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Environmental input-output model and its analysis with a focus on the solid waste management sectors

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Abstract: An environmental input-output model (EIOM) was introduced to the regional solid waste management sectors, which can reflect the direct and indirect relations between the environment and the regional economy development. Some details about how to use the EIOM was discussed. The EIOM was applied to the Changsha City in China. The example results indicate that much useful information related to the environment and the regional economy development can be gained from the solution of the EIOM. Thus, the EIOM can be used as a useful tool for the sustainable development planning including the solid waste management sectors.

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

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Introduction

Since the first environmental input-output model (EIOM) (Cumberland, 1966) was established by incorporating environmental factors into economic models, many interesting extensions to it have been developed and many successful applications about the EIOM have appeared (Leotief, 1970; Daly, 1968; Isard, 1968; Vector, 1972; Giarratantni, 1974; Jonson, 1981; Huang, 1994; Cordon, 1997).

In 1995, the Ministry for International Cooperation of the Netherlands began the Urban Waste Expertise Programme, UWEP, a six-year research and pilot project programme on urban waste in the south, which is coordinated by WASTE (a consulting company for development projects in countries in Africa, Asia and Latin- America). As China is a developing country and there are vivid solid waste management sectors including recycling activities in Changsha. Changsha was selected as a case-study to the UWEP programme according to a contract signed between WASTE and Hunan University in October 1996.

The main concern of this UWEP research is waste related activities and their impact on the urban environment. The activities are dealt with from the perspective of the economic system. The environmental-economic analysis in this UWEP 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. The environmental-economic analysis was performed by the EIOM. This research made some contributions to the EIOM development in both theory and practice.

1 Model development

The EIOM used attempts to trace the environmental flows associated with solid waste management sectors and economic commodities. Environmental inputs are defined as the consumption, depletion or degradation of natural resources as a results of solid waste management treatment/disposal, and outputs are defined as the generation of different types of solid waste. The EIOM 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 follow the traditional input-output modelling theory. The EIOM comprises eight blocks described below.

1.1 Block 1—intermediary supplies and purchases

This comprises the transactions between economic sectors regarding the supply and purchase of commodities and services. Denoting X_i as the total output from sector i . Then we may write:

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

where the Z_{ij} terms on the right-hand side represent the intermediary sales by sector i . Thus the ratio of input to output can be denoted as:

$$A_{ij} = Z_{ij}/X_i, \quad i, j = 1, 2, \dots, n. \quad (2)$$

These ratios are termed as technical coefficients. To have a more compact matrix expression, we can write:

$$Z = A \cdot X^\wedge, \quad (3)$$

where X^\wedge is a diagonal matrix generating from vector X_i , A is the technical coefficient matrix generating from A_{ij} .

1.2 Block 2—primary inputs

Primary inputs comprise the compensation paid for other inputs than intermediary inputs. Defining Y as the matrix of primary input values and W as the matrix of primary input coefficients, we can have:

$$Y = W \cdot X^\wedge \quad (4)$$

1.3 Block 3—final demand

Final demand represents the output of the producing sectors that is sold to end-users. The relationship in this block is:

$$f = hc + gc + in + e - im, \quad (5)$$

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

1.4 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. The relationship in this block is:

$$O = X^\wedge \cdot P, \quad Q = X^\wedge \cdot R, \quad (6)$$

where O is the matrix of solid waste output which remains within the region by the producing sectors in tons; Q is the matrix of solid waste output exported outside the region by the producing sectors in tons; P is the matrix of intra-regional coefficients of solid waste emission by the producing sectors, and R is the matrix of export coefficients of solid waste emission by the producing sectors.

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. The relationship in this block is:

$$M = X^\wedge \cdot Pf, N = X^\wedge \cdot Rf, \quad (7)$$

where M is the matrix of the solid waste output that remains within the region by the final demand in tons; N is the matrix of the solid waste output exported outside the region by the final demand in tons; Pf is the matrix of intra-regional coefficients of the solid waste emission by the final demand, and Rf is the matrix of export coefficients of solid waste emission by the final demand.

1.6 Block 6—environmental input: solid waste inputs

There are the volumes of waste that are used as inputs by producing sectors. The relationship in this block is:

$$S = T \cdot X^\wedge, U = V \cdot X^\wedge, \quad (8)$$

where S is the matrix of the solid waste input from within the region in tons; U is the matrix of solid waste input imported outside the region in tons; T is the matrix of intra-regional solid waste input coefficients; and V is the matrix of imported solid waste input coefficient.

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 recyclable and organic waste of the previous Block 6. In other words, the recyclable and organic waste of Block 6 are substitutes for the virgin materials presented in this block. The relationship in this block is:

$$K = B \cdot X^\wedge, \quad (9)$$

where K is the matrix of the virgin material inputs in tons; and B is the matrix of virgin material input coefficients.

1.8 Block 8—employment

One socio-economic variable is attached to the model, viz. employment. The relationship in this block is:

$$L = J \cdot X^\wedge, \quad (10)$$

where L is the matrix of the labor input values in persons, and J is the matrix of the labor input coefficients.

2 Model results

2.1 Primary model results

The 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 a change in sectoral production. It should be noted that in case certain data are not available, some related coefficients have to be estimated.

2.2 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; $W(I - A)^{-1}$ —the cumulative primary input coefficient matrix; $(I - A)^{-1}P$ —the cumulative intra—regional solid waste emission coefficient matrix by producing sectors; $(I - A)^{-1}R$ —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; $T(I - A)^{-1}$ —the cumulative intra-regional solid waste input coefficient

matrix; $V(I - A)^{-1}$ —the cumulative imported solid waste input coefficient matrix; $B(I - A)^{-1}$ —the cumulative virgin material input coefficient matrix; and $J(I - A)^{-1}$ —the cumulative labor input coefficient matrix.

2.3 Indicators

The primary and intermediary model results can be used to calculate a wide range of indicators. Together the following indicators provide an answer to the research questions. Six types of indicators can be distinguished, viz. economic indicators, computed by using the monetary values of blocks 1, 2 and 3; environmental (solid waste) indicators, computed by using the physical values of blocks 4, 5, 6 and 7; social indicators, computed by using the physical values of block 8; 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; and socio-economic 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.

3 Case study application*

3.1 An overview of the solid waste management sectors in Changsha

Totally there are about 13 state-owned enterprises engaging in the resource recovery sectors, in which there are about 1710 employees. Other privately owned micro-enterprises (totally about 1100) also engage in this field, of which each has 1—3 employees. The employees of those micro-enterprises are mainly low-income urban citizens and farmers from countryside.

The waste management service in Changsha mainly include the formal collection service, the informal collection service, separation and handling service, paper recycling, plastic recycling, rubber recycling, iron and steel recycling, non-ferrous metal recycling, glass recycling, mixed bone recycling, composting and other recycling. The solid wastes in Changsha can mainly be divided into the industrial solid wastes and the municipal solid wastes.

3.2 Data collection

All used data (the number of which is totally about 2046) in the EIOM in the case study are obtained from some related departments and institutions of the local government in Changsha. Some used data are published and some of them are from the reports that have not been published but with high reliability. A good deal of data will not available, or when available, needs to be adjusted to the format required by the EIOM. The rational behind these judgements in the EIOM are: advising the related experts and officials; investigating and analyzing 3—5 representative case enterprises; and experts' estimating according to production technology, product volume, the relation between input and output, and so on.

3.3 Model calculation

The EIOM computation are programmed in a LOTUS 123 spreadsheet. According to the EIOM, the primary model results in 2.1, the intermediary model results in 2.2 and the indicators in 2.3 are calculated.

3.4 Results and discussion

The primary model results, the intermediary model results and the indicators can be used to

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make a full-fledged analysis of the waste management sectors, including economic, operational/technical, social and environmental aspects.

For example, the volume of the solid wastes generated in relation to production and final demand in Changsha is about 824859 tons, including paper waste 27201 tons, plastic waste 6097 tons, rubber waste 1850 tons, iron and steel waste 57333 tons, non-ferrous metal waste 3450 tons, glass waste 15340 tons, mixed bone waste 4433 tons, other recyclables 191288 tons, organic waste 135577 tons and others 382290 tons. From coefficient matrixes P and R , the intra-regional and exported solid waste emissions by producing each 10000 RMB Yuan total monetary output for all producing sectors can be obtained. From the coefficient matrix $(I - A)^{-1}P$ and matrix $(I - A)^{-1}R$, the cumulative intra-regional and exported solid waste emissions by producing each 10000 RMB Yuan final demand for all producing sectors can be obtained. From matrix Pf and matrix Rf , the intra-regional and exported solid waste emissions by consuming each 10000 RMB Yuan final demand for all producing sectors can be obtained. According to the mentioned-above matrices, it is easy to find that the waste emission coefficients for these sectors are relatively high. As the total monetary outputs for the separation and handling, the plastic recycling, the rubber recycling, the iron and steel recycling, and the grass recycling in the waste management service are small compared to other main industries, the reuse for these recycling industries is primary with simpler technology, poorer management, lower efficiency and higher waste emission, and a small part of input recyclable which can not be completely used, the waste emission coefficients for these sectors are relatively high.

The total volume of recyclable used in the production process related to the volume of virgin materials in Changsha is about 234150 tons, including paper waste 13067 tons, plastic waste 701 tons, rubber waste 946 tons, iron and steel waste 39460 tons, non-ferrous metal waste 3278 tons, glass waste 3878 tons, mixed bone waste 1400 tons, other recyclables 165700 tons, and organic waste 5720 tons. The shares of the recyclable in the corresponding virgin materials used in the production process are paper waste 23.23%, plastic waste 4.34%, rubber waste 1.61%, iron and steel waste 12.92%, non-ferrous metal waste 16.11%, glass waste 7.47%, and organic waste 8.94%. From the matrixes T and V , the intra-regional and imported solid waste inputs for producing each 10000 RMB Yuan total monetary output for all producing sectors can be obtained. From the coefficient matrices $T(I - A)^{-1}$ and $V(I - A)^{-1}$, the cumulative intra-regional and imported solid waste input for producing each 10000 RMB Yuan final demand for all producing sectors can be obtained. The above results describe how is the volume of recyclable used in the production process related to the volume of virgin materials from different aspects.

The total monetary output for the recycling industries in Changsha in 1994 is 122942000 RMB Yuan, being 0.27% of the total monetary output for the regional economy and 57.05% of the total monetary output for all waste management services; and that the income (including taxes paid on products and income, subsidies received from the government, the wages and salaries for the male and female workers and the gross profit) for the recycling sectors is 30977000 RMB Yuan, being 0.19% of the income for all producers and 43.87% of the income for all waste management services. The matrix W and the matrix $W(I - A)^{-1}$ are the primary input coefficient matrix and the cumulative primary input coefficient matrix, respectively. From the two matrices, the taxes and subsidies for producing each 10000 RMB Yuan total monetary output for all waste management services and the taxes and subsidies for producing each 10000 RMB Yuan final demand for all waste management services can be obtained. It is easy to find from the two results that the taxes for the waste management services are lower and the subsidies for the waste management services are higher

than the corresponding values for industry, construction, commerce, financing and insurance, and real estates, which shows us that the waste management services in Changsha already enjoy some preferential policies from the government. Several related indicators calculated also show us similar results.

The total employment workers for the recycling sectors is 2258 persons, being about 0.33% of total employment workers and 27.73% of employment workers for all waste management sectors in Changsha in 1994; and that the average labor input for producing each 10000 RMB Yuan total monetary output for recycling industries is 0.18 persons. From matrix J and matrix $J(I - A)^{-1}$, the employment workers for producing each 10000 RMB Yuan total monetary output for all recycling sectors and the cumulative employment workers for producing each 10000 RMB Yuan final demand for all recycling sectors can be obtained, respectively. All these results show us that the recycling sectors provide Changsha with more employment opportunities.

4 Conclusion

This paper develops the EIOM in solid waste management sector and discusses the details about how to use it with a case study in Changsha, which provides a suitable framework for the analysis of the solid waste management sectors. In the EIOM, the environmental commodity outputs representing the amount of solid waste generated, and the environmental commodity inputs representing the amount of environment resources consumed. Thus, the environmental outputs are related to solid waste management sectors' generation rates, and the environmental inputs 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 EIOM, which can quantitatively quantify the contribution of the resource recovery sectors to the urban economy and the urban environment. The EIOM results can provide both policy makers at the local government and other related authorities and development agencies with much useful information, which will enable them to make better decisions about the resource recovery sectors.

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