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Application of the Input-Output Approach in Environmental Analysis in LCA*

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Abstract

Life cylce assessment evaluates the total burden on the environment in the life cycles of goods and services. However, to obtain the cumulative effects attributed by each material inputs necessary involved high cost. As the quality of the analysis results are not positively related to the amount of time and cost spent on the estimation, this undermines the incentive to carry out LCA investigation. Hence, in this paper, we make use of the input-output tables that have been extended for environmental analysis in LCA analysis. For the production of automobiles, we found that the indirect effect it contributed is greater than the direct effect, and the total CO_2 emission from general inputs such as wholesale trade and advertising are in fact greater than that from the prodution of the car body.

1. LCA and Input-Output Analysis

Recently, there has been an attempt to capture the impact of the production of goods and services on the environment using the concept of Life Cycle Assessment(LCA). LCA is an attempt to evaluate the burden effect caused by the production of a good on the environment, and it involves the retrospective accumulation of effects on the environment produced by energy and materials required directly and indirectly in the production of a particular good. The accumulation of these effects involves firstly, measuring the impact of energy consumption on the environment (e.g. CO_2 emission), secondly, measuring the impact on the environment from energy consumption occurs during the production of the various energies and materials required in the production process, and so on, retrospectively.

However, it is almost impossible for an individual firm to know the effect its products exert on the environment as its products pass through many hands. While it may not be difficult to calculate the burden to the environment generated by the production process within the firm, it is difficult for the firm to know the burden on the environment produced in the manufacturing of parts and components and raw materials that are supplied by other firms. Even if it is possible to obtain these information, the range is extremely limited considering the human effort put into it and we may also be forced to calculate the effect of the burden arbitrarily in actual circumstances. Moreover, if the linkage effects of the retrospective accumulation are omitted, this will result in an underestimation of the burden to the environment. As the greater the amount of time and cost spent, the worse the results obtained, this undermines the incentives to carry out the investigation.

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On the other hand, in the case of input-output analysis in economics, while it only takes into account the national average, arbitrariness is reduced if the tables from a particular year is used as a base, as the retrospective accumulation of the burden effect on the environment and its linkages could be calculated till the very final stage. Hence, in this paper, we introduce the LCA analysis using the input-output table that has been extended for environmental analysis.

Although we only consider CO_2 as the burden to the environment in this paper, similar calculations could also be applied to NOx and SOx. Further, due to the limitation in products data, we only consider products manufactured domestically. However, as this method of analysis could be easily extended to other kinds of burden on the environment and linkage effects abroad, it could be considered as a useful prototype for analysis along this line of approach.

2. Calculating the burden on the environment based on input-output analysis

We assumed that n types of goods and services are produced in the economy. These goods and services are used in the production of other goods and services, and they are also consumed as final demand or used as investment goods. The relationship in the quantities of these inputs and outputs are illustrated in matrix forms which constitute the input-output tables.

The quantity of input requires in the production of 1 unit of the various components of the matrices in the input-output tables are written as a_{ij}, i.e. the input coefficient. The value of a_{ij} refers to the quantity of the ith good required in the production of 1 unit of the jth good. Here, both the values of i and j, which represent the number of goods and services, take values from 1 to n. The input coefficients could also be rewritten in the following form,

$$\mathbf{A} = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix} \quad : \text{Input coefficient matrix} \tag{1}$$

Further, we let the burden on the environment generated by the production of 1 unit of the jth good as e_j. For convenience in calculation, it is written in the following diagonal matrix form,

$$\mathbf{e} = \begin{pmatrix} e_1 & & 0 \\ & \ddots & \\ 0 & & e_n \end{pmatrix} \quad : \text{Environmental burden diagonal matrix} \tag{2}$$

Let $\mathbf{f} = \begin{pmatrix} f_1 \\ \vdots \\ f_n \end{pmatrix}$ be the demand on various goods for the production of a particular good. Here, the direct burden on the environment arises from the production of vector $\mathbf{f}$ of goods and services inputs is $\mathbf{e}\cdot\mathbf{f}$.

For example, the burden on the environment generated by the production of 1 unit (1 million yen unit in 1985 fixed prices) of automobile (kth good) is written as follows,

$$\mathbf{e_k} = \begin{pmatrix} e_1 & & \\ & \ddots & \\ 0 & & e_n \end{pmatrix} \begin{pmatrix} 0 \\ \vdots \\ 1 \\ \vdots \\ 0 \end{pmatrix} \tag{3}$$

This is the direct burden effect on the environment.

Next, for the first order indirect effect, the production of demand $\mathbf{f}$ requires addition production $\mathbf{Af}$, which is used as intermediate good. Therefore, the first order indirect burden effect on the environment amounts to $\mathbf{e} \cdot \mathbf{Af}$. Within which, its linkage effect on intermediate goods is again linked to the second order indirect effect. As the production of $\mathbf{Af}$, in turns requires intermediate good, $\mathbf{AAf} = \mathbf{A}^2\mathbf{f}$, the second order indirect effect on the environment amounts to $\mathbf{e} \cdot \mathbf{A}^2\mathbf{f}$.

The above effects could be summarized as follows,

$$\mathbf{x} = \mathbf{f} + \mathbf{Af} + \mathbf{A}^2\mathbf{f} + \cdots = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} \tag{4}$$

where $\mathbf{x}$ is called the total production inducement vector. The total burden on the environment is thus written as

$$\mathbf{e} \cdot \mathbf{x} = \mathbf{e} \cdot \mathbf{f} + \mathbf{e} \cdot \mathbf{Af} + \mathbf{e} \cdot \mathbf{A}^2\mathbf{f} + \cdots = \mathbf{e} \cdot (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} \tag{5}$$

where $(\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse matrix. The Leontief inverse matrix, being the sum of an unlimited number of columns, is equivalent to the retrospective accumulation of the linkage effects of the intermediate goods to the very last stage. It is worth noting that due to the unlimited number of items to be included in the summation, accumulation could only be carried out within a small range. Further, it could also be proved that the inverse matrix exists under normal conditions.

3. The production of automobile: an example

Given the demand $\mathbf{f}$ of the various goods, the burden on the environment generated directly and indirectly by the intermediate goods could be calculated by $\mathbf{e} \cdot (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f}$. In the following section, we use the production of 1 unit (1 million yen) of automobile as an illustration (The details are based on the 440 sectors table in the 1985 Input-output Tables for Environmental Analysis which we compiled[1]. Figure 1 and 2 shows the calculation results of the CO_2 emission from per unit production of automobile. Due to the limits of space, Figure 1 focuses on items which their indirect effects have an emission of more than 1kg and total effects that exceed 4kg.

Firstly, for the direct effect, the production activities of a 1 million yen unit of automobile induced a CO_2 emission of 105kg. Various types of parts and components, and energy are used in the production of automobiles. From the perspective of the emission of CO_2, the production of plastic, tyres and inner tube, sheet glass, motor vehicle bodies, internal combustion engine for motor vehicles induce a larger emission comparatively. In addition, high CO_2 emission is induced from electric power generation and road freight transport. The total first order indirect effect induces a CO_2 emission of 383kg.

[1] See Yoshioka et al.(1992a) and Hayami et al.(1993).

In the next round of the linkage effect, intermediate goods are again required in the production of the goods in the first order indirect effect. Here, a high level of CO_2 is emitted in the production of cold finished steel and cast iron. Moreover, electric power generation, as a general input, has a CO_2 emission of 208kg. Hence, a total of 571kg of CO_2 is emitted in the second order indirect effect. It should be noted that the peaks in CO_2 emission for the various intermediate goods are different. For instance, the peak of CO_2 emission for electric power generation occurs in the second order effect whereas the peak for road freight transport occurs in the first order effect. While it is relatively easy to estimate the peaks for car body or internal combustion engine, it is difficult to estimate the required production of inputs used in the manufacturing of the various kinds of intermediate goods demanded simultaneously. In the calculation process of the second order indirect effect, in trying to know the quantity of the ith good required in the production of the jth good, we have to aggregate the derived demand in the production of the ith good due to jth good, through the linkage effect on the kth good. In other words, the calculation involves $\sum_{k=1}^{440} a_{ik}a_{kj}$ (440×440 =193,600 items in total), to obtain the CO_2 emission induced in the production of the jth good. While the retrospective accumulation method is simple, it is clear that an enormous amount of calculation is involved in the estimation of the second order indirect effect alone.

Further, as for the third order indirect effect, items such as crude oil, pulp, dyeing and finishing, cement, crude steel, zinc, and aluminum induced an emission of more than 1kg, and cold finished steel and cast iron required in the second order indirect effect have great inducement effect on the production of pig iron and hot rolled steel. While the CO_2 emission from electric power generation remains large at 179kg, it is on a decreasing trend. On the contrary, emission from self-power generation is on the increase. The total emission of CO_2 in the third order effect amounts to 576kg, the highest level of emission within the different stages considered.

For the fourth order indirect effect, CO_2 emissions from crude petroleum, coal products, pig iron and crude steel increased. Emission peaks are located for pulp, crude steel and self-power generation. The quantity of CO_2 emission from transport related activities should not be neglected, although it is on a decreasing trend.

For the inducement effect after the fourth order, the emission peak of pig iron occurs at the fifth order indirect effect, whereas the emission peak of coal products (coke) is found to occur at the sixth order. Besides, the peak of ferro alloy (8kg) also occurs at the fifth order. The total CO_2 emission amount to 484kg and 282kg at the fifth and the six order effect, respectively, while declining thereafter. The cumulative total upto the sixth order effect amount to 2,907kg, which is equivalent to about 90% of total cumulative emission of 3,421kg obtained through the inverse matrix. However, the emission of CO_2 continues until the very last stage for the case of petroleum related products, pulp, pig iron, power generation and transport related sectors.

4. An evaluation of the total effect

It is found that in terms of the total cumulative effect, 3.2 tons of CO_2 is emitted in the production of per unit of automobile. The characteristics of the total cumulative effect could be summarized as follows. Firstly, electric power generation has the highest level, 888kg of CO_2 emission, follow by pig iron (421kg), self-power generation (183kg), and cast iron (148kg). Secondly, as the direct effect contributed by automobile amount to only 105kg, the indirect effect it generated is much larger. Thirdly, CO_2 emission from the transport sector is large, as the total emission from bus transport, hired car & taxi transport, road freight transport, self-passenger transport and self-freight transport by private motor car, coastal and inland water transport, and air transport amount to 227kg. The CO_2 emission from these sectors are rather constant at all stages. Moreover, we should not ignore electric power generation and other general inputs that are required in all the manufacturing processes of various products. Fourthly, the accumulation of CO_2 emission from production activities such as salt, dyeing and finishing, inorganic pigment, wholesale trade and advertising, which we are likely to neglect could also sum up to a considerable amount. In fact, the total emission from these activities is about the same magnitude as the emission from the production of the car body, and wholesale trade and advertising could be considered as general inputs.

With regards to efficiency in production processes which consume a large amount of energy, Japan is quite advance among the industrial countries. However, it should be noted that transport, distribution and services are general inputs, just as the case of electricity or iron, required in the production of all types of goods. Therefore, it is a characteristic of general inputs that they are induced largely by the production of other goods. As it is also shown in our calculation, their effects should not be ignored. However, the efficiency of these services related sectors have not received much attention in Japan.

5. Towards LCA

For other goods and services, we have also calculated the CO_2 emission from the production of intermediate goods required in their production[2]. In this paper, we have illustrated using the example of automobile, analysis involving the retrospective accumulation method based on input-output analysis.

However, problems regarding the use of LCA remain. First, as we have used Japan's input-output table, CO_2 emission from the production and transport of raw materials and energy from abroad have not been included in the calculation. However, CO_2 emission effects induced abroad could be captured using the international input-output tables. Moreover, in this paper we have assumed that imports from abroad are produced using the same technology as that in Japan, while the transport of imports has been ignored in the study.

Second, we are still in the process of extending the input-output tables to include the effects of recycling and the absorption of CO_2 by plants.

The third point is that, we have also ignored the CO_2 emission induced from the production of manufacturing facilities. However, as seen in case of electricity, CO_2 emissions induced from the construction of manufacturing facilities are relatively small compared to that induced from production activities[3].

As the concept of LCA is based on the accumulation of all the burden which the products of individual firms exert on the environment. It is necessary to single out the effects each product exerts on the environment.

As the results of the input-output tables are available, there should be incentives to carry out detailed survey so as to differentiate the data contain in both. Further, with the information provided in the input-output table, they help to reduce the omissions that may occur in the accumulation process. Therefore, the introduction of input-output tables in LCA is important from both the point of view of calculation efficiency and comprehensive coverage.

[2] Yoshioka et al.(1992b)
[3] Yoshioka et al.(1994)

Nevertheless, there is a limit individual firm could claim about the burden its product exerts on the environment. For instance, even if the burden one's product exerts on the environment is small, but the reason behind being that electricity input is obtained from nuclear power instead of coal-fired power, then the evaluation will become rather difficult.

References

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