ANALYSIS OF WASTE FLOWS USING WIO TABLE

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Received: 10 May 2018; Accepted for publication: 21 August 2018

ABSTRACT

As industrial sectors and waste management sectors are related to each other in IO table, this paper aims to inventory waste cycles among the sectors in Vietnam using IO (Input – Output) table and WIO (Waste Input - Output) model. The national published data of 164 product sectors are based on the 2012 IO table updated for 2016. The material flows that each sector contributes to the others are quantified and then combined with the corresponding waste generation coefficient to determine the load of waste generated, collected and treated for each sector. The investigated data include quantity and composition of hazardous and solid waste handled by 200 waste treatment facilities in 2016. The type of waste is limited to 3 categories including wastewater, domestic and normal industrial waste, and hazardous waste. The research drives towards to build an economic mathematical model for Vietnam that gives a quantified analysis of waste flows.

Keywords: IO table, WIO model, waste cycle analysis.

1. INTRODUCTION

An IO table presents balanced interrelationships of the providing and demanding sectors of the economy. IO tables have important applications in the fields of economics, energy as well as environment. In the field of waste, Y. Kondo and S. Nakamura have developed WIO model (Waste Input - Output) and used the model as an inventory tool in supporting environmental management in Japan [1, 2, 3]. This model focuses on a systematic and cross-cutting approach to interdisciplinary interdependence between production activities, waste generation and waste management (including recycling and treatment activities). Apart from Japan, a number of related researches have been developing in European countries [4, 5].

In Vietnam, this approach has been done at a level of qualitative analysis of material flows. A number of studies have used on-site inventory method to estimate solid waste generation rates for single sectors [6, 7]. In some more in-depth study, the pathways of Cu and Pb metals from being exploited, put into production and used up to disposal and/or recycling have been analyzed [8, 9]. Those studies follow a bottom-up approach and focus on one or more material flows within a certain range.

This study aims to develop WIO model that is expanded from Vietnam’s IO tables in order
to obtain data sets for quantifying certain environmental burdens of the economy. With a top-down approach, the country’s waste management and treatment capacity as well as its energy requirements and CO$_2$ emissions can be evaluated.

2. METHOD

2.1. Structure of WIO table

The WIO table shows inter-relationships among goods/services and waste of an economy. Structure of the table is described in table 1a, which is developed by Nakamura [10]. According to his classification, waste is divided into “waste” and “effluents”. The former is involved in waste management processes while the latter is emitted into the environment. For example, municipal solid waste belongs to “waste” because it is collected, processed and gone into landfills while the air emissions from production activities belong to “effluents”.

In Table 1a, “industry” sectors, “waste treatment” sectors and “final demand” sectors are respectively denoted by $o$, $z$, and $f$ while “waste” and “effluents” is respectively denoted by $w$ and $e$. The inter-sectoral flows of goods/services are represented by $X_{io}$, $X_{iz}$, and $X_{if}$. The emission of waste and effluents associated with goods/services are represented by $W_{wo}$ and $W_{eo}$, respectively. The emission of waste and effluents associated with waste treatment sectors are respectively represented by $W_{wz}$ and $W_{ez}$. The emission of waste and effluents associated with final demand sectors are represented by $W_{wf}$ and $W_{ef}$, respectively. In matrix form, the balancing equation for the flow of waste is formed as the following:

$$X_o = X_{wo} + X_{oz} + X_{of} \quad (1)$$

$$W_w = W_{wo} + W_{wz} + W_{wf} \quad (2)$$

$$W_e = W_{eo} + W_{ez} + W_{ef} \quad (3)$$

Table 1a. Inter-relationship among goods and waste.

<table>
<thead>
<tr>
<th></th>
<th>$o$</th>
<th>$z$</th>
<th>$f$</th>
<th>$\Sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$o$</td>
<td>$X_{oo}$</td>
<td>$X_{oz}$</td>
<td>$X_{of}$</td>
<td>$X_o$</td>
</tr>
<tr>
<td>$w$</td>
<td>$W_{wo}$</td>
<td>$W_{wz}$</td>
<td>$W_{wf}$</td>
<td>$W_w$</td>
</tr>
<tr>
<td>$e$</td>
<td>$W_{eo}$</td>
<td>$W_{ez}$</td>
<td>$W_{ef}$</td>
<td>$W_e$</td>
</tr>
</tbody>
</table>

Table 1b. Matrix of coefficients.

<table>
<thead>
<tr>
<th></th>
<th>$o$</th>
<th>$z$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$o$</td>
<td>$A_{oo}$</td>
<td>$A_{oz}$</td>
</tr>
<tr>
<td>$w$</td>
<td>$G_{wo}$</td>
<td>$G_{wz}$</td>
</tr>
<tr>
<td>$e$</td>
<td>$G_{eo}$</td>
<td>$G_{ez}$</td>
</tr>
</tbody>
</table>

2.2. Analytical tools

In IO work, a fundamental assumption is that the inter-industry flows from $i$ to $j$ depend entirely on the gross output of sector $j$. That is, if sector $j$ represents vacuum cleaners, we assume that if there is an increase in the sales of vacuum cleaners, there will be a corresponding increase in the sales of electric motors that are used in vacuum cleaners. From this concept, a ratio of input to output was formulated and called a technical coefficient [11]. In WIO work, the technical coefficients denoted by $a_{ij}$ can be made by “dividing the column elements of $o$ and $z$ by the corresponding activity (output/disposal) levels” [10], as in Table 1b.

In matrix form the complete $n \times n$ system is:

$$AX + F = X \quad (4)$$

In most of the cases, the number of waste management processes is smaller than the types
of waste. In order to make the matrix in the middle panel of Table 1b into a square one, Nakamura has transformed the row elements referring to waste into the corresponding waste disposals [10].

The $A$ matrix is known as technical coefficient matrix or structural matrix. If $|I - A| \neq 0$ then $(I - A)^{-1}$ can be found and a unique solution is given by:

$$X = (I - A)^{-1}F$$  (5)

The matrix of effluent emission coefficients represents technology (in use) and institutions (such as emission standards). If this matrix is denoted by $G_e$, then the additional environmental loads can be determined by:

$$W_e = G_eX = G_e(I - A)^{-1}F.$$  (6)

3. RESULTS DISCUSSION

3.1. Waste from the industry sectors to the waste treatment sectors

In this study, the original 2012 IO table is updated for 2016 using standard RAS method [11]. All sectors of the updated IO table are numbered from 1 to 164 according to the General Statistics Office [12], among which there are 163 industry sectors and 03 waste treatment sectors included: Sewerage and wastewater treatment services ($S103$); Solid waste collection, treatment (including recycle scrap) and disposal services ($S104$) and Hazardous waste treatment services and other waste management activities ($S105$). The investigated data include quantity and composition of hazardous waste handled by 200 waste treatment facilities in the same year.

As the results, wastewater (WW), domestic and industrial solid waste (DISW), and hazardous waste (HW) from the sectors in 2016 is shown in Figure 1.

- Total volume of treated and discharged WW was $896,365,973$ m$^3$, in which the biggest WW dischargers included: Production of gasoline and lubricants (sector 60 - S60); Trade (S114); Seafood processing (S36); Pulp and papers (S37); Instant food processing (S45), etc.
- Total volume of collected, treated and buried DISW was $10,670,734$ tons, in which the biggest DISW generators included: Natural water extraction (S102); Trade (S114); Health services (S154); Food services (S126); Metallurgies (S73-75); Costume, leather, shoes (S53-55); Pulp and papers (S37), etc.
- Total volume of treated and managed HW was $596,537$ tons, in which the biggest HW generators included: Crude oil extraction (S29); Trade (S114); Electricity production and delivery (S99); Color metallurgy (S76); Yarn, woven fabric and finishing textiles (S51); Pulp and papers (S37), etc.

The effect of the recycling was negligible, as shown by very small negative values in the figures. There were only two sectors that had used the waste as its input materials: Remaining petroleum products ($S61$ recycled all WW, DISW and HW); and Synthetic plastic and ($S64$ recycled both DISW and HW).
Compared to the published data of waste generation, it can be seen that the collecting and treating rate of DISW and HW in Vietnam was very low. The forms of industrial waste collection have different characteristics corresponding to different industries. In thermal power sector, most plants are coal dust recovery systems. Furnace slag deposited at the bottom was collected along with fine particles dust, then transported and stored in the dumps. A small part of the waste was used as building materials. Pha Lai Thermal Power Plant has a dump up to 5 million tons of solid waste, accumulated over the years. In oil and gas exploitation, a majority of offshore drilling rigs was weekly collected and taken ashore by Petroleum Services Corporation.

In many industrial parks, there are no collection focus points as prescribed. The industrial waste containing hazardous ingredients was being rented/delivered/sold to licensed facilities. However, the issues related to HW control after the contract has not been performed well. Recycling and exchange waste have not been the main treatment method in the current industrial parks. According to our surveys, 58.4 % of enterprises contracted for collecting or disposing HW because of no choice for a self-burning, composting and land-filling; 37 % of enterprises stored HW temporarily on-site. Normal industrial solid waste centralized processing zones or large-scale handling facilities have been lacked.
3.2. Energy consumption and CO\(_2\) effluents from the waste treatment sectors

During waste management processes, the waste is treated and transformed into other types and/or effluents. As the results, energy consumption and CO\(_2\) emissions from waste treatment sectors in 2016 is calculated and described in Table 2 and Figure 2, respectively.

Table 2. Energy used for waste treatment in 2016.

<table>
<thead>
<tr>
<th></th>
<th>WW</th>
<th>DISW</th>
<th>HW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard coal and lignite, tons</td>
<td>-</td>
<td>15,201</td>
<td>-</td>
</tr>
<tr>
<td>Gasoline and lubricant, tons</td>
<td>394,040,768</td>
<td>4,872,625</td>
<td>193,712</td>
</tr>
<tr>
<td>Electricity, kwh</td>
<td>154,470,896</td>
<td>603,302</td>
<td>6,909</td>
</tr>
<tr>
<td>Natural gas and LPG, m(^3)</td>
<td>23,098,891</td>
<td>15,491</td>
<td>-</td>
</tr>
</tbody>
</table>

Figure 2. CO\(_2\) emissions from waste treatment sectors in 2016 (10\(^3\) tons).

This model is being developed to evaluate the waste flows of Vietnam in order to unveil the embodied emissions from the current waste treatment facilities as well as proposed alternatives. The most concerned alternative nowadays is using incinerators due to difficulties in landfilling. It is obvious that composting and waste-to-energy are effective remedies for this purpose. The model is expected to provide an effective life-cycle assessment tool for alternative waste management policies.

4. CONCLUSION

This paper derived the associated 2016 static IO model and applies it to analyze the WW, DISW and HW from the industry sectors to the waste treatment sectors and the CO\(_2\) effluents from the waste treatment sectors. As resulted, CO\(_2\) emissions from WW, DISW and HW treatment sectors in 2016 is 1,179,024 thousand tons, 14,077 thousand tons and 557 thousand tons, respectively. The study also evidenced that the collecting and treating rate of DISW and HW was low and the recycling effect was negligible. Therefore, it is necessary to have alternative solutions in order to improve the waste management effects and reduce the environmental burdens. The research drove towards to complete WIO model for Vietnam that gives a quantified analysis of waste flows.

Acknowledgment. The authors wish to thank Ha Noi University of Science and Technology for the supports. This research is funded by MOET under the framework of B2017 – BKA – 42 project.

REFERENCES


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