Chapter 17
Quantitative Analysis Method of Environmental Burden Using Input-Output Models

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Abstract As a prerequisite to fully consider the socioeconomic situation in one country at a certain time and to implement appropriate environmental policies there, methodology and analysis models need to be established to quantitatively measure the environmental burden generated by human activities. This chapter outlines the use of input-output models for environmental analysis and case studies, as one method of quantitative analysis of environmental burden. First, the essence of an input-output table is explained, followed by an explanation of the basic framework of an input-output model and its application for environmental analysis. In addition, the emission structure of the environmental burden in Asia is examined by introducing international case studies of input-output models for environmental analysis. Due to limited space, the explanation of the input-output theory is given in simplified form in order to comprehend the general framework and purpose of environmental analysis by an input-output model. Please refer to Miller and Blair (Input-output analysis: foundation and extensions, 2nd edn. Prentice-Hall, Englewood Cliffs, 2009) and Shishido et al. (Input-output analysis handbook. Toyo Keizai Inc, 2010), for example, in order to fully understand the basic principles and application of input-output theory.

Keywords Input-output table • Leontief inverse • Induced CO_2 emissions • Carbon leakage

17.1 Introduction

As a prerequisite to fully consider the socioeconomic situation in one country at a certain time and to implement appropriate environmental policies there, methodology and analysis models need to be established to quantitatively measure the environmental burden generated by human activities. This chapter outlines the use of input-output models for environmental analysis and case studies, as one

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method of quantitative analysis of environmental burden. First, the essence of an input-output table is explained, followed by an explanation of the basic framework of an input-output model and its application for environmental analysis. In addition, the emission structure of the environmental burden in Asia is examined by introducing international case studies of input-output models for environmental analysis. Due to limited space, the explanation of the input-output theory is given in simplified form in order to comprehend the general framework and purpose of environmental analysis by an input-output model. Please refer to Miller and Blair (2009) and Shishido et al. (2010), for example, in order to fully understand the basic principles and application of input-output theory.

17.1.1 What Is an Input-Output Table?

An input-output table is a kind of flowchart originally devised by Wassily W. Leontief, showing the transactions of one economy (country, regions, etc.) over a certain time period (usually 12 months). In more specific terms, an input-output table shows economic activity in detail at a certain time, especially from the viewpoint of transactions between industries. It does this by entering transactions of goods and services between various sectors, including industry, household, and government, into one table.

A System of National Accounts (SNA) is one of the economic statistical systems describing the quantity and structure of flow transactions in the economy of a country. It consists of five parts: "national income accounts," "input-output table," "flow of funds accounts," "balance of payments table," and "national balance sheet." For the purpose of rudimentary understanding, an input-output table can be regarded as an economic statistical table showing the complete state of an economy.

Next, in order to understand an input-output table in a practical context, it is necessary to understand how to read it, as well as understand its structure as an economic statistical table. Figure 17.1 is an outline table to show the structure of an input-output table. One of its key features is that the production value (value of sales) of each industry is entered from two viewpoints. The market structure of the production value (output) of each industry can be read from the rows (horizontal) of transaction amount in the table, while the cost structure of the production value (input) of each industry can be read from the columns (vertical) of transaction amount. For example, focus on manufacturing in Fig. 17.1. What we can read is that manufacturing sells products worth 3 billion yen to agriculture, 12 billion yen to manufacturing (itself), 10 billion yen to commerce, 10 billion yen to consumers, and 15 billion yen as investment assets, and the total output amounts to 50 billion yen. At the same time, when the cost is broken down, we can read that this sales amount of 50 billion consists of intermediate goods input worth 3 billion yen, 12 billion yen, and 12 billion yen from agriculture, manufacturing, and commerce sections, respectively, 15 billion yen of labor cost, and 8 billion yen of profit.

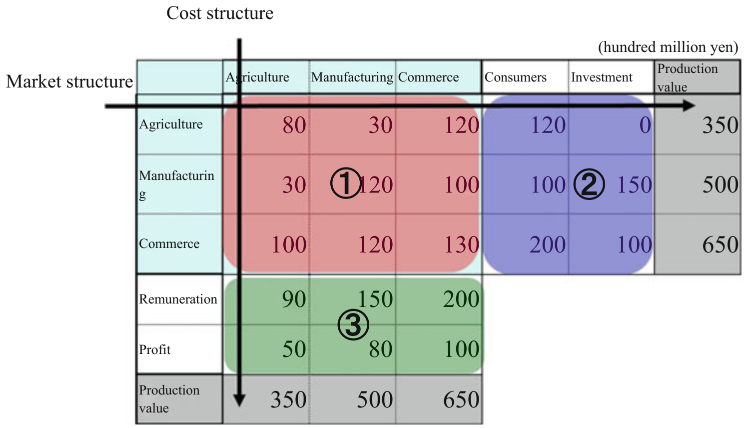

Fig. 17.1 Outline figure of input-output table

As is seen here, unlike national income statistics, the transactions of intermediate goods input among industries can be understood from an input-output table by simultaneously showing the structure of the transaction amount of each industry in two dimensions. Item (1) in Fig. 17.1 is called the endogenous sector, (2) the final demand sector, and (3) the value-added sector. In an input-output model, (1) the endogenous sector is literally handled endogenously. Then (2), the final demand sector and (3) the value-added sector are handled exogenously. Therefore, these are put together and called the exogenous sector.

Next is the explanation of an input-output model. Information is given on a quantitative model which has the most application examples. Table 17.1 is a mathematical representation of an input-output table using numerical formulae. For simplification, it has fewer sectors than Fig. 17.1, and import/export (overseas transactions) are entered. The balance formula is structured in the row direction in quantitative models. Therefore, the following quantitative model is developed as seen below in Table 17.1 and the following equations:

$$\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} = \begin{pmatrix} a_{11}x_1 & a_{12}x_2 \\ a_{21}x_1 & a_{22}x_2 \end{pmatrix} + \begin{pmatrix} f_1 \\ f_2 \end{pmatrix} + \begin{pmatrix} e_1 \\ e_2 \end{pmatrix} - \begin{pmatrix} m_1 \\ m_2 \end{pmatrix}$$
$$\begin{aligned} &\Leftrightarrow \mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{f} + \mathbf{e} - \mathbf{m} \\ &\Leftrightarrow (\mathbf{I} - \mathbf{A})\mathbf{x} = \mathbf{f} + \mathbf{e} - \mathbf{m} \\ &\Leftrightarrow \mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}(\mathbf{f} + \mathbf{e} - \mathbf{m}) \end{aligned} \quad (17.1)$$

where $\mathbf{x}$ in Formula (17.1) indicates the output vector, $\mathbf{A}$ is the input coefficient matrix, $\mathbf{f}$ is the final demand vector, $\mathbf{e}$ is the export vector, $\mathbf{m}$ is the import vector, and $\mathbf{I}$ indicates the identity matrix. Each factor in the input coefficient matrix $\mathbf{A}$ is a value, that is, each transaction amount in the endogenous sector, divided by the input of each industrial sector, the result indicating the percentage of each intermediate goods input value in the input. Therefore, each factor in the endogenous

Table 17.1 Mathematical presentation of input-output table

	First sector	Second sector	Final demand	Export	Import	Production value (Output)
First sector	$a_{11}x_1$	$a_{12}x_2$	f_1	e_1	m_1	x_1
Second sector	$a_{21}x_1$	$a_{22}x_2$	f_2	e_2	m_2	x_2
Value-added	v_1	v_2				
Production value (Input)	x_1	x_2				

sector, that is, a transaction of intermediate goods between industries, can be described as $a_{ij}x_i$ as shown in Table 17.1. When **f**, **e**, and **m** are exogenously given in Formula 17.1, the output **x** is endogenously determined depending on $(\mathbf{I}-\mathbf{A})^{-1}$. $(\mathbf{I}-\mathbf{A})-^{1}$ is called the Leontief inverse and can be interpreted as the scale of the ultimate economic repercussion multiplier generated in the total economy when final demand is produced.

Formula 17.1 is called an import exogenous model since imports are treated exogenously. In such an import exogenous model, a balance formula is established by deducting imported goods included in intermediate goods and final demand, by lumping together. Therefore, the input coefficient matrix (**A**) contains imported goods, and the production value (induced production value) determined by the $(\mathbf{I}-\mathbf{A})^{-1}$ type of Leontief inverse includes overseas production value generated for producing imported goods. In such circumstances, domestic production value is calculated on the assumption that the imported goods were produced in Japan as well.

On the other hand, in the import endogenous model where imports are treated endogenously, there is a presupposition that the demand for imported goods depends on the scale of domestic demand such as intermediate goods and final demand. Therefore, we assume that the demand for imported goods is at a certain ratio of domestic demand.

In such circumstances, import vector (**m**) is modified as shown below:

$$\mathbf{m} = \begin{pmatrix} \hat{m}_1 & 0 \\ 0 & \hat{m}_2 \end{pmatrix} (\mathbf{Ax} + \mathbf{f}) \tag{17.2}$$

where $(\mathbf{Ax} + \mathbf{f})$ in Formula 17.2 indicates domestic demand, and it is considered that the demand for imported goods is at a certain ratio $(\hat{\mathbf{m}})$ of domestic demand; $\hat{\mathbf{m}}$ is called the import coefficient vector and is derived by $\hat{m}_i = \frac{m_i}{a_{ij}x_i + f_i}$ when each element is $\hat{m}_i$.

The import endogenous model is derived by modifying Formula 17.1 as shown below:

$$\begin{aligned} &\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{f} + \mathbf{e} - \mathbf{M}(\mathbf{A}\mathbf{x} + \mathbf{f}) \\ &\Leftrightarrow \mathbf{x} - \mathbf{A}\mathbf{x} + \mathbf{M}\mathbf{A}\mathbf{x} = \mathbf{f} + \mathbf{e} - \mathbf{M}\mathbf{f} \\ &\Leftrightarrow \{\mathbf{I} - (\mathbf{I} - \mathbf{M})\mathbf{A}\}\mathbf{x} = (\mathbf{I} - \mathbf{M})\mathbf{f} + \mathbf{e} \\ &\Leftrightarrow \mathbf{x} = \{\mathbf{I} - (\mathbf{I} - \mathbf{M})\mathbf{A}\}^{-1}\{(\mathbf{I} - \mathbf{M})\mathbf{f} + \mathbf{e}\} \end{aligned} \tag{17.3}$$

Formula 17.3 is the import endogenous model, and **M** in the formula indicates a square matrix diagonalizing import coefficient vector ($\hat{\mathbf{m}}$). The Leontief inverse is shown as $\{\mathbf{I} - (\mathbf{I} - \mathbf{M})\mathbf{A}\}^{-1}$ in the import endogenous model. In such circumstances, the induced production value based on the production of imported goods is deducted, and only the domestically generated production value is included. Needless to say, the scale of the economic repercussion multiplier is smaller in the $\{\mathbf{I} - (\mathbf{I} - \mathbf{M})\mathbf{A}\}^{-1}$ type of Leontief inverse than in the $(\mathbf{I} - \mathbf{A})^{-1}$ type.

17.1.2 Environmental Analysis by Input-Output Method

In addition to monetary transactions between each sector which an ordinary input-output table deals with as the subject of entry, the table can be applied to environmental analysis of input-output theory by including environmental burden and resources/energy demand, that is, generated along with such economic activities, in the input-output model. Generation of environmental burden accompanying economic activities is strongly related to the complex transaction structure existing between each sector of industry, household, and government. One type of economic activity may have an impact on generation of environmental burden either directly or indirectly between sectors through the economic ripple effect, which makes it difficult to clearly understand the causal relationship between generation of environmental burden and economic activity between sectors. However, it makes it possible to comprehensively and systematically measure the generation of environmental burden, which has a complex causal relationship with economic activities detectable by applying input-output analysis to enable quantitative understanding of the economic ripple effect.

The input-output model for environmental analysis is established at an advanced level, and there are a large number of case studies. Environmental analysis by the input-output method can be divided into two approaches.

The first approach involves making a supporting table concerning environmental burden. A supporting table shows the input and output amount of employment and materials in addition to the basic transaction table, where monetary transaction flow is entered such as in Fig. 17.1. A supporting table of various types of environmental burden enables environmental analysis by drawing out a generating unit of environmental burden and entering it into the input-output model formula. As for a publicly available supporting table of environmental burden, *Embodied Energy and Emission Intensity Data for Japan Using Input-Output Tables (3EID)* by Nansai and Moriguchi (2012) published by the National Institute for Environmental Studies is well known as an industry-classified database concerning energy consumption and environmental burden caused by it in Japan.

The second approach involves expanding the basic transaction table of an input-output table and applying it to environmental analysis by entering emission of environmental burden as outputs and by establishing an industry sector to remove/treat the environmental burden. This approach was developed by Leontief himself, and he made use of it to carry out empirical analysis on air pollution (Leontief 1970). Moreover, Nakamura and Kondo (2002) produced an input-output table for waste based on this approach.

Here, the structure of an input-output model for environmental analysis is explained. It is based on the aforementioned first approach, which has a simpler model structure and a larger number of applied case studies.

In Formula 17.4, d_j stands for CO_2 emission directly emitted accompanying production activity from each industrial sector. Next, the emission coefficient (c_j), indicating emission per one unit of production, is derived. This is the total emission (d_j) in each industry divided by the input (x_j), and this process is shown in the following formula:

$$c_j = \frac{d_j}{x_j} \tag{17.4}$$

The total emission (d_j) in each industry can be described as the product of emission coefficient (c_j) and output (x_i), when the emission coefficient of Formula 17.4 is used. Based on the input-output table in Table 17.1, the CO_2 emission in each industry is shown below as an input-output model formula:

$$\begin{aligned} \begin{pmatrix} d_1 \\ d_2 \end{pmatrix} = \begin{pmatrix} c_1 & 0 \\ 0 & c_2 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} \Leftrightarrow \mathbf{d_p} = \mathbf{Cx} \\ = \mathbf{C}\{\mathbf{I} - (\mathbf{I} - \mathbf{M})\mathbf{A}\}^{-1}\{(\mathbf{I} - \mathbf{M})\mathbf{f} + \mathbf{e}\} \end{aligned} \tag{17.5}$$

where $\mathbf{d_p}$ in Formula 17.5 indicates direct CO_2 emission accompanying production in each industry and can be called production-based emission or direct emission. Of course **f** and **e** in Formula 17.5 are exogenous values, and measuring production-based emission depending on random production of **f** and **e** can be done.

On the other hand, deriving consumption-based emission ($\mathbf{d_c}$) can be done by a similar idea:

$$\underbrace{\mathbf{d_c} = \mathbf{C}\{\mathbf{I} - (\mathbf{I} - \mathbf{M})\mathbf{A}\}^{-1}(\mathbf{I} - \mathbf{M})\mathbf{f}}_{\text{Induced emission}} \quad \underbrace{+d_h}_{\text{Direct emission in household}} \tag{17.6}$$

The first item on the right side of Formula 17.6 is emission, including indirect emission, induced by production of final demand such as private consumption, and can be called induced emission. The $\{\mathbf{I} - (\mathbf{I} - \mathbf{M})\mathbf{A}\}^{-1}$ type of Leontief inverse is used in Formula 17.6, based on the import endogenous model; therefore, emission induced overseas based on import demand is not included. This induced emission

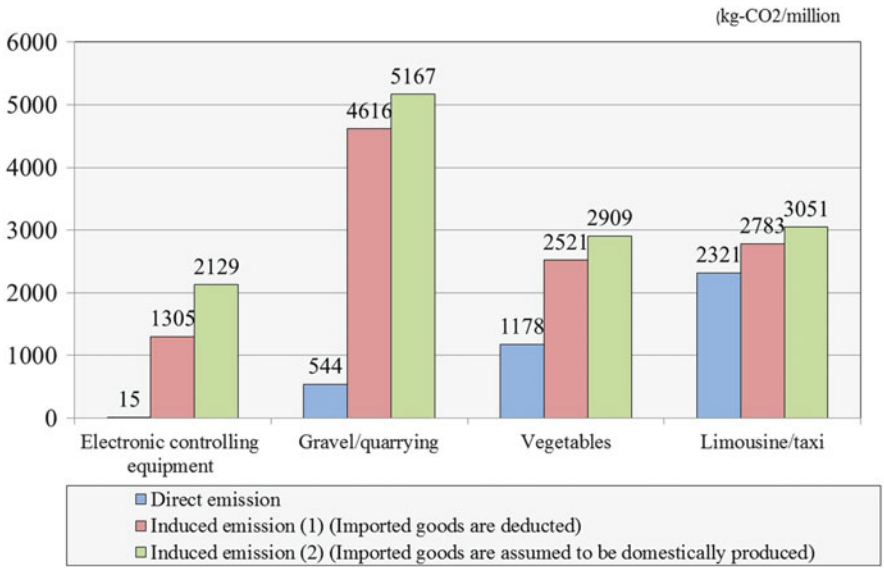

Fig. 17.2 CO_2 emission per production unit in industrial sectors in Japan (Source: Nansai and Moriguchi 2012)

with the addition of direct emission from households d_h can be considered consumption-based emission.

Next, direct emission (emission coefficient) and induced emission per unit of accompanying production, estimated in actual industrial sectors based on this idea, are compared and examined. Figure 17.2 shows direct CO_2 emission and induced CO_2 emission that is inevitable per unit (1 million yen) of production, in some industrial sectors as examples, using the aforementioned database of 2005 by the National Institute for Environmental Studies (Nansai and Moriguchi 2012).

Induced emission in Fig. 17.2 includes indirect emission, so we can see that it ends up being higher than direct emission in any industry. Moreover, induced emission (17.1) is measured by $\{\mathbf{I}-(\mathbf{I}-\mathbf{M})\mathbf{A}\}^{-1}$ type of Leontief inverse, and emission accompanying production of imported goods is deducted. On the other hand, induced emission (17.2) is calculated by $(\mathbf{I}-\mathbf{A})^{-1}$ type, including emissions due to imported goods, on the assumption that they are produced domestically. Note that induced emission (17.2) is higher than induced emission (17.1).

When direct emission is focused, it is lower in “gravel/quarrying” than it is in “vegetables” or “limousine/taxi.” However, when compared with induced emission, that in “gravel/quarry” surpasses that of the other two industries, in fact, it is higher than in any industry in Fig. 17.2. When the ratio of direct emission and induced emission is focused, the balance between the two is relatively small in “limousine/taxi,” while the balance is quite large in “electronic controlling equipment” where induced emission (17.2) is 138 times higher than direct emission. We can see that this ratio can vary widely among industries.

Examination of Fig. 17.2 suggests that there is a possibility of coming to the wrong conclusion when only direct emission of the industry is considered for evaluation of the burden that various industries place on the environment. Ripple effect analysis of environmental burden, based on the input-output method, indicates the importance of considering comprehensive impact on the environment including indirect impact.

17.1.3 Multiregional Input-Output Model and International Environmental Analysis

The type of input-output table explained so far is an input-output table that has the economy of a single country as its subject, but there are also input-output tables consisting of multiple countries or regions. Such input-output tables are called world input-output tables or interregional input-output tables, depending on the spatial levels. Generally, they are grouped under the blanket term of a multiregional input-output table (MRIO).

Suppose there is a world input-output table for country A and country B (Table 17.2) to explain the structure of the multiregional input-output table in Table 17.2, the transaction amount is divided into spatial level, and transactions between country A and country B are explained per sector. In such a multiregional input-output table, the transaction relation of economic flow is entered at the spatial level between two countries in addition to sectors of industry, household, and government. This enables clear understanding of which industry in which country

Table 17.2 Structure of a multiregional input-output table

		Intermediate demand		Final demand		Export to R.O.W.		Import from R.O.W		Production value
		Country A	Country B	Country A	Country B	Country A	Country B	Country A	Country B	
Intermediate input	Country A	Self-sufficiency of intermediate goods in Country A	Export of intermediate goods from Country A to Country B	Self-sufficiency of final goods in Country A	Export of final goods from Country A to Country B	Export of Country A		Import of Country A		Production value of Country A
	Country B	Export of intermediate goods from Country B to Country A	Self-sufficiency of intermediate goods in Country B	Export of final goods from Country B to Country A	Self-sufficiency of final goods in Country B		Export of Country B		Import of Country B	Production value of Country B
Added value		Added value of Country A	Added value of Country B							
Producti on value		Production value of Country A	Production value of Country B							

Notes: ROW stands for rest of world, indicating countries besides country A or country B. For example, "export of intermediate goods from country A to country B" can be phrased as "import from country A to country B." Therefore, the transaction amount can be read from the viewpoint of the imported amount in both countries the intermediate goods and final goods were produced and, thus, in which of the two countries it should be input. This means imports and exports between the two countries become endogenous in the structure of the input-output table.

The multiregional input-output model can be applied to development of the input-output model and environmental analysis, as already mentioned. In particular, the necessity for investigating the impact of, and measures to deal with, environmental problems from a global viewpoint is becoming more important with the background of intensifying overseas expansion of companies and changes in the international division of labor. Therefore, international environmental analysis using the multiregional input-output model plays a very important role.

Analysis cases of CO_2 emission using the multiregional input-output model are explained below. Table 17.1 shows CO_2 emission of various countries, mainly in Asia, estimated by Shimoda et al. (2011) This study uses the Asian International Input-output Table 2000 made by the Institute of Developing Economies, Japan External Trade Organization. This table is a multiregional input-output table consisting of 76 industrial sectors in ten countries and regions of Indonesia, Malaysia, the Philippines, Singapore, Thailand, China, Taiwan, Korea, Japan, and the USA. It is widely used in studies concerning environmental and economic analysis, especially in Asia (e.g., Shimoda et al. 2011; Su and Ang 2011). The Institute of Developing Economies also makes the BRICs International Input-Output Table 2005 edition.

In Table 17.3, emission based on the demand of each country is entered vertically per supplier nation, and the vertical sum is, simultaneously, the total consumption-based emission and the sum of induced emission. Emission based on supply in each country is entered horizontally per consumer nation, and the horizontal sum is simultaneously the total production-based emission and direct emission emitted in each country. That is to say, Table 17.3 can be considered a

Table 17.3 Trade structure of CO_2 emission in Asian countries in 2000 (million tons-CO_2)

Emission based on demand

Emission based on supply	Indonesia	Malaysia	Philippines	Singapore	Thailand	China	Taiwan	Korea	Japan	U.S.A.	Others	Total (production base)
Indonesia	184	2	1	2	2	5	3	4	16	19	53	292
Malaysia	1	47	1	5	2	5	2	2	11	23	48	146
Philippines	0	0	49	0	0	1	1	1	3	8	13	76
Singapore	1	2	1	20	1	3	1	1	2	5	35	71
Thailand	1	1	1	1	104	3	1	1	8	13	42	174
China	5	5	2	5	6	2,466	10	20	104	199	399	3,221
Taiwan	1	1	1	1	1	14	143	2	8	20	56	248
Korea	2	1	1	1	1	20	4	356	18	29	103	537
Japan	1	2	1	2	2	8	5	5	919	34	70	1,051
U.S.A.	2	3	2	3	3	13	10	12	43	5,448	519	6,058
Total (consumption base)	197	65	59	40	123	2,537	180	403	1,134	5,797	1,339	11,873

Source: Table 8 (p. 215) in Shimoda et al. (2011)

matrix table indicating the trade balance of CO_2 emission by distributing the total emission of the ten subject countries, from the viewpoint of supply and demand.

For example, focus on Indonesia. Of the total emission of 292 million tons (sum of production base), directly emitted in Indonesia, emission produced in satisfying the demand from its own population is 184 million tons. Some 2 million tons were emission for demand in Malaysia and 1 million tons for demand in the Philippines; thus, we can interpret this to mean that 108 million tons of CO_2 were emitted in Indonesia to satisfy overseas demand. Hence, in the case of Indonesia, 37 % of direct emission was induced by overseas demand. This figure varies widely, from 72 % in Singapore to 10 % in the USA.

When the sums of both consumption base and production base are compared, the consumption base surpasses the production base only in Japan, making it the sole net importer of CO_2 emission among the ten countries in Table 17.3. However, Table 17.3 does not include consumption base emission based on imports from countries other than the included ten. Therefore, care should be taken: whether these countries are actually net importers or net exporters cannot be judged from Table 17.3 alone.

The trade structure of CO_2 emission mainly in Asia is examined based on the environmental analysis method, using the input-output model. The environmental burden generated by economic activities in one country is not limited to that country alone, but has impacts on various countries. This phenomenon is sometimes called carbon leakage in the case of CO_2 emission. Carbon leakage among Asian countries is tending to increase due to recent rapid economic development and more advanced and complicated international division of labor. A phenomenon such as carbon leakage is one of the factors that obscure the causes and structure of environmental problems in Asia and that make solution of environmental problems more problematic. In such circumstances, further development and application of environmental analysis methodology, using the multiregional input-output model, is required to implement effective environmental analysis and policy recommendations.

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