \end{vmatrix} \end{bmatrix} = \begin{bmatrix} -10 & 10 & -5 \\ 47 & -27 & 6 \\ 24 & 9 & -2 \end{bmatrix}.$$

Using the cofactor expression along row i,

determinant of $|I - A| = \sum_{j=1}^{n}(I - A)_{i,j} \, C_{i,j}$, and taking $i = 1$, we can compute

$$|I - A| = 0 \times (-1)^{3+1}\begin{vmatrix} 2 & 9 \\ 4 & 6 \end{vmatrix} + 2 \times (-1)^{1+2}\begin{vmatrix} 1 & 6 \\ 3 & 8 \end{vmatrix} + 9 \times (-1)^{1+3}\begin{vmatrix} 1 & 4 \\ 3 & 7 \end{vmatrix} = \text{-25}. \quad (I - A)^{-1} =$$

$$\frac{1}{-25} = \begin{bmatrix} -10 & 47 & 24 \\ 10 & -27 & 9 \\ -5 & 6 & -2 \end{bmatrix}.$$