이형단위 에너지산업연관 분석의 호환성 분석 및 응용

- 에너지원별 연쇄효과 평가 -

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Convertibility of Monetary and Physical Input-output Analysis

- an Application to Energy Sources -

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ABSTRACT

In the midst of the LCA concept is becoming more important, an input-output approach is emerging as an useful methodology to assure the robustness of a solution. Basically, the input-output analysis is based on input-output table using monetary unit. Nowadays, the importance of material flow analysis is increasing. Thus, it is attempted to construct the input-output table in terms of the hybrid in units by reflecting physical units.

In this study, typical process for both from the conventional input-output approach and from the input-output approach with hybrid in units were compared. The convertibility of these approaches are demonstrated using an energy model including the monetary unit and calorie unit for an input-output approach. And, the linkage effects of various energy sources were analyzed with the energy input-output table.

요약문

LCA 개념의 중요성이 날로 높아지고 있는 가운데, 산업연관 접근법도 해법을 보장하는 유용한 방법으로 대두되고 있다. 산업연관분석은 기본적으로 화폐단위로 구성된 산업연관표로부터 분석을 시작하지만, 최근 들어 물질흐름의 중요성이 높아지면서 물리적 단위들이 반영된 이형단위 산업연관표의 작성이 시도되고 있다.

본 연구에서는 전통적인 산업연관 분석과 이형단위 산업연관분석의 분석 과정을 비교하였다. 분석의 호환성은 에너지 산업연관분석에서 사용되는 화폐단위와 열량단위가 포함된 두 단위 혼합모형을 통해 예시하였다. 그리고 이형단위로 구성된 에너지 산업연관표를 이용해 에너지원들의 영향도를 분석하였다.

주제어 : 산업연관분석, LCA, 이형단위, 물량단위, 단위의 혼용, 영향도

1. Energy analysis case review with IO analysis

Input−output(IO) analysis is commonly used since it describes the survey results of inter−sectoral transactions so it makes it possible for various meaningful analysis on an energy policy. IO table that demonstrates exchanges of goods and services between industrial sectors as a matrix form was originated by Wassily Leontief who won the Nobel prize for it in 1973. This table is mostly presented by using monetary units and because of its high usability, and it is applied broadly for analysis of energy.

There are many cases for an energy analysis worldwide that use a conventional IO analysis. The following are the representative examples. Studies of Wright(1974) and Herendeen(1975), which used US IO table to determine the primary energy requirements to all sectors has been regarded as the first. Peet et al.(1985) performed an energy analysis of direct and indirect consumption of households in New Zealand from 1974 to 1980. And Park and Heo(2007) used process analysis for energy intensive products and applied IO analysis to other energy consumption products by referring to Lenzen(1998).

Contrary to the analysis, the following studies relied on the hybrid in units IO model, Miller and Blair(1985) composed a well−organized textbook on energy IO(E−IO) analysis. Pachauri and Spreng(2002) determined indirect energy requirement of India's households according to private final consumption expenditures based on India's IO tables of 1983/84, 1989/90 and 1993/94.(Table 1)

Table 1. Rearrangement of 14 energy sectors

conventional IO	hybrid IO
Wright(1974) Herendeen(1975) Peet et al.(1985) Park and Heo(2007)	Miller and Blair(1985) Pachauri and Spreng(2002)

2. Typical process

2.1. Process of conventional IO analysis

IO table is classified by intermediate demand sectors with value added derived from materials purchased from related sectors and final consumption sectors such as household or government sector. For instance, thermal power generation sector provides electricity as its output to almost every industrial sectors by receiving input from energy sectors such as coal or fuel oil, and non−energy sectors such as machinery & equipment or plastic products.

Therefore, the original model can be defined with the total sum of an intermediate demand and final demand as seen in eq (1) as follows:

$$x_i = \sum_j z_{ij} + y_i \qquad (1)$$

where,

x_i be the total production of sector i,

$z_{i,j}$ be the amount of transaction in sector j after producing sector I,

y_i be the amount of final consumption that products of sector i

When input ratio like eq (2) is introduced to this definition and converted, an efficient modelling equation is expressed as follows:

$$z_{ij} = a_{ij} x_j \quad \text{for } all \ i \qquad (2)$$

where, $a_{i,j}$ be the ratio that of total output from sector j and input from i to j

Here a_{ij} is a coefficient of linear relation. It reflects the technological requirements of production by sector j for the inputs from sector i; such a_{ij} are therefore known as 'technological coefficients' or 'input coefficients'. For example, if sector i is 'thermal & self power generation', and sector j is 'fuel oil', then a_{ij} is the (average) quantity of fuel oil needed to produce one unit of thermal & self power generation. Or if we express our relationships in terms of values rather than physical quantities, it is the number of monetary worth of fuel oil needed to produce one unit of monetary worth of an average thermal & self power generation.

Therefore, when eq (2) is introduced to eq (1), eq (3) is redefined as follows:

$$x_i \equiv \sum_j a_{ij} x_j + y_i \qquad (3)$$

IO approaches seen the above was devised for the first time by Wasilly Leontief in 1930. Afterwards, it can be explained with linear algebra which allows denote briefly. To demonstrate economic activities of groups that are desegregated by n sectors, first of all, the following matrix must be defined.

Let X be a vector (n×1) of goods required for total output of the economy.
Let Y be a vector (n×1) of goods required to satisfy final demand.
Let $\boldsymbol{A}$ be a matrix (n×n) of input coefficients for the economy.

Then, eq (3) can be used as linear equation form like eq (4) as follows:

$$X = AX + Y \qquad (4)$$

Here, AX expresses intermediate demand of economic activity and Y denotes final demand. If eq (4) is reorganized as to matrix X, it can be reformulated like eq (5) as follows:

$$X = (I - A)^{-l} Y \qquad (5)$$

where $(I-A)^{-l}$ is known as the 'Leontief inverse matrix' or simply 'inverse matrix'. The inverse matrix includes all the direct plus indirect requirements for production in the economy, which are necessary to satisfy a certain vector of final demand commodities. Here, expansion of infinite geometric series like eq (6) is applied as follows:

$$(I - A)^{-1} = I + A + A^2 + A^3 + \cdots$$
(6)

Substitution of eq (6) in eq (5) gives

$$X = Y + AY + A^2Y + A^3Y + \cdots$$
(7)

So it can decompose the total demand for the n goods produced in the economy as follows:

① Y is required for final demand (i.e. by consumers).

② AY is needed to produce the goods Y. This is the 'first-round indirect effect'.

③ A^2Y is needed to produce the goods AY. This is the 'second-round indirect effect'.

④ A^3Y is needed to produce the goods A^2Y. This is the 'third-round indirect effect', etc.

Clearly, the process traces inputs or outputs back to primary resources; the first-round of energy inputs or environmental pollution emission are the direct energy requirement or emission intensity, respectively; subsequent rounds of second-round of energy inputs or environmental pollution emission are the indirect energy requirement or emission intensity, respectively. And the sum of these two is the total energy requirement or emission intensity. Especially the total energy requirement is called with embodied energy.

2.2. Process of E-IO analysis

In E-IO analysis, it is often concerned with energy measured in physical units - for example, TOE or some other convenient energy units and non-energy flows in money.

The basic process of E-IO method introduced in detail by Miller & Blair(1985), and applied to energy system by Kim(1998), Pachauri and Spreng(2002) and Choi and Lee(2004).

As may be expected, one way to obtain these quantities in physical units is to first compute the total money requirement by conventional IO analysis, then convert these values to TOE by means of prices relating money outputs to energy outputs.

To analysis the linkage effects for each energy sources, the basic concept can be explained briefly.

By E-IO mixed with heterogeneous units, to calculate energy inventory and environment inventory caused by economic activities, the additional definition is needed as follows:

Z^* is matrix of $(n \times n)$ dimension and it is a new transaction matrix because k energy sectors in a conventional IO table has row-wise changed from monetary price to energy unit. Thus, this matrix has the original inter-sector transactions matrix (Z) in non-energy sectors and the energy rows are replaced by the corresponding rows in the energy flow matrix(E).

X^* and Y^* is $(n \times 1)$ vector, which designates total output and final demand respectively. Two vectors is mixed with monetary units and energy units according to sectors as well.

F^* is $(n \times 1)$ vector and, it is artificial vector to isolate energy rows in matrix manipulation. The definition of these quantities are as follows:

$$Z_i^* = \begin{cases} E_k & \text{for } energy\ rows \\ Z_j & \text{for } non-energy\ rows \end{cases} \quad (8)$$

$$X_i^* = \begin{cases} F_k & \text{for } energy\ rows \\ X_j & \text{for } non-energy\ rows \end{cases} \quad (9)$$

$$Y_i^* = \begin{cases} e_{k,y} & \text{for } energy\ rows \\ Y_j & \text{for } non-energy\ rows \end{cases} \quad (10)$$

$$F_i^* = \begin{cases} F_k & \text{for } energy\ rows \\ 0 & \text{for } non-energy\ rows \end{cases} \quad (11)$$

E is (k×n) matrix and designates energy flows. E_y and F, vector expressed as (k×1) physical units designates energy consumed by final demand and total energy consumption in the economy respectively. Hence, the total amount of energy consumed(and produced) by the economy means addition of energy (of each type depicted by the rows of E) consumed by intermediate sectors and that consumed by final demand. This is shown in eq. (12) as follows:

$$E_i + E_y = F \quad (12)$$

When this definition is used, corresponding matrices, $A^* = Z^*(\hat{X}^*)^{-1}$ and $(I-A^*)^{-1}$can be calculated easily. Hat(^) represents that elements of vector is changed into diagonal matrix.

However, these matrices have different characteristics from traditional Leontief model. For example, input coefficient matrix, A^* that means direct requirements and inverse coefficient matrix, $(I-A^*)^{-1}$ that means total requirements have different elements because these are mixed with matrix of heterogeneous units.

$$Z^* = \begin{bmatrix} toe & toe \\ \$ & \$ \end{bmatrix}; Y^* = \begin{bmatrix} toe \\ \$ \end{bmatrix}; X^* = \begin{bmatrix} toe \\ \$ \end{bmatrix};$$

$$F^* = \begin{bmatrix} toe \\ 0 \end{bmatrix}$$

Here, when calculate input coefficient matrix, it is composed of four elements of heterogeneous characteristics as shown in eq. (13).

$$A^* = Z^*(\widehat{X^*})^{-1} = \begin{bmatrix} \frac{toe}{toe} & \frac{toe}{\$} \\ \frac{\$}{toe} & \frac{\$}{\$} \end{bmatrix} \quad (13)$$

$(I-A^*)^{-1}$ matrix has the same characteristic as A^* shown in eq. (13).

3. Inductive evidence to convertibility in energy IO

Conventional IO table of unique unit based on money and E-IO table of hybrid in units combined with various kinds produce same results. Yet, input coefficients matrix is manipulated based on price information according to sectors.

To demonstrate to lead to the same results, two transaction matrices are assumed that has a homogeneous unit conventional IO table and has hybrid in units E-IO table that is composed of two kinds of units respectively.(Table 2)

Table 2. Structure of two kinds of transaction matrix (example)

I	$e-1$	$e-2$	$m-3$	$m-4$	$\sum_j x_{i,j}$
$e-1$	$m_{1,1}$	$m_{1,2}$	$m_{1,3}$	$m_{1,4}$	mx_1
$e-2$	$m_{2,1}$	$m_{2,2}$	$m_{2,3}$	$m_{2,4}$	mx_2
$m-3$	$m_{3,1}$	$m_{3,2}$	$m_{3,3}$	$m_{3,4}$	mx_3
$m-4$	$m_{4,1}$	$m_{4,2}$	$m_{4,3}$	$m_{4,4}$	mx_4

II	$e-1$	$e-2$	$m-3$	$m-4$	$\sum_j x_{i,j}$
$e-1$	$e_{1,1}$	$e_{1,2}$	$e_{1,3}$	$e_{1,4}$	ex_1
$e-2$	$e_{2,1}$	$e_{2,2}$	$e_{2,3}$	$e_{2,4}$	ex_2
$m-3$	$m_{3,1}$	$m_{3,2}$	$m_{3,3}$	$m_{3,4}$	mx_3
$m-4$	$m_{4,1}$	$m_{4,2}$	$m_{4,3}$	$m_{4,4}$	mx_4

Sectors e−1 and e−2 denotes energy sector and m−3 and m−4 sectors designates non−energy industry sector. In elements of transaction matrix $m_{i,j}$ is a value expressed as a monetary unit and $e_{i,j}$ is a value expressed as a energy unit(e.g. joule, calorie, TOE etc.). Also, in a total output column mx_i is monetary unit and ex_i is a value expressed as an energy unit.

Energy input coefficient is a value that divides $m_{i,j}$ expressed as money amount unit by energy price $p_{i,j}$.

Here, input coefficient matrix that is calculated in matrix in the right of (Table 2) has different unit values divided by 4 elements as shown in eq (13). Their expressions are as follows:

① for a sector from energy to energy representing $\frac{toe}{toe}$,

$$a'_{i,j} = \frac{e_{i,j}}{ex_j} = \frac{(m_{i,j}/p_i)}{(mx_j/p_j)} = \frac{m_{i,j}}{mx_j}\frac{p_j}{p_i} = a_{i,j}\frac{p_j}{p_i}$$

② for a sector from energy to non−energy representing $\frac{toe}{\$}$,

$$a'_{i,j} = \frac{e_{i,j}}{mx_j} = \frac{(m_{i,j}/p_i)}{mx_j} = \frac{m_{i,j}}{mx_j}\frac{1}{p_i} = a_{i,j}\frac{1}{p_i}$$

③ for a sector from non−energy to energy representing $\frac{\$}{toe}$,

$$a'_{i,j} = \frac{m_{i,j}}{ex_j} = \frac{m_{i,j}}{(mx_j/\ p_j)} = \frac{m_{i,j}}{mx_i}p_j = a_{i,j}p_j$$

④ for a sector from non−energy to non−energy representing $\frac{\$}{\$}$,

$$a'_{i,j} = \frac{m_{i,j}}{mx_j} = a_{i,j}$$

As seen above, if conversions through price vector according to each energy source, conventional model and energy model can be modified from conventional input coefficients matrix to energy simply. This will be applied to a combined unit model of two or more units.

Therefore, values for energy sectors can be used as it's inherent physical units to prepare an initial IO table to perform the energy analysis by using an IO analysis.

To estimate of co−relationship for each energy sources, this study used an IO table with heterogeneous units which are energy consumption date designated as physical unit, TOE for energy sectors, and money transaction units for non-energy sectors.

4. Application to linkage effects analysis of energy sources

4.1. Composition of input coefficients matrix in energy sector

Regarding the energy flow in the energy sector, for the primary energy such as coal, crude petroleum, and natural gas, the energy input is few, while the energy

output become a large amount (that is, a_{ij} has small values). On the contrary, the non-primary energy such as naphtha, gasoline, fuel oil, and thermal & self power generation has a plenty of energy input.(that is, a_{ij} has large values). Especially, the atomic power generation has a huge amount of the energy output but has small amount of the energy input. (Table 3)

4-2. estimation of linkage effect

4-2-1. Linkage effects

The linkage effects have 2 viewpoints: one is the backward linkage(BL) effect which illustrates the degree of purchasing the intermediate goods from other industries and the other is the forward linkage(FL) effect which shows the degree of providing the intermediate goods to other industries. It can be obtained through both way as follow.

In the conventional IO analysis, the linkage multiplier is used to measure the aforementioned effects. The linkage multiplier for each energy source uses Leontief's coefficients eq (14) and eq (15). Actually, the eq (14) and (15) denote the averages of row-wise a_{ij} and column-wise a_{ij} with respect to the average of total technological coefficients matrix, respectively.

Table 3. Input coefficients matrix of an energy sector (a_{ij})

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0.0E+00	0.0E+00	0.0E+00	1.2E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.6E+00	0.0E+00	0.0E+00	3.1E-01	0.0E+00
2	0.0E+00	0.0E+00	0.0E+00	0.0E+00	6.1E-01	8.7E-01	7.6E-01	1.5E-01	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
3	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.5E+00	0.0E+00	0.0E+00
4	0.0E+00	0.0E+00	0.0E+00	2.0E-03	0.0E+00	0.0E+00	0.0E+00	1.0E-03	0.0E+00	1.9E-01	0.0E+00	3.9E-05	0.0E+00	0.0E+00
5	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.4E-05	3.5E-03	1.3E-04	5.8E-05	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
6	1.5E-05	0.0E+00	0.0E+00	3.6E-04	1.4E-04	1.5E-02	6.7E-04	7.0E-04	9.2E-04	8.1E-04	6.0E-04	3.1E-04	1.4E-04	0.0E+00
7	2.1E-04	0.0E+00	0.0E+00	2.9E-03	4.0E-03	3.5E-02	2.0E-02	2.0E-02	1.0E-02	4.4E-01	5.3E-03	2.8E-02	2.6E-01	0.0E+00
8	2.8E-05	0.0E+00	0.0E+00	4.6E-03	4.0E-04	1.5E-03	1.2E-03	1.2E-01	2.1E-03	1.6E-03	8.9E-04	8.6E-04	7.3E-04	0.0E+00
9	1.0E-05	0.0E+00	0.0E+00	1.4E-05	1.7E-05	4.1E-05	5.6E-05	1.9E-05	4.6E-03	2.8E-05	3.2E-04	1.0E-04	1.4E-04	0.0E+00
10	2.4E-04	0.0E+00	0.0E+00	4.0E-04	5.3E-04	2.9E-03	2.1E-03	8.0E-04	2.4E-03	4.9E-02	9.9E-03	2.6E-03	3.2E-02	0.0E+00
11	1.9E-04	0.0E+00	0.0E+00	2.5E-04	3.0E-04	8.9E-04	1.1E-03	4.2E-04	3.9E-03	4.8E-03	1.3E-02	1.9E-03	2.9E-03	0.0E+00
12	0.0E+00	0.0E+00	0.0E+00	7.3E-06	0.0E+00	0.0E+00	0.0E+00	4.9E-07	0.0E+00	2.0E-01	0.0E+00	2.0E-03	4.1E-02	0.0E+00
13	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.0E-07	3.9E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.6E-01	0.0E+00
14	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00

$$FL\ coefficient = \frac{\frac{1}{n}\sum_{i} a_{ij}}{\frac{1}{n^2}\sum_{i}\sum_{j} a_{ij}} \quad (14)$$

$$BL\ coefficient = \frac{\frac{1}{n}\sum_{j} a_{ij}}{\frac{1}{n^2}\sum_{i}\sum_{j} a_{ij}} \quad (15)$$

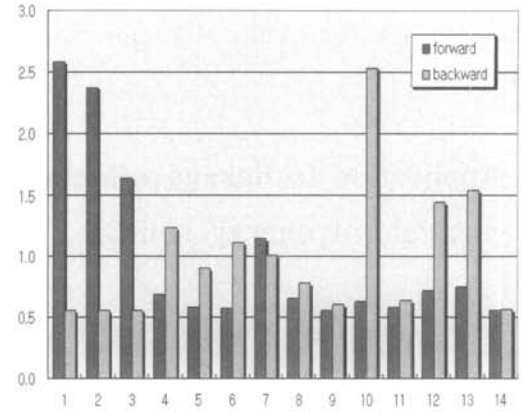
Therefore the 2 kinds of linkage analysis are useful to evaluate the level of intermediate demand or input of an energy source.

4-2-2. Result of estimations

The results obtained from the analysis of forward and backward linkage effects for each energy sources are summarized in (Table 3). The forward linkage effect means the effect of downstream(i.e., the effect caused to the sale). Backward linkage effect is a coefficient which evaluates the effect evoked in upstream (i.e., the effect from the purchase).

According to the eq. (8) and (9), the forward linkage effect showed up as follow order : #-1(2.581), #-2(2.375), #-3(1.644), #-7(1.141), #-13(0.747), #-12(0.715), #-4(0.683), #-8(0.648), #-10(0.630), #-5(0.578), #-11(0.577), #-6(0.570), #-9(0.557), and #-14(0.554).

And the backward linkage effect calculated as follow order: #-10(2.531), #-13(1.532), #-12(1.443), #-4(1.231), #-6(1.114), #-7(1.008), #-5(0.901), #-8(0.778), #-11(0.637), #-9(0.603), #-1(0.555), #-2(0.554), #-3(0.554), and #-14(0.560).(Fig. 1)



code	energy source	code	energy source
1	Coal	8	Misc. Petroleum refinery products
2	Crude petroleum	9	Water power generation
3	Natural gas	10	Thermal & self power generation
4	Coal products	11	Atomic power generation
5	Naphtha	12	Town Gas
6	Gasoline	13	Heat
7	Fuel Oil	14	woods

Fig. 1. Estimation of Linkage effects coefficient

The results from the two effects can be summarized. It is observed that there are same evaluation pattern for primary energies, which are excavated from the nature, from #-1~3 and #-7 in final energy has larger forward linkage coefficient. It means that the primary energies have a larger effect on the other industries.

On contrary, forward linkage coefficients in almost final energies, which are used at the final user, except #-7 show smaller coefficient.

5. Policy recommendations

In this study, typical process for both from the conventional input-output approach and from the input-output approach with hybrid in units were compared. The convertibility of these approaches are demonstrated using an energy model including the monetary unit and calorie unit for an input−output approach. And, the linkage effects of various energy sources were analyzed with the energy input−output table.

Under the circumstance of sharp increase of energy prices and with the increasingly intense international pressure for Korea to become a party to the post−Kyoto Protocol, national energy policy should be positioning at more higher priority. And the to make effective and efficient policy establishment, radical changes are required in Korean energy and environment policy.

Such transition in the policy perspective starts from the analysis of interrelations among economic activity, energy use, and GHG emission. Application of input−output approach which incorporates material flow analysis could be a very useful tool for the investigation in terms of policy.

The IO method used in this study can be a excellent complementary tool to a process LCA to meet these requirements.

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