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Assessment of solid waste generation and treatment in the Australian economic system: a Closed Waste Supply-Use model

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Abstract

The Household sector (HS) is not only the major cause of waste generation in industrial sectors, but also the same function as an industrial sector to generate waste. Current researches mainly focus on waste generation caused by the demand of the HS based on the environmentally-extend input-output (EEIO) models while the effect of the HS as an industrial sector on waste flow has not been analysed. In addition, there is uncertainty around the economic cost of waste management discussed in EEIO models due to the lack of the calculation of the cost of labor.

We adjust waste supply-use table to analyse effects of the HS as an industrial sector on waste flow, resulting in closed waste supply-use table (CWSUT). The novelty of the method lies in a shift in the effect of the HS, from an exogenous factor to an endogenous factor. Results derived from Australian CWSUT in 2009–10 illustrate waste generation effects of intermediate sectors and the mixed waste flows of the HS. The definition of "intermediate sector" is that the sector consumes intermediate inputs from producing sectors and generates intermediate outputs to Final demand (Acemoglu, Aghion et al. 2003). They show that: (1) the Construction sector has the largest waste generation effects, in which the amount of masonry waste has accounted for the most direct and total effects of waste generation; (2) investigations regarding the HS in CWSUT can calculate the amount of direct and total waste generation, the monetary flow, and effects of the Income for the Household sector. Base on the above results, the paper puts forwards the application of the CWSUT on other types of environmental issues and waste policies.

Keywords: Waste management, Closed waste supply-use table, Australian economy, the Household sector.

1. Introduction

In 2009–10, 53.7 million tonnes of waste were generated from Australian territory (ABS 2013a). Of these, 27% came directly from the Households sector, while the others stems from industrial sectors (ABS 2013a). From the perspective of the demand of consumers, the former part of the waste is directly derived from the Households sector, and the latter part of the waste constitutes an indirect waste generation from the goods and services produced from industrial sectors and consumed by consumers. In addition, as an indicator of the economic cost for waste treatment (Bartelings and Sterner 1999, Yuan and Wang 2014), the waste levy fee aims to reduce the amount of waste being placed into landfill and promote recycling and resource recovery. For example, Section 113 of the Environment Protection Act 1993 requires certain licensed waste facilities in South Australia to pay a contribution for each tonne of waste received at the facility, which is referred to as the 'waste levy' (Attorney-General's Department 2011). The waste levy fee has increased in Australian states in recent years. For instance, the waste levy fee for the Metropolitan area in New South Wales (NSW) has increased from 58.80 AUD$ in 2009–10 to 135.70 AUD$ in 2016–17 (The NEW Environmental Protection Authority 2017). It is one of the most complex challenges for waste management to measure the amount of waste directly and indirectly caused by the demand of consumers and the costs of waste treatment due to the lack of available data regarding waste generation and treatment (Lebersorger and Beigl 2011, Karak, Bhagat et al. 2012).

Environmentally-extended input-output (EEIO) model is a method– a mathematically defined procedure applying economic and environmental accounts to determine the direct and indirect effects of industrial sectors on environmental issues, such as greenhouse gas (Lenzen 1998, Chen and Zhang 2010, Meng and Sager 2017), water (Lenzen and Foran 2001, Velazquez 2006, Deng, Zhang et al. 2014), energy (Liang, Fan et al. 2007, Nässén, Holmberg et al. 2007, Liu, Xi et al. 2010), and waste (Huang, Anderson et al. 1994, Nakamura and Kondo 2002, Wang, Huisman et al. 2013).

As a branch of EEIO analysis, waste input-output (WIO) connects monetary flow between industrial sectors and the Final demand with physical waste flows. It is constructed by (Nakamura and Kondo 2002) and has been applied to tackle with a series of problems in the domain of waste management including the emission of waste (Nakamura and Kondo 2002), material flow analysis (Nakamura and Nakajima 2005, Nakamura, Nakajima et al. 2007), recycling of electrical home appliances (Nakamura and Kondo 2006), direct and indirect emission induced by households' consumption patterns (Takase, Kondo et al. 2005), formation of a waste supply-use (WSU) format and its application in Australia (Lenzen and Reynolds 2014, Reynolds, Piantadosi et al. 2014), publication of an Australian Multi-Regional Waste Supply-Use framework(Fry, Lenzen et al. 2015), and direct and indirect waste arisings in the UK economy (Salemdeeb, Al-Tabbaa et al. 2016). These traditional EEIO models comprehensively capture the relationships between industrial sectors and waste treatment sectors, which are determined by all types of Final demand (Household consumption, Government expenditure, Gross Fixed Capital Formation, Changes in Inventories, and Export). The traditional EEIO model is termed the ‘Open’ EEIO model. However, the above-mentioned literature only analyse the effect of household consumption in the Final demand and rarely specifically focus on the mutual effect between industrial sectors and household consumption. The comparison between Open and Closed IO models applied in environmental issues have been widely discussed in CO_2 intensities (Kondo, Moriguchi et al. 1996, Kainuma, Matsuoka et al. 2000) and sustainability criterion (Proops, Atkinson et al. 1999).

Theoretically, there is a mutual effect between household consumption and waste generation of industrial sectors. The Household sector causes waste generation of industrial sectors through household consumption. The income of households from industrial sectors in turn influence the household consumption. The mutual effect between the Turkish production structure and labor income with different policy strategies has been studied through the partially closed supply-driven input-output model (Dietzenbacher and Günlük-Şenesen 2003). This type of effect regarding how the situation of industrial sectors affects household income and how the household income influences the consumption of industrial products has also been discussed by (Miller and Blair 2009). Chen, Dietzenbacher et al. (2015) has indicates that the semi-closed model is better than the open model for analyzing the contribution of changes in labor compensation coefficients. Zhang, Yu et al. (2017) has shown that more comprehensive impacts of household consumption on carbon emissions can be analyzed by utilizing a semi-closed input-output model. Duchin (2005) has constructed a globally closed input-output model by considering different types of the final demand, such as exports and the other types of the final demand, as endogenous variables. These studies have described that some important finding can be obtained from closed IO model rather than open IO model. Moreover, the Household sector directly causes environmental pressures, including generation of GHG emissions and waste in the economic system (Choe and Fraser 1999, Beck-Friis, Smars et al. 2001). For example, the Household sector in Australia generated the second largest volume of waste with approximately 12.4 Mt in 2009–10 and 14.27 Mt in 2010–11 (ABS 2013a). This indicates that the Household sector is an important endogenous factor for the WSU table. Therefore, moving the Household sector and the Income into the quadrant of intermediate sectors to construct the Closed WSU (CWSU) table is significant for the analysis of the mutual effect of the Household sector on Australian waste management.

This study has a novel methodological contribution with no other waste management studies using the household consumption as an endogenous sector. But a semi-closed input-output model, which moves the Household sector into the intermediate use, has been applied to how different income levels affect greenhouse gas emission (Zhang, Yu et al. 2017). Other similar non waste management studies have been published by Chen, Dietzenbacher et al. (2015) and Chen, Dietzenbacher et al. (2016)

Effective waste management involving the recovery of materials, recycling, and disposal to landfill is provided primarily by the Waste Management Services Industry and depends on reliable data of waste flows. Currently, there are two main types of Australian waste accounts: (1) waste data generated by states and territories are published in the National Waste Report produced by the Department of the Environment and Energy (Australian Government Department of the Environment and Energy 2009) and (2) waste data generated by intermediate sectors are published in the Waste Account, Australia, Experimental Estimates, 2013 (ABS 2013a).

The Australian waste account in the National Waste Report was first published in 2010 to provide a one-stop shop for key national waste and recycling information in Australia. It shows the amount of total waste generated per capita over the period 2006–07 to 2010–11 generated by each jurisdiction in Australia and treated by the three waste treatment methods of disposal, recycling, and energy recovery (Australian Government Department of the Environment and Energy 2013). The Waste Account, Australia, Experimental Estimates, 2013 was produced on the basis of an environmental-economic accounting framework, which is a subset of accounting aimed at incorporating both economic and environmental information (ABS 2017). The Waste Account is part of a set of integrated environmental-economic accounts currently being published by the ABS that uses the System of Environmental and Economic Accounts (SEEA) adopted by the UN Statistical Commission in 2012 to provide a range of metrics on the economy and the environment (UN et al. 2014). The Waste Account is composed of a series of tables displaying information on the monetary and physical flow of waste generated by intermediate sectors, the Household sector, and the Imports sector and treated by the Landfill sector, the Recovery sector, and the Exports sector over the period 2009–10 to 2010–11 (ABS 2017). Two major advantages of the Waste Account, Australia, Experimental Estimates, 2013 are shown: (1) It can be cooperated with the Australian input-output table in 2009–10 (ABS 2013b) to build a uniform framework for monetary and physical flow in the Australian economic system and (2) It marks an important milestone to bring international comparability of environmental statistics between Australia and other countries. Hence, the present paper will examine the direct and indirect waste generation and treatment in Australia caused by effects of the Household sector based on the data from the Waste Account, Australia, Experimental Estimates, 2013.

This article presents a new scheme called CWSU model that extends the WSU model to take account of effects of the Household sector as an industrial sector on waste generation and treatment in a national scale. The CWSUT incorporates the column of the Household sector and the row of the Household income to the WSUT to analyze effects of the Household sector as an 'endogenous' factor. In addition, the Import sector and the Export sector are considered as a column and a row treating the waste to balance the waste flow, respectively. The Section 'Results' presents a case study of Australian CWSU table to direct and total effects for each of industrial sectors and waste treatment sectors as well as mixed waste flows of the Household sector in the Australian economy.

2. Methods and materials

In this section, the novel framework of the CWSU model is first presented based on the formulation of Lenzen and Reynolds (2014). Following this, the sources of the Australian economic and waste data for the application of the CWSU model are introduced.

2.1 Methods

In this section, the CWSUT is shown according to the formulation of Lenzen and Reynolds (2014) to include the column of the Household sector and a row of the Income. The reason for adding the column and row to the table is that the Household sector is considered as one of the most important endogenous components of the national economic system and waste generation because households generated the second largest amount of waste from 1995 to 2010 (ABS 2013a). In addition, the Import sector and the Export sector are considered as a column and a row treating the waste, respectively, because the amount of waste caused by the Import sector and the Export sector are not omitted according to the Australian waste accounts (ABS 2013a). Table 1 shows the framework of the CWSUT model.

A sample CWSUT is shown in Table 1 that contains additional rows and columns, e.g. the columns for the Household sector and the Import sector as well as the rows of Income and the Export sector. We adopt the notation described in (Lenzen and Reynolds 2014, Fry, Lenzen et al. 2015). The individual CWSUT elements shown in Table 1 can be interpreted in the following way:

Intermediate sectors:

T_{11}: transactions between N_1 intermediate sectors ($);

T_{12}: inputs from N_1 intermediate sectors to the Household ($);

T_{21}: income of N_1 intermediate sectors ($);

Waste treatment sectors:

T_{13}: transactions between N_1 intermediate sectors and N_2 waste treatment sectors ($);

T_{23}: income of N_2 waste treatment sectors ($);

Waste generation:

W_{51}: the amount of N_3 types of waste generated by intermediate sectors (tonnes);

W_{52}: the amount of N_3 types of waste generated by household (tonnes);

W_{53}: the amount of N_3 types of waste generated by waste treatment sectors (tonnes);

W_{54} : the amount of N_3 types of imported waste (tonnes);

Waste treatment:

W_{35} : the amount of N_3 types of waste treated by waste treatment sectors (tonnes);

W_{45} : the amount of N_3 types of exported waste (tonnes);

Final demand:

f: the final demand matrix ($);

W_f: the amount of N_3 types of waste generated by final demand (tonnes);

The gross output:

x_1: total output of the economic system ($);

x_2: total output of income ($);

x_3: total waste treated by waste treatment sectors (tonnes);

x_4: exported waste (tonnes);

x_5: total waste generated by intermediate sectors, waste treatment sectors, the Households sector, the Import sector and Final demand (tonnes).

The total waste generated by intermediate sectors, waste treatment sectors, the Household sector, the Import sector, and Final demand equals that treated by waste treatment sectors and the Export sector.

The CWSUT in balanced form is written as:

$$\begin{pmatrix} T_{11} & T_{12} & T_{13} & 0 & 0 \\ T_{21} & 0 & T_{23} & 0 & 0 \\ 0 & 0 & 0 & 0 & W_{35} \\ 0 & 0 & 0 & 0 & W_{45} \\ W_{51} & W_{52} & W_{53} & W_{54} & 0 \end{pmatrix} + \begin{pmatrix} f \\ 0 \\ 0 \\ 0 \\ W_f \end{pmatrix} = \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{pmatrix} \tag{1}$$

The coefficient matrices based on Eq. (1) is given by

$$\begin{pmatrix} A_{11} & A_{12} & A_{13} & 0 & 0 \\ A_{21} & 0 & A_{23} & 0 & 0 \\ 0 & 0 & 0 & 0 & G_{35} \\ 0 & 0 & 0 & 0 & G_{45} \\ G_{51} & G_{52} & G_{53} & G_{54} & 0 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{pmatrix} + \begin{pmatrix} f \\ 0 \\ 0 \\ 0 \\ W_f \end{pmatrix} = \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{pmatrix} \tag{2}$$

Here I define the coefficients matrices $A_{11} = T_{11}\hat{x}_1{}^{-1}\left(\frac{\$}{\$}\right)$, $A_{12} = T_{12}\hat{x}_2{}^{-1}\left(\frac{\$}{\$}\right)$,

$A_{13} = T_{13}\hat{x}_3{}^{-1}\left(\frac{\$}{t}\right)$, $A_{21} = T_{21}\hat{x}_1{}^{-1}\left(\frac{\$}{\$}\right)$, $A_{23} = T_{23}\hat{x}_3{}^{-1}\left(\frac{\$}{t}\right)$, $G_{51} = W_{51}\hat{x}_1{}^{-1}\left(\frac{t}{\$}\right)$, $G_{52} = W_{52}\hat{x}_2{}^{-1}\left(\frac{t}{\$}\right)$, $G_{53} = W_{53}\hat{x}_3{}^{-1}\left(\frac{t}{t}\right)$, $G_{54} = W_{54}\hat{x}_4{}^{-1}\left(\frac{t}{t}\right)$, $G_{35} = \mathrm{W}_{35}\hat{x}_5{}^{-1}\left(\frac{t}{t}\right)$, and $G_{45} = W_{45}\hat{x}_5{}^{-1}\left(\frac{t}{t}\right)$, where the "hat" over a vector x denotes a diagonal matrix with the elements of the vector along the main diagonal. . For instance, if $X = \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix}$ then $(\hat{X}) = \begin{matrix} x_1 & 0 & 0 \\ 0 & x_2 & 0 \\ 0 & 0 & x_3 \end{matrix}$.

The unit of \$/\$ indicates how much money is input to satisfy each dollar of output for the intermediate sector from other intermediate sectors. The unit of \$ /t indicates how much money is input to waste treatment sectors to dispose one tonne of waste. The unit of t/\$ indicates how much waste is generated per dollar of output for the intermediate sector. The unit of t/t indicates how much waste is generated in disposing of one tonne of waste in waste treatment sectors. The Leontief inverse of the CWSUT is formulated as follows:

$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{pmatrix} = \begin{pmatrix} I - A_{11} & -A_{12} & -A_{13} & 0 & 0 \\ -A_{21} & I & -A_{23} & 0 & 0 \\ 0 & 0 & I & 0 & -G_{35} \\ 0 & 0 & 0 & I & -G_{45} \\ -G_{51} & -G_{52} & -G_{53} & -G_{54} & I \end{pmatrix}^{-1} \begin{pmatrix} f \\ 0 \\ 0 \\ 0 \\ W_f \end{pmatrix} \qquad (3)$$

Note that in the CWSUT model, even though the Household is an endogenous sector we understand that economic activities are still induced by the Household sector. As Miller and Blair (2009) state when discussing closed IOTs: households earn incomes (at least in part) in payment for their labour inputs to production processes, and, as consumers, they spend their income in rather well patterned ways. And in particular, a change in the amount of labour needed for production in one or more sectors – say an increase in labour inputs due to increased output – will lead to a change (here an increase) in the amounts spent by households as a group for consumption. Although households tend to purchase goods for "final" consumption, the amount of their purchases (consumption) is related to their income, which depends on the outputs of each of the sectors. It means that the Household consumption is induced by its income.

2.2 Data sources and processing

Australian waste accounts in 2009–10 from 12 waste categories[1] are sourced from the ABS database in 1000 tonnes (kt) describing the amount of waste generated by 7 intermediate sectors, the Household sector, and the Import[2] as well as treated by 2 waste treatment sectors and the Export sector (ABS 2013a). Therefore, the waste data of CWSUT blocks W_{51}, W_{52}, W_{53}, W_{54}, W_{35}, and W_{45}, originate from the Australian waste accounts. The elements of the matrix of Australian CWSUT block W_f are zeros. Because the Household sector and Export sector in the Final demand have connected with waste generation and treatment in Australian Environmental-Economic Accounts (ABS 2017). The Household sector has been considered as an endogenous factor. It means that the amount of 'W_f' is equal to 'W_{45}'. Therefore, when the model moves 'W_{45}' to the row of waste treatment, the amount of 'W_f' are zeros.

Data of intermediate transactions for the Australian CWSUT blocks T_{11}, T_{12}, T_{13}, f, and x_1 in 2009–10 have been aggregated by He, Reynolds et al. (2017) while T_{21} and x_2 have been aggregated from Australian input-output table of 2009–10 (ABS 2013b).

3. Results

[1] Paper and cardboard = Pap & C; Glass = Gl; Plastics = Pl; Metals = Me; Organics = Org; Masonry = Mas; Electrical and electronic waste = EE; Solid hazardous waste = SH; Leather and textiles = L & T; Tyres and other rubber = T & OR; Timber and wood products = T & Wood; Inseparable/unknown waste = I/U.

[2] Agriculture, forestry, and fishing = Ag; Mining = Mi; Manufacturing = Ma; Electricity, gas, and water = EGW; Waste management services = WMS; Construction = Co; Public administration = Pa; All other industry = AOI; Final demand = FD.

3.1 An example of Australian aggregated CWSU table

An overview of the results of the Australian aggregated CWSU model analyzed in 2009–10 are present in Tables 2, 3, and 4. Table 2 displays the monetary and waste flows of Australia as a 23 × 23 table, in which rows and columns of the table both include 7 aggregated intermediate sectors, the Income sector, 2 waste treatment sectors, the Export sector, and 12 waste types.

Tables 3 and 4 display the aggregated coefficient matrix and total waste generation multipliers, respectively, that have been calculated from the Australian CWSUT in 2009–10 presented in Table 2. Table 3 is calculated by utilizing Eq. (2) and Table 4 is calculated by utilizing Eq. (3). Caution should be taken when reading Tables 3 and 4 because there are multiple scales presented in the one table (million $AUD per million $AUD, million $AUD per 1000 tonnes, tonnes per 1000 tonnes, and tonnes per million $AUD).

3.2 Analysis of direct, indirect, and total waste generation effects

The definitions of direct, indirect, and total waste generation effects have been introduced by Reynolds, Piantadosi et al. (2014). To be specific, the definitions of direct and indirect waste generation effects are the waste that was produced directly and indirectly in the associated sector due to economic activity within that sector. The total waste generation effects is the total waste effect of a change in an industrial activity by accounting Final demand and non-Final demand deliveries (Szyrmer 1992).

We analyze total waste generation in direct, indirect, and total effects for intermediate sectors and the Household sector (Figure. 1). The Construction sector had the highest direct, indirect, and total waste generation effects in 2009–10. It illustrates that the Construction sector generated the most amount of waste for the same monetary value of outputs of any of the intermediate sectors in the Australian economy. Australian waste policies should pay more attention to the Construction sector, and waste levy fee for disposing the construction waste should increase to lessen environmental pressure caused by the Construction sector. The Mining sector has the lowest percentage of direct waste generation effects (1%), but its indirect waste generation effects (14%) is just lower than those in the Construction sector (15%) and the Agriculture, forestry, and fishing sector (15%). It indicates that most of waste the Mining sector are generated in its supply chain. A comparative analysis between direct and indirect effects reveals that the amount of indirect waste generation from each intermediate sector is greater than that from direct waste generation in Figure. 1.

This research mainly analysed the top two types of waste generation effects generated in intermediate sectors and the Household sector in Table 5. The most direct and total effects of waste generation effects belonging to masonry waste from the Construct sector are 43.7034 and 67.9564 tonnes per million $AUD of output in all sectors, respectively. Although the direct and total effects of waste generation effects for organic waste from the Agriculture, forestry, and fishing sector are lower than that masonry waste from the Construct sector, the indirect effect of the former is higher than the latter.

This paper only analyzes the data of waste treated by the Landfill and Recovery sectors because the research focused on Australian domestic waste generation and treatment. The function of the Export sector and the Import sector in the CWSUT is to balance the waste flow. Table 6 shows direct, indirect, and total effects of the Landfill and Recovery sectors. All three categories of effects for the Landfill sector are greater than that for the Recovery sector, which indicates that the environmental pressure caused by the Landfill sector is greater than that by the Recovery sector. The direct, indirect, and total economic costs in the Landfill and Recovery sectors for disposing per kt of waste are analyzed in Table 7. The economic costs, including the cost of labor, of all categories of effects for the Landfill sector are more than that in the Recovery sector. The result implies there is space to lower the economic costs of treating waste by transferring more waste from the Landfill sector to the Recycling sector. In addition, data in Table 7 can be considered as a reference of the amount of waste levy fee in Australia.

3.3 Mixed flows of the Household sector in the Australian CWSUT model

To display the power of the CWSU model for analysis the effects of the Household sector as an endogenous sector on waste generation and treatment, the research investigated the direct and total inputs from intermediate sectors, types of waste generated by the Household sector, and types of waste treatment to reveal the detailed information shown in Figures. 2 and 3.

Figure. 2 shows that each million $AUD output of the Household sector directly requires 1.08 million $AUD inputs from all intermediate sectors. The Household sector is a consuming sector compared with other intermediate sectors. The All other industry sector contributes the most amount of direct monetary flows for the output of the Household sector. Waste directly generated by the Household sector accounts for 22.73 tonnes per million $AUD of the Household sector's output. Of this, the largest components were organics waste (10.7714 tonnes) and Paper and cardboard waste (5.2387 tonnes).

Figure. 3 shows the total waste generation multipliers of the Australian CWSUT in 2009–10 for the Household sector. The Income sector contributes the second largest amount of money flow for the total output of the Household sector. The total amount of waste generated by the Household sector was 81.40 tonnes compared to the amount of waste directly generated by the Household sector (22.73 tonnes) in Figure. 2. The Landfill sector is the most significant method for waste treatment, disposing just above 50% of household waste.

4. Discussion

In this study we constructed a CWSUT model by considering the Household sector as an "endogenous" factor to the economic system. The aim of the model was to analyse the economic system and waste flow affected by the endogenous factor in detail. An application of the CWSUT in Australia was given to connect Australian economic and waste accounts to illustrate the feasibility and effectiveness of the model. The results of the paper show a series of features of the Australian CWSUT. First, the Construction sector in Australia generated the largest direct, indirect, and total waste effects in 2009–10. Similar results have been found by Reynolds, Piantadosi et al. (2014) observing that the Service (notably construction) industry generated the largest direct and total waste effects in 2008 and Fry, Lenzen et al. (2015) showed the Construction sector produced the largest amount of waste in 2011–2012. Second, the indirect waste generation effects of the intermediate sectors are greater than the direct waste generation effects of that group. This indicates that waste management strategies (Reuse, Recycling, and Reduce) should focus on the supply chain rather than the production process of goods and services. This result has been discussed by many researchers to minimise waste generation in the Green Supply Chain (Hervani, Helms et al. 2005, Diabat and Govindan 2011). Third, masonry waste from the Construction sector has the most direct and total effects of waste generation, however, organic waste from the Agriculture, forestry, and fishing has the highest indirect effect of waste generation. It means that Australian government should apply more technologies and publish more environmental policies on how to management these two types of waste. Fourth, the Landfill sector generated more waste and cost more money for disposing per 1000 tonnes than the Recovery sector in 2009–10. Although the W_{35} section of Table 2 indicates the Landfill sector is the dominant treatment method, treating 25864.66kt in 2009–10, the method of landfilling waste could not be encouraged in the Australian waste management system due to the environmental pressure and higher economic costs. More than 50% of waste generated in the Household sector has been treated by the Landfill sector. These results quantitatively confirm that the combination of techniques, technologies, and waste management policies is necessary to lessen the pressure of biosphere space. Moreover, the direct cost of the Landfill sector in this study is AUD $34.14 per tonne in 2009–10 and the total cost of the Landfill sector is AUD $155.26 per tonne. It is an average value of Australian waste levy fee, which offers information for the publication of waste levy fee. The highest waste levy fee for Metropolitan Levy Area in Australian has increased from AUD $58.80 per tonne in 2009–10 to AUD$138.20 per tonne in 2017–18 in NSW (The NEW Environmental Protection Authority 2017). The growth of the waste levy fee indicates that the government has realized the potential environmental and economic costs during the process of waste treatment. It also means that the growth of the waste levy fee is not only corresponding to the Consumer Price Index (The NEW Environmental Protection Authority 2017), but also includes the indirect cost for waste treatment and the cost of labor.

Our results that imply there is space to lower the economic costs of treating waste by transferring more waste from the Landfill sector to the Recycling sector – in essence increasing the economy of scale. However, the feasibility of greater uptake of recycling needs to be carefully considered for each type of waste and recycling method. Our current CWSUT model does not allow us to identify the exact tonnages diverted to each waste treatment method, by each sector. Instead our model supplies an economy wide level of recycling and landfill. Future research and modelling needs to be undertaken in order to consider which waste types generated by each particular industry are currently landfilled, and can be more effectively treated by the recycling sector with the greatest ease.

As for the analysis of mix waste flows of the Household sector, the total effects of the Income sector on waste generate is an important factor for household waste generation. It links the income with waste generation from the view of macroeconomics. The organic waste is the major component of household waste, which is similar to the result that the largest component of HW is food organics (Fry, Lenzen et al. 2015). And more than 50% of HW is treated by the Landfill sector. These results quantitatively confirm that the combination of techniques, technologies, and waste management policies is necessary to lessen the pressure of biosphere space. And the information regarding more waste indirectly generated by the Household sector than directly generated by the Household sector indicates that Australian waste policies should focus more on the supply chain of goods and services consumed by household consumption rather than only on-site waste generation.

It should be noted in our example CWSUT that the economic activities of the household sector are not directly linked with the waste generation in the analyzed year as there is a time gap between 1) the economic activity (the consumption of products, the generation of waste, and the treatment of waste; and 2) the waste data and the IOT/economic data. This type of time gap of waste generation has been dealt with the construction of time-series closed waste supply-use tables. Time-series CWSUTs can conduct a comparative analysis about the relationships between waste generation and treatment in a designated period, which can diminish the negative effects of time gap. There is a further discussion about this question by He, Reynolds et al. (2017).

5. Conclusion

Assessment of the effects of the Household sector on the economic system and waste generation are essential to deliver effective information for waste management planning. The purpose of this research was to develop a novel methodology and apply it in Australia to analyse the effects. There were three steps in the process: 1) extension of the WSUT to develop the CWSU model; 2) the novel model was applied to build the Australian CWSUT in 2009–2010 to analyse the direct, indirect, and total waste generation effects for intermediate sectors as well as the economic costs of waste treatment sectors; and 3) the mixture of flows of the Household sector display the monetary flows from intermediate sectors to the Household sector and the physical flow regarding HW generation and treatment. The CWSU model for the analysis of effects of the Household sector as an endogenous factor is novel to waste IO analysis and a major step towards exploring HW generation and treatment in the national economic system. In addition, the CWSU model can also been applied to analyse the effect of the Household sector as an ‘endogenous’ factor on other environmental issues, such as greenhouse gas emissions and energy consumption.

Two main limitations to the CWSU model need to be acknowledged. First, the model does not provide the dynamic analysis regarding how the change of income affects HW generation and treatment. This major limitation indicates an interesting future research direction whereby research on time-series Australian CWSUT models would provide more details for how the development of Australian income impacts on waste generation and treatment. Second, the model only considers the Household sector as an endogenous factor for waste generation and treatment. The differences of the effects of the Household sector as an endogenous factor (Closed WSUT) or an exogenous factor (Open WSUT) on waste generation and treatment should also be analysed. A comparative analysis of the Closed and Open Australian WSUTs will explore these differences.

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