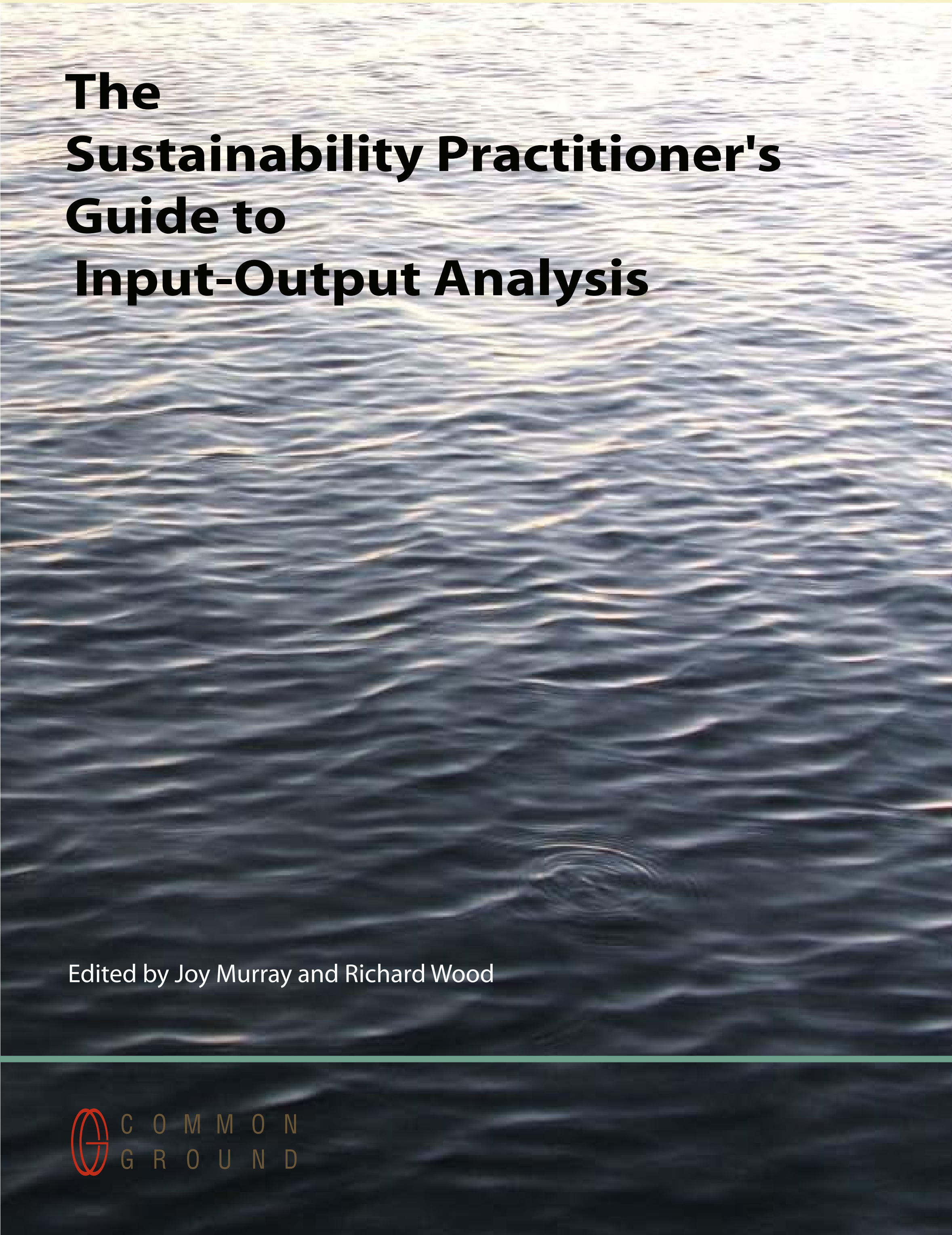
ON SUSTAINABILITY

The Sustainability Practitioner's Guide to Input-Output Analysis



Edited by Joy Murray and Richard Wood

COMMON GROUND

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Chapter 14

Environmentally Extended Multi-Region Input-Output Model

Sharing Responsibility Across the Globe

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Introduction

National economies are increasingly interacting with each other through international trade, foreign direct investment, capital flow and the spread of technology. Among Fortune 500 companies, many of them are multinational corporations that have branch offices, manufacturing factories or contract manufacturers in countries other than the location of their original and main headquarters. In a supply chain of a product, the finished product is identified by a trademark or an indicator of geographical origin. However in most cases not all of the stages, from the extraction of raw materials to component construction, assembly and distribution until the delivery to the end users, occur in the same country.

The cooperation among suppliers located in different countries to complete the supply chain of a product is a phenomenon of economic globalization, a process by which a spatially interwoven and sophisticated network of business and trade has been formed. As a consequence of this process, countries are bound economically to each other. A change in one national or local economy will have propagating effects on other economies. From an environmental perspective, owing to global trade, people have access to cheaper and better quality goods, which are not produced domestically. However, emissions and other environmental loads may be generated elsewhere, in particular in developing countries where the environmental requirements are generally low. The environmental costs caused by damage to the environment, productivity and public health are usually not included in the price of finished goods. These external environmental costs may be borne by somebody other than the producers and consumers, e.g. by the community nearby a factory or by a neighbouring country next to the producing country via trans-boundary air pollution, or by those who are suffering because of global climate change. Though not all actors who benefit from the value chain of a product contribute directly to the environmental impacts, they all play a role and should share the responsibilities for reducing the adverse impacts.

In the supply chain of a product, such as a desktop personal computer (PC) (see Box 1), the final assembly of different components into a finished PC is not particularly polluting, while other stages such as resource extraction, component manufacturing and international transportation are more polluting and exert more environmental impacts. Good environmental performance in the final stage cannot ensure that the product has low environmental impacts from the perspective of the complete chain. It is therefore important to know both the total environmental impacts of the supply chain and the contributions of each stage. The former knowledge helps us compare various PCs provided by different supply chains. The latter helps us identify the most polluting stage(s) that should be addressed as priorities to achieve holistic and effective environmental management.

Box 1 The supply chain of desktop PCs

In the supply chain of desktop PCs, the design and technology of critical components, such as chipsets, motherboards, printed circuit boards and LAN chips, etc., are usually owned by some brand companies, such as Intel (USA), Compeq (Taiwan), Foxconn (Taiwan) and Broadcom (USA), among others. The mass production of these critical components is often conducted in China, Taiwan or other Asian countries where the resource and labour costs are low. In some cases, semi-assembled components are sent back to the original countries and assembled into finished products. In other cases, the complete assembly is also conducted in China or other Asian countries with the provision of some electronic components by Japan or Korea, etc. The finished PCs marked with e.g. “Acer”, “Apple”, “Dell” or “Gateway” are shipped to regional and national markets around the world until they reach the consumers.

Embodied emissions as an indicator can be used to address the issue of external costs and to communicate among various actors about the impacts induced by the supply chain. *Embodied emissions* refers to CO_2 or other pollutants emitted from each upstream stage of the supply chain of a product (see an example in Box 2). Consumers and downstream producers (e.g. final assembly) can use this indicator to request their last upstream suppliers (e.g. semi-assembly) to improve. Then their suppliers further request their upstream suppliers (e.g. component manufacturing) to improve, and so on, to the very beginning of the supply chain (e.g. resource extraction). Through such a "pressure chain" created by consumers and downstream producers, an improvement in the overall environmental performance of a finished product can be expected.

Box 2 Emissions embodied in a desktop PC

The following is an example of CO_2 embodied in the supply chain of a desktop PC:

Stages in the supply chain	**Direct CO_2 emissions**	**Embodied emissions**
Resource extraction	1 unit	1 unit
Component manufacturing	1 unit	1+1=2 units
Semi-assembly	0.3 unit	1+1+0.3=2.3 units
International transportation of	1.5 units	1+1+0.3+1.5=3.8 units
semi-products	0.2 unit	1+1+0.3+1.5+0.2=4 units
Final assembly	1 unit	1+1+0.3+1.5+0.2+1=5
Distribution and delivery to the end user		units

Therefore CO_2 emissions embodied in the semi-products that arrive at the place for final assembly are 3.8 units and the total emissions embodied in a desktop PC used by the consumer are 5 units.

As introduced in Chapter 1, the hybrid input-output (IO) table and analysis can be applied for accounting for emissions embodied in finished goods produced by an industry of a country. However when the supply chain consists of suppliers and consumers located in different countries, a single-country IO table is not enough and an accounting framework covering all associated countries is required. A multi-region input-output (MRIO) table is such a kind of accounting framework.

In this chapter, we introduce multi-region input-output analysis (MRIOA) and its extensions to accounting for emissions embodied in international trade. We first introduce the basic framework of a MRIO table and the differences between MRIOA and input-output analysis (IOA) that is based on a single country. Then we provide an example of using MRIOA for the calculation of carbon emissions embodied in international trade.

Multi-region input-output analysis

What does a MRIO table look like?

As it is named, a multi-region input-output table shows the interconnections among various industries located in different geographic regions to fulfil their production. A region can refer to a country in a multiple-country accounting framework or refer to a state, a province, or the eastern part or western part of a country in a national accounting system. In this chapter, we refer to a region as a country. A MRIO table records the flow of products from each industry in each country as a producer to each of the industries in each of the countries as consumers.

Table 1 is an example of the framework of a MRIO table for three countries (A, B and C) and three sectors (agriculture, manufacturing and service). The fundamental information on inter-country and inter-industry trade is presented in a blocked matrix (the area within bold borders), consisting of 9 blocks (3 countries × 3 countries). Each block tells the country of origin by row and the country of destination by column. Therefore three blocks on the diagonal (in shaded areas) indicate trade from within the same country and six off-diagonal blocks document bilateral trade between each pair of countries. Each block is also a matrix recording the details of source sectors by row and destination sectors by column in the same way as in a single-country IO table.

Table 1: Example of a MRIO table

			Inter-industry Sales									Sales to Final Demand			Total Sales
			Country A			Country B			Country C			Country A	Country B	Country C	
			Agri	Manu	Serv	Agri	Manu	Serv	Agri	Manu	Serv				
Inter-industry Purchases	Country A	Agri	15	35	4	0	0.3	0.1	0	0.1	0.1	47	0.8	0.1	102.5
		Manu	24	400	45	0	5	0.7	0	7	3	215	9.8	15.6	725.1
		Serv	3	45	20	0	0	0	0	0	1	76.2	0	0	145.2
	Country B	Agri	0	0	0	3	22	4	0	0	0	0	14.1	0.1	43.2
		Manu	0.2	10	0.7	12	640	160	0.2	17	4	4.3	768	28	1644.4
		Serv	0	0	0	4	195	190	0	0	0	0	728	0	1117
	Country C	Agri	0.1	0.1	0	0.1	2	0.2	18	46	5	0.2	0.5	12	84.2
		Manu	0.2	5	0.5	0.1	10	2	21	930	330	3.3	13	1360	2675.1
		Serv	0	0	0	0	0.1	0	15	390	720	2	3	1873	3003.1
Value Added			60	230	75	24	770	760	30	1285	1940				
Total Purchases			102.5	725.1	145.2	43.2	1644.4	1117	84.2	2675.1	3003.1				

A MRIO table provides data on the production recipe of each country and the bilateral trade of each pair of countries in a uniform and symmetrical way. It is handy to compare different countries in terms of production technology, dependency on foreign trade and trade relations with different countries. A MRIO table can also help analyse the impact of a change in one economy on others systematically (see details in the next section).

For example, to produce 1 unit of output, the manufacturing sector in Country A purchases 0.05 unit from the agriculture sector (calculated by (35+0+0.1)/725.1), 0.57 unit from the manufacturing sector (calculated by (400+10+5)/725.1) and 0.06 unit from the service sector (calculated by (45+0+0)/725.1) and generates 0.32 unit value-added (calculated by 230/725.1). By the same calculation, the manufacturing sector in Country C purchases 0.02 unit from the agriculture sector, 0.36 unit from the manufacturing sector and 0.14 unit from the service sector and generates 0.48 unit value-added for producing 1 unit of output. Therefore, the manufacturing sector in C generates more value-added in producing 1 unit of output and its intermediate inputs are relatively more dependent on the service sector than is the case in A. In addition, for intermediate inputs, the manufacturing sector in A is 97% self-sufficient (calculated by (35+400+45)/(725.1-230)) and imports 3%, while in C the self-sufficiency is 98%. For the supply to final demand, the manufacturing sectors in both A and C are 97% self-sufficient (calculated by 215/(215+4.3+3.3) for A and 1360/(15.6+28+1360) for C). Furthermore, Country A totally imports 11.4 units from Country C (calculated by 0.1+0.2+0.1+5+0.5=5.9 for intermediate inputs and 0.2+3.3+2=5.5 for final demand) and exports 26.9 units in total to Country C (calculated by 0.1+7+0.1+3+1=11.2 for inter-industry sales, and 0.1+15.6=15.7 for final demand). Therefore Country A has a surplus of 15.5 units in the bilateral trade with Country C.

What are the differences between MRIOA and single-country based IOA?

One of the fundamental differences between a single-country IO table and a MRIO table is their framework. On the one hand, a single-country based IO table aims at intra-national transactions among industries for a particular country and imports from and exports to its major trading partners and the rest of the world (see an example in Table 2). Usually the intra-national transactions constitute the main body of a single-country IO table with import and export accounts varying from a highly aggregated level such as one entry for each sector to a detailed product by industry level for imports. Levels of aggregation for import and export accounts depend on the purpose of the IO table, the relative importance of international trade and data availability, etc.

On the other hand, a MRIO table is compiled based on single-country IO tables and bilateral trade data. Countries in a MRIO table are symmetrical to one another. Imports to each country are explicitly recorded by their source industry and by country of origin. In addition, the detailed use of imports by industries and by the final consumption is also clearly documented. To generate such detailed and systematic accounts for each country in a MRIO table requires intensive data on international trade and compilation techniques to coordinate different presentations used in single-country IO tables and match different classification of sectors. These difficulties constrain the availability of MRIO tables compared to national IO tables and therefore influence their extensive application.

Table 2: Example of a single-country IO table

Country A		Inter-industry Sales			Sales to Domestic Final Demand	Exports	Total Sales
		Agri	Manu	Serv			
Inter-industry Purchases	Agri	15	35	4	47	1.5	102.5
	Manu	24	400	45	215	41.1	725.1
	Serv	3	45	20	76.2	1	145.2
	Imports	0.5	15.1	1.2	5.5		
Value Added		60	230	75			
Total Purchases		102.5	725.1	145.2			

One major purpose of input-output analysis for a country is to predict the impacts throughout the economy induced by a change in one industry. As for open economies, one country also wants to know the impacts on domestic industries that are induced by a change in another country and vice versa. MRIOA can help us to do that. For example, say there is 5% increase in the outputs of the manufacturing sector in Country A in the next year due to an incentive policy. By MRIOA, we first can know how much increase can be expected in the outputs of different industries in different countries because each of them provides a fixed portion of inputs into Country A's manufacturing sector. These induced changes are called spillover effects, which are the impacts of a change in one industry in a country on industries in other countries. The induced increase in the service sector of Country B, for example, further causes spillover effects on various industries in different countries based on their fixed input ratios. One of them is an increase in the manufacturing sector of Country A, which is the very source of such propagating changes. These kinds of changes are called feedback effects. Industries in different countries are interacting with one another by the loops of spillover effects and feedback effects (see the left figure of Figure 1). MRIOA can account for these effects systematically.

By using single-country based IOA, we can know the spillover effects on the exports of one country that are caused by a change in a foreign industry (see the right figure of Figure 1). However the feedback effects are not accounted for because import and export accounts are not included in the matrix of inter-industry purchases and sales. This is a major difference between applying MRIOA and single-country based IOA to accounting for open economies.

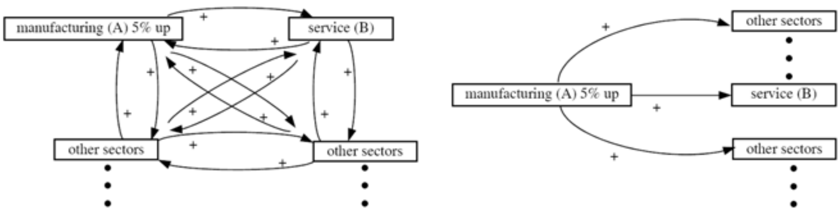

Figure 1: MRIOA (left) vs. single-country based IOA (right)

Accounting for emissions embodied in international trade

National emission inventory and international trade

In 1992, most countries in the world joined an international treaty, the United Nations Framework Convention on Climate Change (UNFCCC), to tackle the challenge posed by climate change. In December 1997, another international agreement, the Kyoto Protocol was adopted in Kyoto, Japan. Linked to the Convention, the Protocol sets binding targets for 37 industrialized countries and the European Community for reducing their greenhouse gas (GHG) emissions to an average of 5% against 1990 levels over the period 2008-2012. The Protocol does not commit developing countries to do so under the principle of "common but differentiated responsibilities" endorsed by the Convention. During the 15th meeting of the Conference of the Parties of the UNFCCC, the Copenhagen Accord was concluded on 18 December 2009 with signatories agreeing that deep cuts in global emissions are required. Though new reduction targets have yet to be set up, industrialized countries that are Party to the Kyoto Protocol will further strengthen the emissions reductions initiated by the Kyoto Protocol and developing countries will implement nationally appropriate mitigation actions.

Parties to the Convention must submit national reports on implementation of the Convention including their national GHG emission inventories. This is required because estimating the levels of GHG emissions and removals is important to achieve the objective of the Convention, which is to stabilize the GHG concentrations in the atmosphere at a level that would prevent dangerous human induced impacts on the climate system. Current national GHG inventories account for all GHG emissions and removals taking place within national territories.

The equity of this territorial GHG inventory has been argued by some major exporting countries. They produce goods that are consumed by other countries, but carbon emissions are charged to their national GHG accounts. This is also argued as one of the barriers keeping developing nations from reduction commitments, because many of them such as China, India and South-eastern Asian countries, have experienced rapid economic development largely owing to the steady growth in exports, which contribute greatly to the increase in their territorial GHG emissions.

In addition, carbon leakage may occur due to the differences in the strictness of national climate policies implemented in industrialized countries and in developing countries. Moving carbon-intensive production offshore to developing countries and importing carbon intensive goods from developing countries result in superficial emission reductions in industrialized countries and increases in emissions emitted from developing countries. The global emissions will not be reduced. Carbon leakage has been cited as an impediment to the effective reduction of carbon dioxide emissions through the Kyoto Protocol.

A key measure of such carbon leakage is the balance of emissions embodied in international trade. In this chapter we present an example of how to extend MRIOA to account for emissions embodied in international trade.

Producer responsibility vs. consumer responsibility

While the generation of territorial GHG inventories is based on producer responsibility, accounting for embodied emissions is based on consumer responsibility. As explained in Box 3, in the calculation of national emissions based on producer responsibility, direct emissions remain in the accounts of each source country. In the calculation based on consumer responsibility, direct emissions are passed on from upstream suppliers to downstream suppliers until the final consumers, and are included in the account of the country where the final consumers reside.

Box 3 Producer responsibility vs. consumer responsibility for national emissions accounting

The following is an example of the supply chain of a desktop PC. It explains how to account for national emissions based on producer responsibility and consumer responsibility.

Stages in the supply chain	**Direct CO_2 emissions**	**Source countries**
Resource extraction	1 unit	A
Component manufacturing	1 unit	B
Semi-assembly	0.3 unit	B
International transportation of semi-products	1.5 units	C
Final assembly	0.2 unit	C
Distribution and delivery to the end user	1 unit	C
Consumer	0 unit	D

National emissions accounting:

Producer responsibility		**Consumer responsibility**	
A:	1 unit	A:	0 unit
B:	1.3 units	B:	0 unit
C:	2.7 units	C:	0 unit
D:	0 unit	D:	5 units

We apply the Asian International Input-Output Table 2000 (AIO 2000) to the calculation of emissions embodied in international trade. AIO 2000 is compiled by the Institute of Developing Economies, Japan External Trade Organization, based on national IO tables of ten economies, including Indonesia (IDN), Malaysia (MYS), the Philippines (PHL), Singapore (SGP), Thailand (THA), Chinese mainland (CHN), Taiwan (TWN), the Republic of Korea (ROK), Japan (JPA), and USA. Table 3 presents the national emissions of ten economies estimated based on both producer responsibility and consumer responsibility. The results indicate that national CO_2 emissions based on consumer responsibility are quite different from those generated based on producer responsibility. For example, the differences vary from -525Mt-CO_2 for Chinese mainland to 543Mt-CO_2 for USA.

Table 3: National emissions of ten economies (in million tons of CO_2)

Economy	National emissions (consumer responsibility)	National emissions (producer responsibility)	Difference
IDN	215	273	-58
MYS	88	118	-30
PHL	67	69	-2
SGP	85	60	25
THA	144	155	-11
CHN	2,651	3,176	-525
TWN	210	217	-7
ROK	442	435	7
JPN	1,443	1,179	264
USA	6,245	5,702	543
Total	11,590	11,384	206

By MRIOA, we can also trace the sources and destinations of emissions embodied in bilateral trade (see Table 4). Rows present CO_2 embodied in the exports from one economy to other economies and columns indicate CO_2 embodied in the imports to one economy from other economies. The rest of world (ROW) other than ten economies is also considered. The results show that Singapore, Japan and USA have a trade deficit, while other countries have a trade surplus in terms of the balance of emissions embodied in international trade. Among ten economies, USA has the largest trade deficit (463.8Mt-CO_2) followed by Japan (190.7Mt-CO_2), while China has the largest trade surplus (452.4Mt-CO_2).

Table 4: Sources and destinations of emissions embodied in bilateral trade (in million tons of CO_2)

Economy	IDN	MYS	PHL	SGP	THA	CHN	TWN	KOR	JPN	USA	ROW
IDN	133.2	0.8	0.2	0.6	0.4	0.2	0.6	0.4	2.6	6.4	32.4
MYS	0.3	47.2	0.3	1.8	0.6	0.5	0.9	0.4	3.5	6.7	27.8
PHL	0	0.1	36.5	0	0.1	0.1	0.1	0.1	1.5	4.1	9.3
SGP	0.1	0.8	0.3	35.7	0.3	0.3	0.4	0.3	1.1	2.9	25.6
THA	0.3	0.5	0.2	0.5	91.8	0.3	0.4	0.2	3.1	5.3	31.3
CHN	1.3	2	0.4	1.9	2	2252.2	3.6	4.8	51.6	103.6	369.1
TWN	0.3	0.5	0.3	0.2	0.4	2.1	94.4	0.4	3.1	8.3	50.2
ROK	0.3	0.3	0.3	0.3	0.2	1.4	1	267.5	4	9.8	77.1
JPN	0.5	1	0.4	0.8	0.9	1.7	2.6	1.6	861.9	15.4	55.2
USA	0.4	1	0.5	0.9	0.8	2.3	4.1	2.6	11.3	4318.5	333.8
ROW	25	19	11	38	25	79	46	76	189	659	
Emissions embodied in imports	28.5	26	13.9	45	30.7	87.9	59.7	86.8	270.8	821.5	
Emissions embodied in exports	44.6	42.8	15.4	32.1	42.1	540.3	65.8	94.7	80.1	357.7	
Trade balance	16.1	16.8	1.5	-12.9	11.4	452.4	6.1	7.9	-190.7	-463.8	

In conclusion, MRIOA can help us to project the propagating impacts caused by one economy on other economies. An environmentally extended MRIOA can help us account for emissions embodied in international trade and trace where the environmental impacts really happen. *Embodied emissions* as an indicator, can be applied by various actors as a means to communicate with each other in the international supply chain of a product or by national governments and relevant international organizations to generated national emission inventories adjusted for trade.

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Further reading

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