ENVIRONMENTAL INPUT-OUTPUT MODEL AND ITS ANALYSIS ON SOLID WASTE MANAGEMENT SECTOR[①]

PART Ⅰ: MODEL RESEARCH

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ABSTRACT An environmental input-output model was introduced to the regional solid waste management sectors, which can reflect the direct and indirect effects of regional solid waste generation and the specific relationships to the development of a regional economy. The results indicated that useful information may be gained from the solution of the input-output model, therefore the model provides a useful tool for the sustainable development planning that considers solid-waste management services sector.

Key words environmental input-output model analysis of economy and environment solid-waste management sector

1 INTRODUCTION

Policy makers have difficulty in making development sustainable. They have to design environmental policies and reconsider economic policies in order to mitigate the harmful environmental impacts. An environmental-economic analysis provides policy makers with information on the relationships between the economy and the environment and vice versa, it contains a quantitative insight into the relations between the economy and the environment, and provides means to predict what the effect of policy measures is in terms of economic and environmental impacts. In this way policy makers are able to balance economic growth and environmental quality in thorough way. The environmental-economic analysis in this research focuses on one environmental commodity viz solid waste. The objective of the research is to quantify the contribution of the solid waste management sector to the urban economy and urban environment. The aim is to provide policy makers at the local government with information, which enables them to make better decisions regarding of the solid waste management sector.

2 APPROACH

Since 1960s, economists have started considering environmental aspects in economic models. Then, many scholars studied the interrelation between the economy and the environment and established a number of models associated with the economic and environmental systems. In general, there are five types of economic-eco-

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logic models: (1) material balance models, portraying the flow and stocks of energy and materials in an economy; (2) environmental input-output models; (3) dynamic stock-flow models, describing the structure and evolution of a part of the economy in relation to its environmental aspects; (4) spatially oriented environmental-economic models; (5) evaluation models in environment-economy. All these models gave insight into the relations between the economy and the eco-system. They provided a great many stimuli for an improved environmental management.

In this research, the environmental-economic analysis is performed by an environmental input-output model. The input-output approach is chosen because it is a practical tool, not too complicated to apply and suitable for regional policy analysis.

Since the first input-output models considering environmental relationships had been developed by Cumberland (1966)[1], there have been a number of interesting extensions. For example, Leontief[2] developed the pollution generation-elimination model, Daly[3] and Isard[4] established the ecological-economic model, etc.

There have also been a number of successful applications based on the environmental input-output model. For example, it has been applied in analyses of the costs associated with the US federal clean air standards by Giaaratani and Miernyk[6]. Kelkar[7] attached estimates of the input requirements associated with air pollution, water pollution and solid-waste abatement to the 1971 US direct input coefficient matrix, in an analysis that emphasizes the employment- and income-generating potential of abatement activities. Furthermore, Johnson and Bennett[8] have demonstrated how abatement costs may also be incorporated with this general framework. Huang[9] applied the commodity-by-industry model to regional solid waste planning.

The environmental commodity-by-industry model provides a suitable framework for the analysis of solid waste management sector. The environmental commodity outputs represent the amount of solid waste generated, and the environmental commodity inputs represent the amount of environment resources consumed. Therefore, the environmental outputs are related to the solid waste management sector generation rates, and the environmental input are related to the environmental resource depletion caused by waste generation. Both direct and indirect effects of solid waste management sector generation can be reflected in the model as environmental inputs.

3 MODEL DEVELOPMENT

The model proposed attempts to trace the flows of environment associated with solid waste management sector and economic commodities. The environmental inputs are defined as the consumption, depletion or degeneration of natural resources as a result of solid waste management treatment/disposal, and the outputs are defined as the generation of different types of solid waste. The environmental input-output model used in this research follows the methodological approach and the mathematical matrix notation that are commonly used in input-output modelling. Model specifications and solving the model follow the traditional input-output modelling theory.

The schematic overview of the environmental input-output is shown in Table 1. The model comprises eight blocks described below.

(1) Block 1 Intermediary supplies and purchases

This comprises the transactions between economic sectors regarding the supply and purchase of commodities and services. We denote the total output of i by X_i. *We may then write*

$$X_i = Z_{i1} + Z_{i2} + \cdots + Z_{in} \quad (1)$$

where $\boldsymbol{Z}$ represents the intermediary sales by sector i. Thus we can have the ratio of input to output denoted as

$$a_{ij} = Z_{ij}/X_i \qquad i, j = 1, 2, \cdots, n \quad (2)$$

This ratio is termed a technical coefficient. In a more compact matrix expression, we have

$$\boldsymbol{Z} = \boldsymbol{A} \cdot (\boldsymbol{X})^{\wedge} \quad (3)$$

where $(\boldsymbol{X})^{\wedge}$ is a diagonal matrix generated from vector $\boldsymbol{X}$.

(2) Block 2 Primary inputs

Primary inputs comprise the compensation paid for other inputs than intermediary inputs. We define Y as a matrix of primary input values, and W as a matrix of primary input coefficients. We have

$$Y = W \cdot (X)^{\wedge} \tag{4}$$

where $(X)^{\wedge}$ is a diagonal matrix of sectoral output values, having the same meaning and form in Block 1.

(3) Block 3 Final demand

Final demand represents the output of the producing sectors that is sold to end-users. It includes the following variables.

f: vector of final demand values, hc: vector of consumptive expenses by households, gc: vector of consumptive expenses by the government, in: vector of investment expenses, e: vector of receipts for exported commodities, im: vector of expenses for imported commodities.

(4) Block 4 Environmental output: solid waste emissions by the producing sectors

This section represents the volumes of solid waste generated by the producing sectors as a result of their producing activities. It is split in an intra-regional and an export component. The former comprises the volume of waste that remains within the urban area. The latter comprises the volume of waste exported outside the research region. We define O as a matrix of solid waste output which remains within the region by the producing sectors in tons, Q as a matrix of solid waste output exported outside the region by the producing sectors in tons, P as a matrix of intra-regional coefficients of solid waste emission by the producing sectors, and R as a matrix of export coefficients of solid waste emission by the producing sectors. We have

$$\left.\begin{aligned} O &= (X)^{\wedge} \cdot P \\ Q &= (X)^{\wedge} \cdot R \end{aligned}\right\} \tag{5}$$

where $(X)^{\wedge}$ is a diagonalized matrix of sectoral output values, having the same meaning and form in Block 1.

(5) Block 5 Environmental output: solid waste emissions by the final demand

This section represents the volumes of solid waste generated by the final demand as a result of its consumption. Similar to Block 4, it is split in an intra-regional and an export component. We define M as a matrix of solid waste output that remains within the region by the final demand in tons, N as a matrix of solid waste output exported outside the region by the final demand in tons, Pf as a matrix of intra-regional coefficients of solid waste emission by the final demand, and Rf as a matrix of export coefficients of solid waste emission by the final demand. We have

$$\left.\begin{aligned} M &= (X)^{\wedge} \cdot Pf \\ N &= (X)^{\wedge} \cdot Rf \end{aligned}\right\} \tag{6}$$

where $(X)^{\wedge}$ is a diagonalized matrix of the final demand.

(6) Block 6 Environmental input: solid waste inputs

These are the volumes of waste that are used as inputs by producing sectors. This block is split into two parts. The intra-regional part contains solid waste fractions which stems from the urban area. The imported part contains the solid waste fractions imported from outside the urban region. We define S as a matrix of solid waste input from within the region in tons, U as a matrix of solid waste input imported outside the region in tons, T as a matrix of intra-regional solid waste input coefficients, and V as a matrix of imported solid waste input coefficient. We have

$$\left.\begin{aligned} S &= T \cdot (X)^{\wedge} \\ U &= V \cdot (X)^{\wedge} \end{aligned}\right\} \tag{7}$$

where $(X)^{\wedge}$ is a diagonalized matrix of sectoral output values, having the same meaning and form in Block 1.

(7) Block 7 Environmental input: virgin material inputs

This section represents those volumes of virgin materials that can be regarded as equivalents of the recyclables and organic waste of the previous Block 6. In other words, the recyclables and organic waste of Block 6 are substitutes for the virgin materials presented in this block. We define K as a matrix of virgin material inputs in tons, and B as a matrix of virgin material input coefficients. We have

$$K = B \cdot (X)^{\wedge} \tag{8}$$

where $(X)^{\wedge}$ is a diagonalized matrix of sectoral output values, having the same meaning and form in Block 1.

(8) Block 8 Employment

One socioeconomic variable is attached to the model, viz. employment. We define L as a matrix of labour input values in persons, and J as a matrix of labour input coefficients. We have

$$L = J \cdot (X)^{\wedge} \quad (9)$$

where $(X)^{\wedge}$ is a diagonalized matrix of sectoral output values, having the same meaning and form in Block 1.

4 MODEL RESULTS

4.1 Primary model results

Primary model results comprise the matrices that contain the direct coefficients related to the sectoral outputs, viz. A, W, P, R, T, V, B and J. These matrices show the effect of change in sectoral production. It can be noted that in case certain data are not available, the direct coefficients have to be estimated. In that case, they are rather an input to the model than an output.

4.2 Intermediary model results

Intermediary model results comprise the matrices that contain the coefficients related to the final demand, also called the cumulative coefficients. These are

$(I - A)^{-1}$: the cumulative technical coefficients, in which I represents the identity matrix;

$W \cdot (I - A)^{-1}$: the cumulative primary input coefficient matrix;

$(I - A)^{-1} \cdot P$: the cumulative intra-regional solid waste emission coefficient matrix by producing sectors;

$(I - A)^{-1} \cdot R$: the cumulative exported solid waste emission coefficient matrix by producing sectors;

Pf: matrix of intra-regional coefficients of solid waste emission by the final demand;

Rf: matrix of export coefficients of solid waste emission by the final demand;

$T \cdot (I - A)^{-1}$: the cumulative intra-regional solid waste input coefficient matrix;

$V \cdot (I - A)^{-1}$: the cumulative imported solid waste input coefficient matrix;

$B \cdot (I - A)^{-1}$: the cumulative virgin material input coefficient matrix;

$J \cdot (I - A)^{-1}$: the cumulative labour input coefficient matrix.

4.3 Indicators

The primary and intermediary model results can be used to compute a wide range of indicators. The following indicators provide an answer to the research questions. Six types of indicators can be distinguished, i.e. economic, environmental, social, environmental-economic, socio-economic and socio-environmental indicators.

(1) Economic indicators, computed by using the monetary values of Blocks 1, 2 and 3;

(2) Environmental (solid waste) indicators, computed by using the physical values of Blocks 4, 5, 6 and 7;

(3) Social indicators, computed by using the physical values of Block 8;

(4) Environmental-economic indicators, computed by combining the monetary values of Blocks 1, 2 and 3 with the physical values of Blocks 4, 5 and 6;

(5) Socioeconomic and socio-environmental indicators, computed by the monetary values of Blocks 1, 2 and 3, the physical values of Blocks 4 and 5 and the physical values of Block 8.

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