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Quantification of indirect waste generation and treatment arising from Australian household consumption: a waste input-output analysis

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Abstract

Waste input-output (WIO) model is a suitable method to explore the nexus between economic activities and waste management. Contemporary research that typically explores this nexus follows two main aspects: either they consider Final demand as a whole, or they identify the nexus between households, with different types of socio-demographic indicators and household waste generation. However, it is complex to apply the WIO model from the perspective of household consumption— a major component of Final demand — because of a lack of economic and environmental data related to household consumption. This paper proposes a new perspective, applying the WIO model to assess the nexus between different patterns of household consumption and indirect waste generation and treatment. This novelty is to combine macro- and micro- economic and environmental data related to Australian industrial sectors, different patterns of household consumption (Mosaic data), and direct waste generation into the WIO model for exploring this nexus in two scenarios. Results indicate that the total amount of indirect waste generation caused by B05 (couples without children who spend the majority of their time at the office) are 99.24 kg more than that of D16 (couples without children who are retired and stay at home) for scenario I. The correlation coefficients for differences of output of economy and indirect waste generation between B05 and D16 are 0.9796 and 0.9773 in scenarios I and II, respectively. Sensitivity analysis indicates the change of the amount of direct waste generation in a reasonable range cannot dramatically affect the major economic activities and waste generation. This research suggests a different perspective of household consumption to estimate indirect waste generation through a WIO model to provide more reliable information for waste management in the supply chain.

Keywords: waste input-output, household consumption, Australian economy, waste footprint

1. Introduction

Humans consume an increasing variety of goods and services produced by industrial sectors, which cause direct and indirect waste generation. Humans are the principal factor for driving production, consumption, and subsequently, the resulting waste generation (Karak et al. 2012). Direct waste generation of household consumption refers to the waste generated from household members at home (Ponis et al. 2017). Indirect waste generation in this research indicates that the waste generated in the supply chain of the economic system caused by household consumption. With the sharp growth of population, the amount of waste generation is forecasted to increase by about 70% globally in 2050 (The World Bank 2018).

Developed countries, such as United States, United Kingdom (UK), and Australia generate more waste per capita per day than developing countries (such as Bangladesh, Vietnam, and Malaysia) (Mmereki et al. 2016). For example, the average amount of waste per capita per day in Australia (7.40 kilograms) (Department of the Environmental and Energy 2017) is about 10 times more than that the global average (0.74 kilograms) (The World Bank 2018) in 2016. The amount of Australian waste generation is forecasted to increase by approximately 60% by 2050 (Big Australia 2018). Developed countries have higher rates of recycling than developing countries. For instance, 60% waste generated in Australia was recycled in 2014–15 (Department of the Environmental and Energy 2017) while only 22% of the total waste generated in Malaysia have been estimated to be recycled (Moh et al. 2014). There are considerable variations and complexities in waste generation due to different patterns of household consumption, the industrialized degree of countries, and the ability of treating waste.

One of the major global waste reduction goals is Sustainable Development Goal (SDG) 12, which seeks to substantially reduce waste generation through prevention, reduction, recycling and reuse (SDG 12.5), and halves per capita global food waste at the retail and consumer levels (SDG 12.3) by 2030 (United Nations Statistics Division 2018). In order to achieve SDG 12, substantially reducing waste generation, and comprehending the complexity of waste management, there must be a systematic analysis of how waste generation and treatment interact with human consumption within an economic system on two fronts. First, how different patterns of human consumption activities affect waste generation and treatment should be analysed. Second, the nexus between the economy and waste generation must be assessed.

Studies regarding how/where waste is generated in the supply chain, and how waste is treated by different waste treatment methods have been proliferated. One popular research framework for displaying and analysing the complexity of waste production and treatment has been input-output (IO) modelling: a type of quantitative macroeconomic accounting that represents the interdependencies between different branches of a national economy or different regional economies. A short summary of IO modelling and waste follows: Joosten et al. (2000) used national supply–use tables to explore the nexus between plastic products and intermediate sectors in the Netherlands in 1990. Kagawa et al. (2004) delivered a simple multiregional IO model for waste analysis to estimate intraregional and interregional effects of industrial wastes caused by regional final consumptions. They have provided the analysis for the nexus between economic activities and waste management, but failed to account for detail analysis for patterns of consumptions and waste types. Nakamura and Kondo (2002) have linked waste types with treatment methods via the development of the waste input-output (WIO) model, which allows different types of waste treatment methods to “treat” or “dispose” of multiple types of waste. The WIO model has been developed further into a waste supply-use tables (WSUTs) that allows this complexity of treatment and waste flow to be seen in a single table (Lenzen and Reynolds 2014). The WSUT framework was used to demonstrate how Australian waste generation is affected by the intermediate sectors and waste treatment sectors (Reynolds et al. 2014). Based on the WSUTs, a multi-regional WSUT was developed to analyse the indicators of waste generation, such as the waste footprint and sectoral waste production intensity (Fry et al. 2015). Salemdeeb et al. (2016) developed the first version of the UK WIO model table to analyse direct and indirect waste arising across the supply chain. He et al. (2017) compiled an Australian WIO table based on data from the Australian Bureau of Statistics (ABS). In terms of WIO model, the nexus between the economic system and waste management has been analysed to offer effective information (e.g. waste footprint and sectoral waste production intensity) for environmental policy-makers. Alabi et al. (2017) applied IO multiplier methods to develop an understanding of demand drivers of phyiscal waste. Zeller et al. (2018) developed regional waste supply and use tables in terms of regional waste statistics and national input-output tables. These were used to quantify waste generation from households. Nakamura et al. (2018) extended function of the WIO model from a static model to a dynamic model, which covers the issue of quality in recycling that involves mixing, dissipation, and contamination. He et al. (2018) investigated the effect of the Household sector as an ‘endogenous’ factor on waste generation and treatment based on the environmentally-extend input-output model. Liao et al. (2015) have analysed the effect of household consumption on waste generation. Ruiz-Peñalver et al. (2019) have estimated total waste generation throughout the supply chain in Spain. These studies adjusted the basic structre of IO table to explore the nexus between economic activies and waste generation and treatment based on the Final demand (Final demand being made up of consumption by households and government as well as capital formaton, inventory and exports). However, there remains a lack of detailed analysis on 1) the effect of changing components within Final demand (ie household consumption), or 2) the socio-demogaphic sub-population effects of consumption on waste generation. Therefore, it is necessary to conduct detailed analysis from the perspective of different socio-demogaphic sub-population types to identify what effects the different patterns of consumption have on waste generation and treatment in the economic system.

Consumption is the major driver for waste generation (Wilson 2007). Consumption can be disaggregated into different types via different socio-demographic characteristics, such as income, education, and household size. Some studies explored the nexus between household consumption and waste generation (see (Parfitt et al., 2010, Song et al., 2015)), or waste composition (see (Daskalopoulos et al., 1998, Edjabou et al., 2015)). How different demographic indicators of consumption, such as income (Johnstone and Labonne 2004, Bandara et al., 2007, Aparcana 2017), household size (Dennison et al., 1996, Triguero et al., 2016), and education (Barr 2007, Benítez et al., 2008, Han et al., 2018) affected waste generation has been illustrated. Although the above-mentioned studies analyse the direct effect of the household consumption on waste generation, little attention has previously been paid to the effect of household consumption on indirect waste generation and treatment in the economy. The analysis of indirect waste generation in the supply chain can give a description of how human consumption patterns affect waste generation and treatment, which benefits decision-making for waste management. This lack of publications in this area is mainly due to the limitation of supply chain level waste data – rather than any conceptual or mathematical restriction. In addition, it is difficut to compare the results of how the different patterns of household consumption affect indirect waste generation and treatment across the regions and time frames because of inconsistencies of the scope and the substantial gaps in the available information (Thyberg et al., 2015, Reutter et al., 2017).

This paper aims at filling this knowledg gap through providing a novel perspective and case study to analyse the effects of different patterns of household consumption on the indirect waste generation and treatment in Australia, along with two novel variants to overcome limitations shown in the literature: (i) a version of Mosaic data discribing the information of different patterns of consumption categorised by different socio-demographic data for the household; and (ii) on-site collected data for household waste generation and treatment corresponding to different patterns of consumption to refine and compile the WIO table. This linking of Mosaic data and on-site waste collection data to a WIO table is a novel and new contribution to the literature.

The paper is structured as follows: the Method section gives information on the method of WIO model, data sources, sensitivity analysis, and the design of different scenarios. The Results section shows the effects of different patterns of household consumption on indirect waste generation and treatment and the comparative analysis between different scenarios with the sensitivity analysis. The Discussion section indicates the major findings based on different patterns of household consumption and scenarios with the discussed sensitivity analysis. The Conclusions section displays the novelty of the research, the advantages and disadvantages of the comparative analysis, and future research.

2. Method

2.1 Method of the WIO model

The basic method and notation of the WIO model was introduced in Nakamura and Kondo (2002). The WIO model in balanced form from He et al. (2017) is written as

$$\begin{pmatrix} \mathrm{K}_{\mathrm{I,I}} & \mathrm{K}_{\mathrm{I,II}} \\ \mathrm{PG}_{\cdot,\mathrm{I}} & \mathrm{PG}_{\cdot,\mathrm{II}} \end{pmatrix} + \begin{pmatrix} \mathrm{X}_{\mathrm{I,F}} \\ \mathrm{PW}_{\cdot,\mathrm{F}} \end{pmatrix} = \begin{pmatrix} \mathrm{x}_{\mathrm{I}} \\ \mathrm{x}_{\mathrm{II}} \end{pmatrix} \qquad (1)$$

where $\mathrm{K}_{\mathrm{I,I}} \in \mathrm{R}^{\mathrm{N}^{\mathrm{I}} \times \mathrm{N}^{\mathrm{I}}}$ represents intermediate sectors' matrix for N^{I} goods and service-producing sectors, the components of $\mathrm{K}_{\mathrm{I,II}} \in \mathrm{R}^{\mathrm{N}^{\mathrm{I}} \times \mathrm{N}^{\mathrm{II}}}$ mean the monetary inputs from per intermediate industry into N^{II} waste treatment sectors, P is an $\mathrm{N}^{\mathrm{II}} \times \mathrm{N}^{\mathrm{w}}$ nonnegative matrix for N^{w} waste types, and the p_{ij} in the matrix represents the proportion of waste j treated by waste treatment method i, $\mathrm{G}_{\cdot,\mathrm{I}}$is defined as an $\mathrm{N}^{\mathrm{w}} \times \mathrm{N}^{\mathrm{I}}$ matrix for the category of waste generated by intermediate sectors, $\mathrm{G}_{\cdot,\mathrm{II}}$ represents an $\mathrm{N}^{\mathrm{w}} \times \mathrm{N}^{\mathrm{II}}$ matrix that the waste is generated by N^{II} waste treatment sectors. A Final demand matrix for N^{I} goods and service-producing sectors is defined as $\mathrm{X}_{\mathrm{I,F}}$ for N^{F} sectors, and $\mathrm{W}_{\cdot,\mathrm{F}}$ is the waste generated by Final demand. $\mathrm{x}_{\mathrm{I}} \in \mathrm{R}^{\mathrm{N}^{\mathrm{I}} \times 1}$ refers to a gross output vector for N^{I} goods and service-producing sectors, and $\mathrm{x}_{\mathrm{II}} \in \mathrm{R}^{\mathrm{N}^{\mathrm{II}} \times 1}$ presents the total amount of waste to be treated by N^{II} waste treatment sectors.

The coefficient matrix of WIO model can be expressed

$$\begin{pmatrix} \mathrm{A_{I,I}} & \mathrm{A_{I,II}} \\ \mathrm{B_{I,I}} & \mathrm{B_{II,II}} \end{pmatrix} \begin{pmatrix} \mathrm{x_{I}} \\ \mathrm{x_{II}} \end{pmatrix} + \begin{pmatrix} \mathrm{X_{I,F}} \\ \mathrm{PW_{\cdot,F}} \end{pmatrix} = \begin{pmatrix} \mathrm{x_{I}} \\ \mathrm{x_{II}} \end{pmatrix} \tag{2}$$

where the research defines input coefficients matrices $\mathrm{A_{I,I}} = \mathrm{K_{I,I}}\hat{\mathrm{x}}_{\mathrm{I}}^{-1}$ (million $AUD/million $AUD), $\mathrm{A_{I,II}} = \mathrm{K_{I,II}}\hat{\mathrm{x}}_{\mathrm{II}}^{-1}$ (million $AUD/ tonne), $\mathrm{B_{I,I}} = \mathrm{PG_{\cdot,I}}\hat{\mathrm{x}}_{\mathrm{I}}^{-1}$ (tonne/million $AUD), and $\mathrm{B_{II,II}} = \mathrm{PG_{\cdot,II}}\hat{\mathrm{x}}_{\mathrm{II}}^{-1}$ (tonne/tonne), where the “hat” over a vector x denotes a diagonal matrix with the elements of the vector along the main diagonal. For instance, if $\mathrm{x} = \begin{bmatrix} \mathrm{x_1} \\ \mathrm{x_2} \\ \mathrm{x_3} \end{bmatrix}$, then $\hat{\mathrm{x}} = \begin{matrix} \mathrm{x_1} & 0 & 0 \\ 0 & \mathrm{x_2} & 0 \\ 0 & 0 & \mathrm{x_3} \end{matrix}$.

The solution of Equation (2) is given by

$$\begin{pmatrix} \mathrm{x_{I}} \\ \mathrm{x_{II}} \end{pmatrix} = \left(\mathrm{I} - \begin{pmatrix} \mathrm{A_{I,I}} & \mathrm{A_{I,II}} \\ \mathrm{B_{I,I}} & \mathrm{B_{II,II}} \end{pmatrix} \right)^{-1} \begin{pmatrix} \mathrm{X_{I,F}} \\ \mathrm{PW_{\cdot,F}} \end{pmatrix} \tag{3}$$

The research considers household consumption (HC) as the Final demand ($\mathrm{X_{I,F}}$ (million $AUD)) in the WIO model. Data collection and aggregation of household consumption and its direct waste generation and treatment $\begin{pmatrix} \mathrm{X_{I,F}} \\ \mathrm{PW_{\cdot,F}} \end{pmatrix}$ will be discussed in Section 2.2. Then, the total output will be calculated in terms of Equation (3). Finally, the input matrix by industrial sectors of the WIO model $\begin{pmatrix} \mathrm{K_{I,I}} & \mathrm{K_{I,II}} \\ \mathrm{PG_{\cdot,I}} & \mathrm{PG_{\cdot,II}} \end{pmatrix}$ can be obtained from Equation (4). The process of calculation is written as:

$$\begin{pmatrix} \mathrm{K_{I,I}} & \mathrm{K_{I,II}} \\ \mathrm{PG_{\cdot,I}} & \mathrm{PG_{\cdot,II}} \end{pmatrix} = \begin{pmatrix} \mathrm{A_{I,I}} & \mathrm{A_{I,II}} \\ \mathrm{B_{I,I}} & \mathrm{B_{II,II}} \end{pmatrix} \hat{\mathrm{x}}^{-1} \tag{4}$$

2.2 Data sources

The Australian WIO tables in 2009–2010 and 2010–11 can be obtained in the research of He et al. (2017), which are illustrated in Tables A.1 and A. 2, available in the supplementary file. To summarise, the model is a 1 region, 8 intermediate sector model, that is based on domestic technology consumption. This section describes the data collection regarding household consumption ($\mathrm{X_{I,F}}$) and direct waste generation by household consumption ($\mathrm{PW_{\cdot,F}}$). Two types of data source were employed for obtaining $\mathrm{X_{I,F}}$ and $\mathrm{PW_{\cdot,F}}$:

(a) The household consumption ($\mathrm{X_{I,F}}$) were derived from the Mosaic Index of Mosaic data (Nicholas 2016). Australian households are categorised into 13 Mosaic Groups and 49 Mosaic Types according to a series of socio-demographic variables, such as annual income, education, and employment status. The Mosaic data contains information about weekly household consumption on goods and services (e.g. Fish and seafood and Bedroom furniture repair) for different Mosaic groups and Mosaic types. Each Mosaic Group includes three, four, or five Mosaic Types. These Mosaic Types are defined by the Grand index including 398 variables according to the three following categories: (1) Who We Are, (2) Where We Live, and (3) What We Do (Nicholas 2016). D16 refers to couples without children who are retired and stay at home while B05 refers to couples without children who spend the majority of their time at the office. In Australia, these categories of Mosaic types D16 and B05 have accounted for an important proportion representing about 38% of all Australian families (ABS 2017) in the 2016 Census. There is a similar proportion for all Finnish households in 2009 with 28% for couples without children (Katajajuuri et al. 2014). The proportion of these two Mosaic categories are expected to grow to more than 40% of the Australian families by 2036 (ABS 2015).

(b) The amounts of waste generation ($\mathrm{PW}_{\cdot,\mathrm{F}}$) of different types of Australian households were collected from an on-site experiment in the Lochiel Park, which that has recently been completed with approximately 110 homes in the north-east of Adelaide (Land Management Corporation, South Australian Government 2008) and is a living laboratory of CRC Low Carbon Living. The process of collecting data regarding $\mathrm{PW}_{\cdot,\mathrm{F}}$ is described below. First, on-site survey about the amount of waste generated in eight households at Lochiel Park Green Village in South Australia has been conducted to collect data from households' waste bins (Ethics Approval, Application ID: 0000032810). In these eight households, seven of them belonged to D16 while one of them belonged to B05 of Mosaic types. The classifications of these eight households are based on the file of CRC Study Zone SA1 (Nicholas 2016). The research weighed these households' bins every week for a total of 14 times from December 2nd 2015 to March 2nd 2016 by using an instrument marked in standard units. The three bin Kerbside Waste Collection service at Lochiel Park indicates the function of the blue bin for general waste, the yellow bin for recyclables, and the green bin for green organics (Campbelltown City Council 2017). The municipal solid waste collected from these households' bins are considered as the direct waste generation, which excludes bulky waste, Waste Electrical and Electronic Equipment recycling waste, and construction waste. Corresponding to the waste treatment sectors (the Landfill sector and the Recovery sector (resource recovery)) in the Australian WIO table, the research considered that the amount of waste in the blue bin were treated by the Landfill sector and that in the yellow and green bins was treated by the Recovery sector. Due to data limitations, it is not possible to distinguish between energy recovery and material recovery (material recycling). The amounts of waste ($\mathrm{PW}_{.,\mathrm{F}}$) generated by D16 and B05 and treated by the Landfill sector and the Recovery sector are shown in Tables 1 and 2, respectively. The household consumption per week on 755 types of goods and services are shown in the sheet of DollarUnique of HES Mosaic Index (Nicholas 2016). These 755 types of goods and services were aggregated into 8 types of goods and services ($\mathrm{X}_{\mathrm{I,F}}$) corresponding to the number of intermediate sectors in the Australian WIO table, which are shown in Table 3. The data of $\mathrm{X}_{\mathrm{I,F}}$ and $\mathrm{PW}_{.,\mathrm{F}}$ were multiplied by 52 to obtain the annual household consumption and waste generation and treatment because the period of data of $\mathrm{X}_{\mathrm{I,F}}$ and $\mathrm{PW}_{.,\mathrm{F}}$ was weekly.

The exact composition of the waste was not recorded by the survey, only the bin destination (recycling or landfill). Though we do not have individual waste composition analysis, we provide supplemental data of South Australian and Adelaide population level municipal waste compositional analysis.

The source of the waste data the wider economy activities was sourced from He et al. (2017), which was based on the Australian Bureau of Statistics waste accounts (2009–2010 and 2010–2011), (ABS 2013, 2014). The scope of waste from economic activities that is covered by Paper & Cardboard, Glass, Plastics, Metals, Organics (e), Masonry, Electrical & Electronic, Solid Hazardous Waste, Leather & Textiles, Tyres & Other Rubber, Timber & Wood Products, and Inseparable/Unknown. These waste accounts were cross checked with the previous estimates of Reynolds et al (2015a). Both included estimates of household waste. these were used to validate the results of our fieldwork.

Table 1 The average amount of waste per week for D16 (couples without children who are retired and stay at home).

Address	Mosaic Type	The amount of waste landfilled (kg)	The amount of waste recycled (kg)
1	D16	2.97	7.63
2	D16	9.04	5.43
3	D16	6.06	18.39
4	D16	2.74	5.14
5	D16	5.92	8.54
6	D16	4.82	7.12
7	D16	8.01	7.71
Average	D16	5.77	8.60
Total (52 weeks)	D16	300.04	447.2

Table 2 The average amount of waste per week for B05 (couples without children who spend the majority of their time at the office).

Address	Mosaic Type	The amount of waste landfilled (kg)	The amount of waste recycled (kg)
8	B05	3.83	7.85
Total (52 weeks)	B05	199.16	408.20

Table 3 Aggregated household consumption per week on intermediate sectors.

Mosaic types	Ag	Mi	Ma	EGW	Co ($AUD)	Pa	AOI	WMS	Total
D16	59.21	0	533.61	91.23	0	18.43	674.01	0.54	1377.03
B05	54.65	0	533.49	79.85	0	23.93	807.48	0.74	1500.14

Note: 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.

2.3 Method of the sensitivity analysis

The sensitivity analysis is a technique of assessing how the uncertainty in the output of a model can be apportioned to different sources of uncertainty in the model input (Doubilet et al. 1985, Saltelli 2002, Hamby. 1994). Sensitivity analysis has been widely applied into IO model to identify the uncertainty of the model output. As one of the major methods for sensitivity analysis, Monte Carlo method has been used for the assessment of uncertainty relating to the level of aggregation (Bullard and Sebald 1988), total CO_2 emission intensities (Hondo et al. 2002), multi-regional IO model to convert currencies (Lenzen et al. 2010), impacts of the model on eco-efficiency assessment (Egilmez et al. 2016), and technical waste and primary input coefficients (Yazan et al. 2016). Sensitivity analysis has also applied to other environmental models. Clavreul et al. (2012) developed a general method with a sequence of four steps for quantitative uncertainty assessment of life cycle analysis (LCA) of waste management systems. Salemdeeb et al. (2017) applied the similar method to conduct sensitivity analysis for the parameter values in the hybrid LCA approach. Due to the limitations of household waste, this section conducts a sensitivity analysis to determine how the amount of household waste (HW) collected on-site impacts the major variables in the WIO tables under a given set of assumptions.

The first step is to generate a random sample of the amount of HW based on the sample which have been collected on-site. The research first calculated the mean and standard deviation of the amount of HW and then followed the method of Pollard (1979) to calculate the adjusted means and deviations using a truncated normal distribution using the iterative Equations 5, 6, 7, and 8. The truncated normal distribution is used as the amount of waste cannot be negative, and the authors have assumed the maximum amount of waste to be the largest amount of on-site HW. The suffix n denotes the nth approximation to the maximum likelihood estimate, the B and C are the maximum and minimum numbers of the collected sample, and the symbols ϕ and Φ refer to the ordinate and cumulative area of the unit normal curve, $\overline{\mathrm{X}}$ is the average of the collected data, S is the standard deviation of the collected data. We found that after 5 iterations, stable estimates of the population mean and standard deviation, μ_{n} and σ_{n} , were reached:

$$\alpha_{\mathrm{n}} = (\mathrm{B} - \mu_{\mathrm{n}})/\sigma_{\mathrm{n}} \quad (5)$$

$$\beta_{\mathrm{n}} = (\mathrm{C} - \mu_{\mathrm{n}})/\sigma_{\mathrm{n}} \quad (6)$$

$$\mu_{\mathrm{n+1}} = \overline{\mathrm{X}} + \sigma_{\mathrm{n}}(\phi(\beta_{\mathrm{n}}) - \phi(\alpha_{\mathrm{n}}))/(\Phi(\beta_{\mathrm{n}}) - \Phi(\alpha_{\mathrm{n}})) \quad (7)$$

$$\sigma^2_{\mathrm{n+1}} = \mathrm{S}^2 + (\overline{\mathrm{X}} - \mu_{\mathrm{n+1}}) + \sigma^2_{\mathrm{n}}(\beta_{\mathrm{n}}\phi(\beta_{\mathrm{n}}) - \alpha_{\mathrm{n}}\phi(\alpha_{\mathrm{n}}))/(\Phi(\beta_{\mathrm{n}}) - \Phi(\alpha_{\mathrm{n}})) \quad (8)$$

The second step is to apply the stable μ_{n} and σ_{n} to obtain a random sample of the amount of HW and input the sample into the WIO model to obtain the major indicators for waste generation and treatment. This research chose 10 values of the sample as the amount of HW for sensitivity analysis. This research also applies the same method to analyse 15 variables. It kept the variables of the column of the Household sector in the WIO table constant and input these 10 values of the amount of HW to obtain the corresponding indicators, such as the most inputs from the All other industry (AOI) sector and the most amount of waste generated in the Manufacturing sector. The last step is to calculate the coefficient of variation of the values of HW and indicators as well as identify whether the accuracy of indicators is affected by the uncertainty of the values of HW or not.

2.4 Design of different scenarios

Due to the different periods of data sources, such as $\mathrm{X}_{\mathrm{I,F}}$ in 2013, $\mathrm{PW}_{\cdot,\mathrm{F}}$ in 2015–16, and Australian WIO tables in 2009–10 and 2010–11, the research built two comparative scenarios. The comparative analysis based on these two scenarios was conducted for illustrating the differences of indirect waste generation caused by household consumption of B05 and D16. The main reason for conducting these two scenarios was to assess the effects of different years' economic situations on indirect waste generation and treatment. The two scenarios are:

1) Scenario I – the year of input coefficient and Leontief matrix is 2009–10, the year $X_{I,F}$ is 2013, and $PW_{\cdot,F}$ is 2015–16.
2) Scenario II – the year of input coefficient and Leontief matrix is 2010–11, the year $X_{I,F}$ is 2013, and $PW_{\cdot,F}$ is 2015–16.

3. Results

3.1 Waste footprint (Indirect) of two scenarios

This section presents waste footprints for household consumption (D16 & B05) with the focus on the share that is indirect generated in each industrial sector. Waste 'footprint' includes the waste people dispose of directly (direct), plus all the waste produced upstream (indirect) during the production of goods and services to satisfy human demand (Fry et al. 2015).
The (indirect) waste footprint caused by the household consumption of D16 (couples without children who are retired and stay at home) in Scenario I is shown in Figure 1. From the left to right, the diagram shows the amount of household consumption by D16, the amount of indirect waste generation in industrial sectors, and finally the amount of waste treated by waste treatment sectors. The amount of household consumption (left) is calculated by summarising the products and services of D16 consumption by retrieving the $X_{I,F}$. The amount of indirect waste generation in industrial sectors (middle) are found by retrieving the $PG_{\cdot,I}$. The amount of waste treated by the Landfill and Recovery sectors (right) are found by retrieving the $PG_{\cdot,I}$ and $PG_{\cdot,II}$. In the supplementary appendix, Figures 2, 3, and 4 have the similar expressions for D16 in scenario II, B05 (couples without children who spend the majority of their time at the office) in scenarios I and II, respectively. In summary, the analysis of waste generation based on a WIO model from 2010 instead of 2009 results in a reduction of indirect waste generation of around 8%.

The amount of direct waste generation for D16 (747.24 kg) and B05 (607.36 kg) in Tables 1 and 2 are less than that of indirect waste generation for D16 (scenario I: 2129.90 kg and scenario II:

1960.76 kg) and B05 (scenario I: 2230.14 kg and scenario II: 2046.23 kg). Each industrial sector generates indirect waste in scenario I more than that in Scenario II, except for the Mining sector. For example, the most amount of indirect waste caused by household consumption of D16 are generated from the Manufacturing sector in scenarios I (1033.81 kg) and II (1026.26 kg). As for waste treatment methods, the amount of indirect waste (1148.43 kg) treated by the Landfill sector is greater than that (981.47 kg) treated by the Recovery sector in scenario I. Scenario II shows the similar situation with the Landfill sector treating 1049.55 kg and the Recovery sector treating 911.21 kg indirect waste. The exact composition of the waste in each stream/treatment method was not analysed due to lack of data.

The B05 has generated more indirect waste than the D16 in scenarios I (B05: 2229.14 kg and D16: 2129.90 kg) and II (B05: 2044.23 kg and D16: 1960.76 kg) with more household consumption (B05: $AUD 77,968.80 and D16: $AUD 71577.48). The indirect waste generation and treatment caused by the household consumption of B05 has similar analysis with that by that of D16, shown in Figures 3 and 4.

3.2 Comparative analysis of different types of households on indirect waste generation in Australian economy with different scenarios

This section compares indirect waste generated in each industrial sector, which are caused by the household consumption of B05 and D16 in different scenarios. The differences of indirect waste generation between B05 and D16 are calculated as the amount of indirect waste generation from the consumption of B05 minus that from that of D16.

Fig. 5 shows the comparative analysis of indirect waste generation for differences between B05 and D16 for scenarios I and II. The total amount of indirect waste generation caused by the consumption of B05 are 99.24 kg more than that of D16 in scenario I. The differences of indirect waste generation in all industrial sectors between B05 and D16 are positive, except for the Agriculture, forestry, and fishing sector and the Electricity, gas, and water sector. The All other industry sector has the largest positive difference for indirect waste generation in scenario I, amounting to 82.6 kg. The total amount of the differences of indirect waste generation (99.24 kg) between B05 and D16 in scenario I are more than that (83.45 kg) in scenario II. The situations for the differences of indirect waste generation in each industrial sector caused by household consumption of B05 and D16 in scenario II are similar to that in scenario I.

Comparative analysis of indirect waste generation for differences between scenarios I and II for B05 and D16 has been presented in Fig. 6. The differences of indirect waste generation between scenarios I and II are calculated as the amount of indirect waste generation in scenario II minus that scenario I for B05 and D16, respectively. The total amount of the indirect waste generation in industrial sectors caused by the household consumption of D16 between scenarios I and II amounts to -169.14 kg. Of this, the largest components were the All other industry (-86.88 kg), the Construction sector (-41.44 kg), and the Electricity, gas, and water sector (-31.26 kg). Difference of indirect waste generation in the Mining sector is the only positive number (8.62 kg). Compared with the data of D16, the household consumption of B05 results in a larger difference of indirect waste generation (-184.91 kg). The differences of indirect waste generation between scenarios I and II for B05 is similar to that for D16.

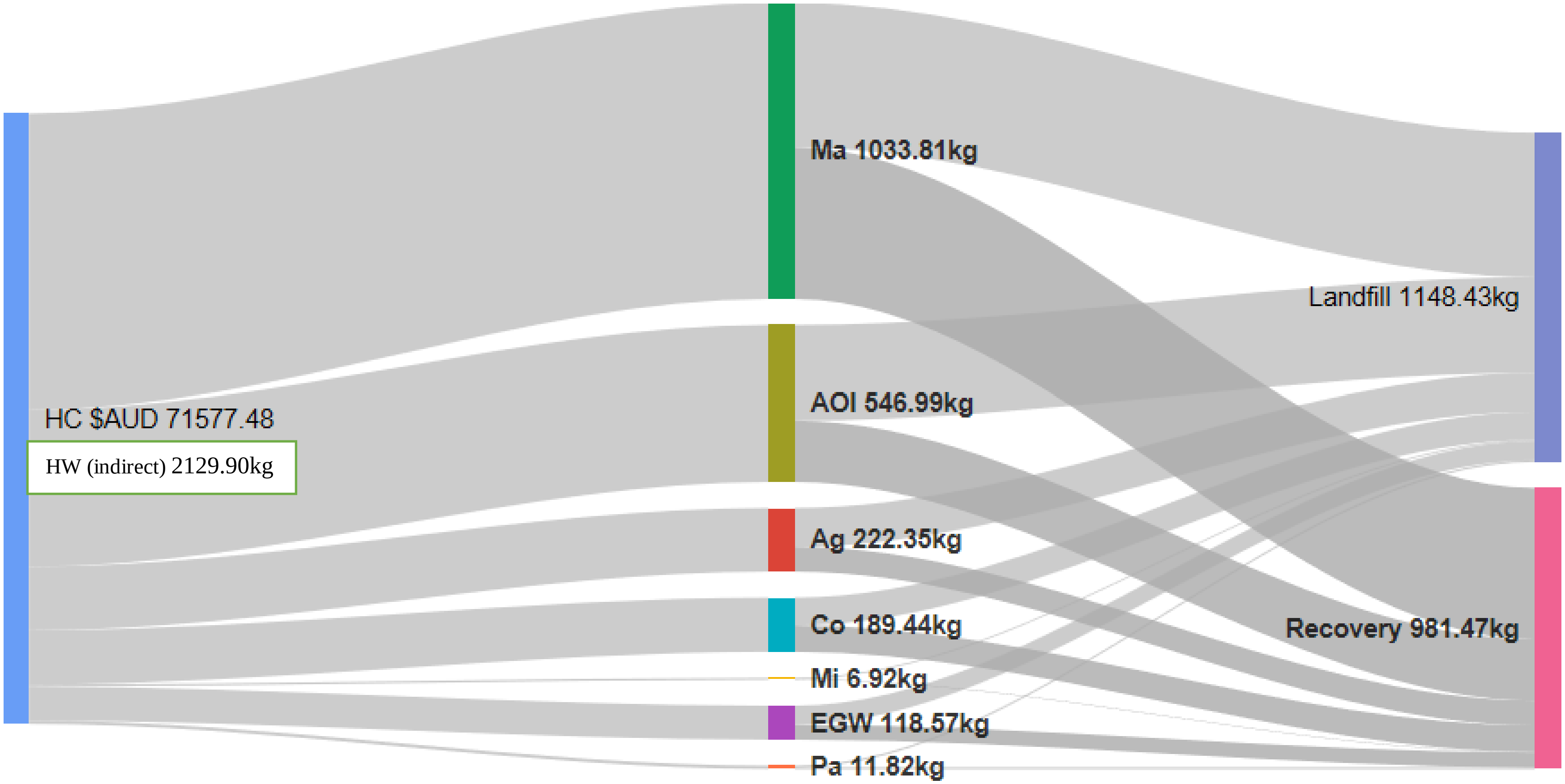

Fig. 1. Waste footprint of industrial sectors in Scenario I; indirect waste generation (industrial sectors) (middle) driven by the household of D16 (left) and treated by the Landfill and Recovery sectors (right). Note: Agriculture, forestry, and fishing = Ag; Mining = Mi; Manufacturing = Ma; Electricity, gas, and water = EGW; Waste management services = WMS; Construction = Co; Public administration = Pa; All other industry = AOI; Household consumption = HC; Household waste = HW.

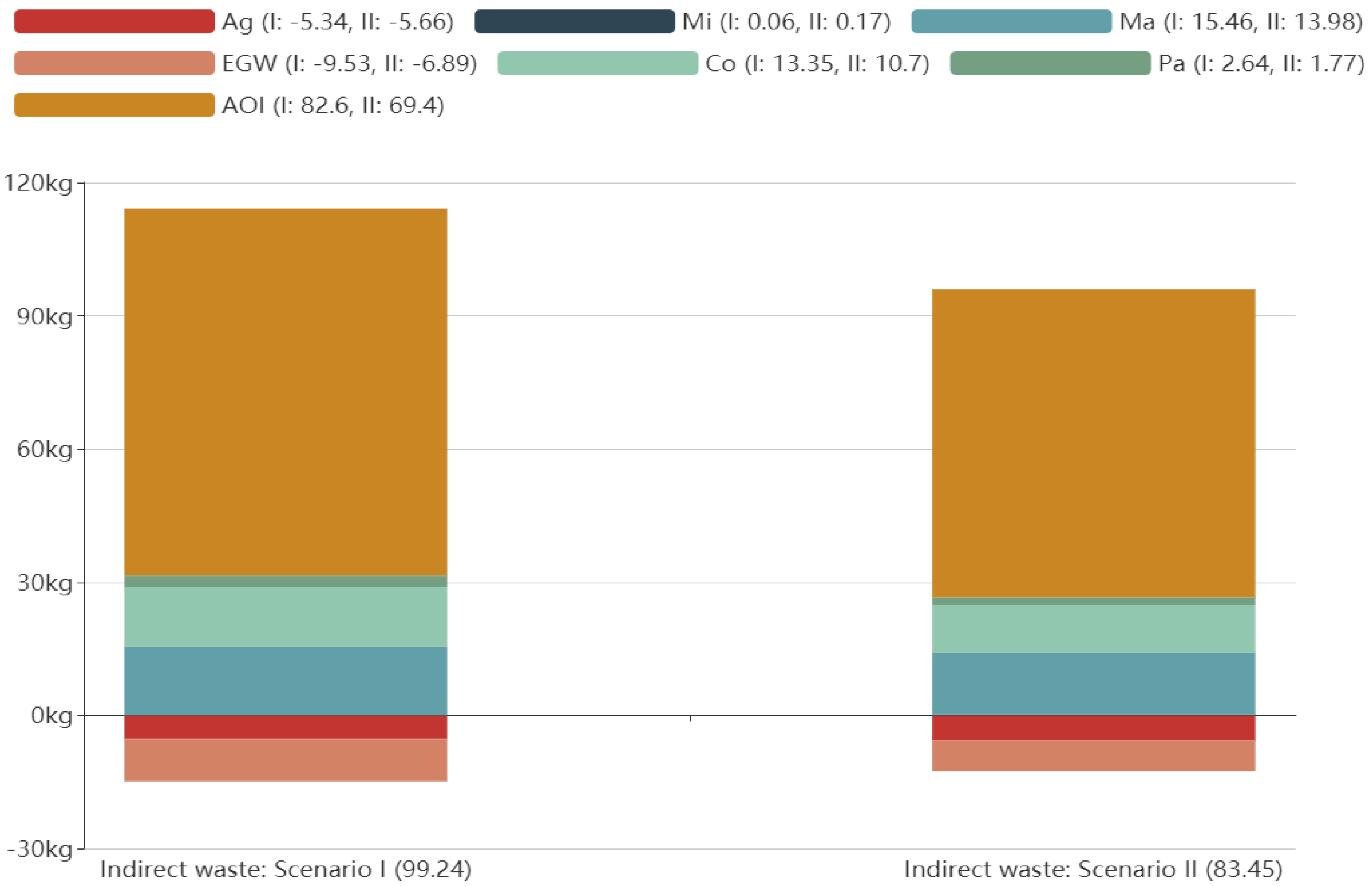
Ag (I: -5.34, II: -5.66)
Mi (I: 0.06, II: 0.17)
Ma (I: 15.46, II: 13.98)
EGW (I: -9.53, II: -6.89)
Co (I: 13.35, II: 10.7)
Pa (I: 2.64, II: 1.77)
AOI (I: 82.6, II: 69.4)
120kg
90kg
60kg
30kg
0kg
-30kg
Indirect waste: Scenario I (99.24)
Indirect waste: Scenario II (83.45)

Fig. 5. Comparative analysis of indirect waste generation for differences between B05 and D16 for scenarios I and II (kg). Note: 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; Household consumption = HC.

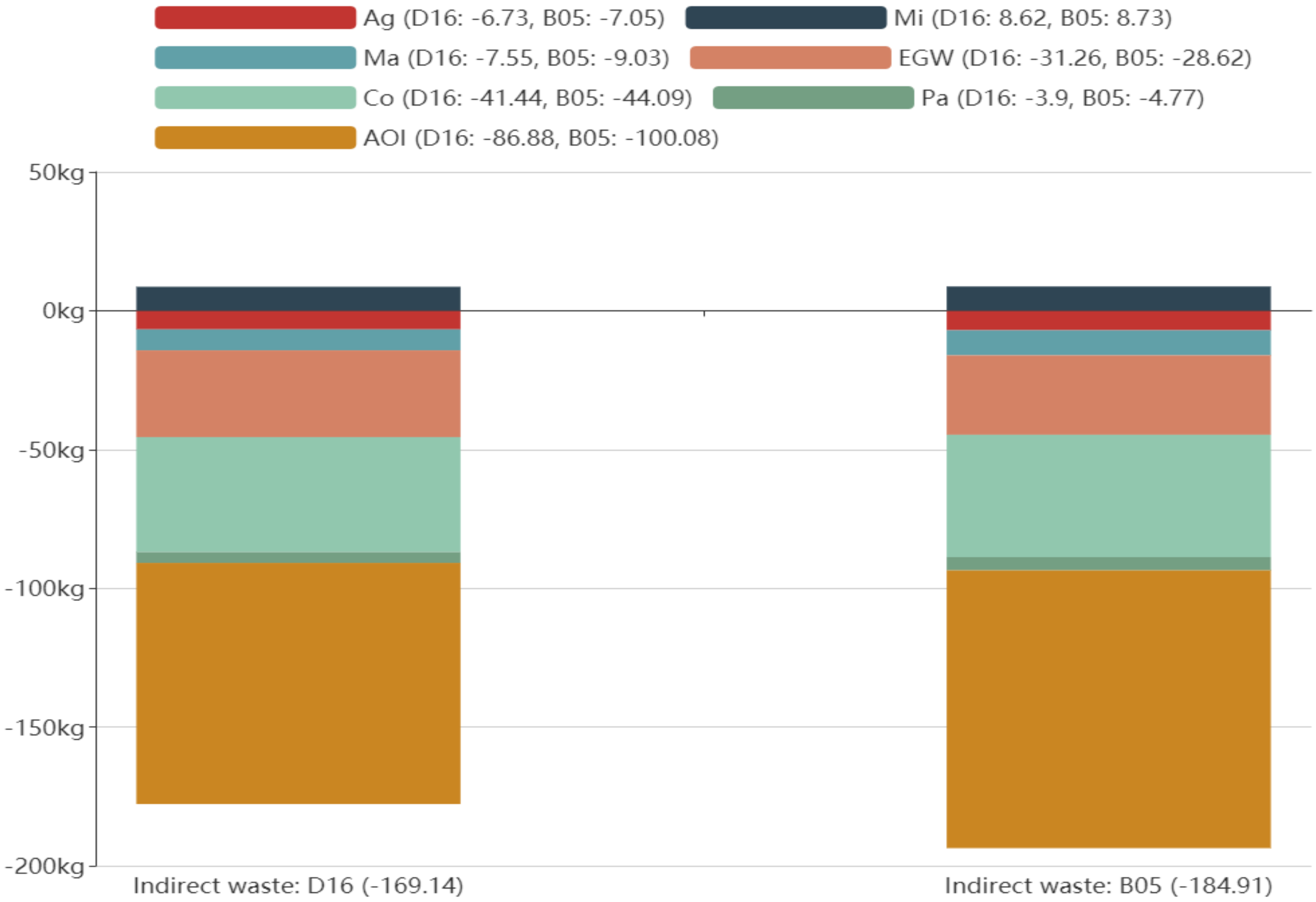

Fig. 6. Comparative analysis of indirect waste generation for differences of scenarios I and II for B05 and D16 (kg). Note: Agriculture, forestry, and fishing = Ag; Mining = Mi; Manufacturing = Ma; Electricity, gas, and water = EGW; Waste management services = WMS; Construction = Co; Public administration = Pa; All other industry = AOI; Household consumption = HC.

3.3 Correlation analysis between output of economy and indirect waste generation in industrial sectors

This section aims at exploring the nexus between the output of economy and waste generation in industrial sectors. The objectives were to perform a) correlation analysis between the output of economy and indirect waste generation in industrial sectors with the consumption of B05 or D16 in scenarios I or II, b) correlation analysis between differences of the output of economy and differences of indirect waste generation in industrial sectors for B05 and D16 in scenarios I or II, and c) correlation analysis between differences of the output of economy and differences of indirect waste generation in industrial sectors in scenarios I and II for B05 or D16. The correlation coefficients between the output of economy and indirect waste generation in industrial sectors are strong and positive (Table 4). Table 5 shows that correlation coefficients between differences of output of economy and differences of indirect waste generation in industrial sectors for B05 and D16 are 0.9796 in scenario I and 0.9773 scenario II, respectively. It is higher than correlation coefficients between the output of economy and indirect waste generation in industrial sectors in scenario I for B05 (0.7515) or D16 (0.7470) and in scenario II for B05 (0.6886) or D16 (0.6887), respectively (Table 4). Table 6 shows that there are weak nexuses between differences of the output of economy and differences of indirect waste generation in industrial sectors for B05 and D16 between scenarios I and II.

Table 4 Correlation coefficient for B05 and D16 in scenarios I and II.

Scenarios	Household types	Total output for indirect waste generation
Scenario I	B05	0.7515
	D16	0.7470
Scenario II	B05	0.6886
	D16	0.6887

Table 5 Correlation coefficient for differences between B05 and D16 in Scenario I or II.

Scenarios	Household types	Differences of total output for indirect waste generation

Scenario I	Between B05 and D16	0.9796
Scenario II	Between B05 and D16	0.9773

Table 6 Correlation coefficient for differences for B05 and D16 between scenarios I and II.

Household types	Scenarios	Differences of total output for differences of indirect waste generation
B05	Between scenarios I and II	-0.04365
D16	Between scenarios I and II	-0.06789

3.4 Results of sensitivity analysis

In this section, the results based on the calculation of three steps mentioned in Section 2.3 have been displayed. HW treated by the Landfill sector is considered as an example to illustrate the calculation in detail. After 5 iterations from the equations 5 to 8, a stable μ_n = 6.22 and $\sigma_n = 3.74$ based on the 7 samples of the Landfill sector was reached. Table 7 shows the 10 values of the amount of HW for the Landfill sector and the Recovery sector selected from the random sample for μ_n = 6.22 and $\sigma_n = 3.74$ based on normal distributions for D16. Figure 7 displays the Box-and-Whisker Plots of the estimated amount of HW landfilled and recovered for D16.

Table 7 The estimated amount of HW for the Landfill and Recovery sectors for D16 (kg per week).

Number	1	2	3	4	5	6	7	8	9	10
Landfill (Kilograms)	3.50	9.69	0.91	12.34	6.04	7.60	15.84	6.89	4.58	0.52
Recovery (Kilograms)	5.21	13.53	1.72	17.09	8.62	10.71	21.79	9.76	6.66	1.20

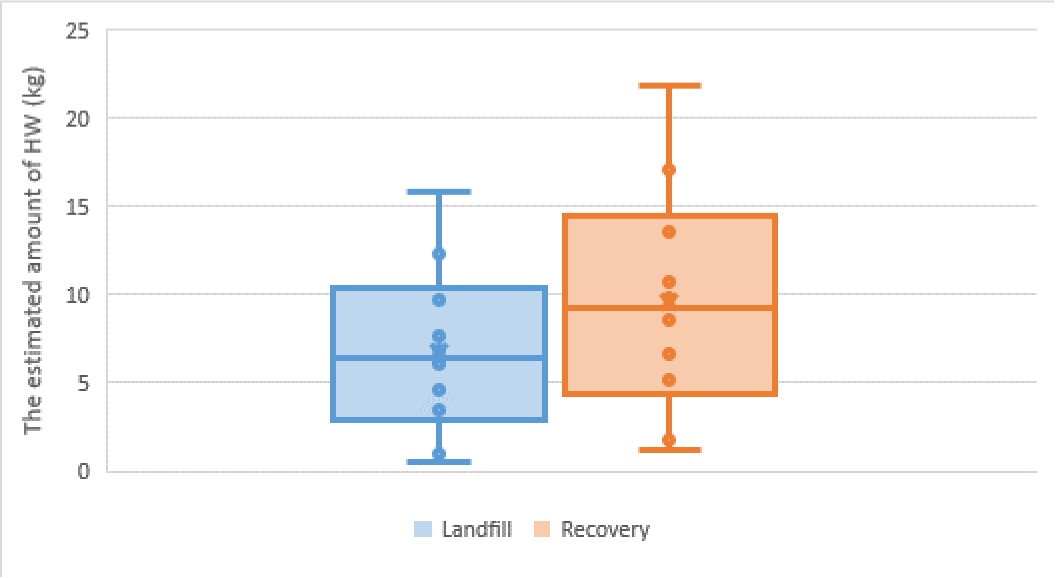

Fig. 7. Box-and-Whisker Plots of the estimated amount of HW landfilled and recovered for D16.

The amount of HW for the Landfill sector for D16 in scenario I were replaced by the values in Table 7. The other values for the Household sector were kept constant for D16 in scenario I. The 10 WIO tables for D16 corresponding to the 10 values of the amount of HW for the Landfill sector were then constructed. This operation was carried out to allow analysis of the uncertainty around the amount of HW treated by the Landfill sector. Specifically how changes to HW for D16 affects two major indicators: 1) the value of monetary inputs (for the All other industry sector) is linked to demand from households ; and 2) changes to the value of waste caused by the shifting demand (and waste generation) of the Household sector.

Table 8 reports the coefficients of variation of the amount of HW landfilled and recovered, the most monetary inputs from the All other industry sector, and the most amount of waste generation by the Manufacturing sector in 2009–10 and 2010–11. As there was only one value for B05, there was no formal method to estimate standard deviation with certainty. In order to perform sensitivity analysis, the research used the standard deviation of the sample of D16 to analyse the sample of B05. Table 9 shows the similar results of B05 in 2009–10 and 2010–11. Coefficient of variation in Tables 8 and 9 is a measure of relative variability. It is the radio of the standard deviation of the numbers of estimated waste generation to the mean of the numbers of estimated waste generation. The coefficients of variation for 10 variables and 15 variables show the similar result. This indicates that there is no need to add more variables since adding extra 5 variables did not make any difference for estimated results.

Table 8 The coefficients of variation of the amount of HW landfilled and recovered and major indicators for D16.

Year	Waste treatment methods	Indicators	Coefficients of variation
2009–10	Landfilled	The amount of HW	0.7143
		The monetary inputs from the All other industry sector	0.0001
		The waste generation by the Ma sector	0.0000
	Recovery	The amount of HW	0.6776
		The monetary inputs from the All other industry sector	0.0001
		The waste generation by the Ma sector	0.0000
2010–11	Landfilled	The amount of HW	0.7143
		The monetary inputs from the All other industry sector	0.0001
		The waste generation by the Ma sector	0.0000
	Recovery	The amount of HW	0.6776
		The monetary inputs from the All other industry sector	0.0001
		The waste generation by the Ma sector	0.0000

Table 9 The coefficients of variation of the amount of HW landfilled and recovered and major indicators for B05.

Year	Waste treatment methods	Indicators	Coefficients of variation
2009–10	Landfilled	The amount of HW	0.7124
		The monetary inputs from the All other industry sector	0.0001
		The waste generation by the Ma sector	0.0000
	Recovery	The amount of HW	0.7790
		The monetary inputs from the All other industry	0.0001
		The waste generation by the Ma sector	0.0000
2010–11	Landfilled	The amount of HW	0.7124
		The monetary inputs from the All other industry sector	0.0001
		The waste generation by the Ma sector	0.0000
	Recovery	The amount of HW	0.7790
		The monetary inputs from the All other industry I sector	0.0001
		The waste generation by the Ma sector	0.0000

4. Discussion

This research has proposed a new perspective to assess the nexus between the Australian household consumption and indirect waste generation and treatment. This is explored further using a case study based on the existing Australian WIO model, the Mosaic data for household consumption, and on-site collection data for direct waste generation and treatment. These have different impact perspectives on the research outcomes. Household consumption is the major factor to result in indirect waste generation. The design of different types of scenarios (existed Australian WIO model) provides more details for better understanding the effect of economy on indirect waste generation. The on-site collection for direct household waste data has been integrated in the WIO table and make the table as a whole.

The strength of this research lies in its somewhat detailed description of economic activities and waste treatment caused by different patterns of household consumption through the combination of macro- and micro- economic and environmental data related to Australian industrial sectors, different types of household consumption, and waste generation. Most previous research relating to the IO model quantified direct waste generation from average or aggregated household consumption (Wiedmann et al. 2006, Reutter et al. 2017, Reutter et al. 2017) and ignored the fact that household consumption can be categorized into different types depending on different socio-demographic indicators. Although some researchers have analysed the indirect waste generation caused by the household in the supply chain (Parfitt et al. 2010), there is a lack of a detailed analysis about how the patterns of household consumption affect indirect waste generated in the supply chain. Now having shown that this method is feasible, a detailed analysis can be undertake using high resolution input-output models (Lenzen et al 2014).

The proportion of direct waste generation from the household has been about 25% in the total amount of waste while that of indirect waste generation is about 75%. Similar results have been illustrated by Kim et al. (2017), which have shown that percentage of industrial waste is high with 76.3%, and lower household waste (26.5%). It is worthwhile indicating that this relationship between direct and indirect waste is based only on the scope and availability of data, if the scope of inclusion changes, then this relationship may change. The waste footprints show how the different patterns of household consumption caused indirect waste generated in industrial sectors and treated by waste treatment sectors. As for the same pattern of household consumption, the indirect waste generated in scenario II (the year of input coefficient and Leontief matrix is 2010–11) is less than that in scenario I (the year of input coefficient and Leontief matrix is 2009–10). This change could illustrate the developments that have been found in other studies, for example, cleaner technologies (Ahamed et al. 2016, Yong et al. 2016), waste management (Zaman 2015), and economic model (Geissdoerfer et al. 2017, Haupt et al. 2017). The Manufacturing sector generated the most amount of indirect waste. This corresponds to the results of other studies generation (Priefer et al. 2016, Van Ewijk and Stegemann 2016) that identified goods, such as food, clothes and electronic (e-) waste, consumed by the household and made by this sector as the main source of indirect waste generation. The waste footprints have illustrated that the total waste generated along the supply chain is about 3 times higher than what households dispose of directly, which is similar to the result from Fry, Lenzen et al. (2016). The B05 has generated more indirect waste than the D16 in the same scenario with more household consumption. The result has been connected with that the higher level of household consumption tends to generate more amounts of waste (Dyson and Chang 2005, Sjöström and Östblom 2010, Suthar and Singh 2015). In the UK the amount of waste generation, such as food, clothing, paper, plastics, electronic (e-) waste, and glass, had an important growth due to the growth in the overall household expenditure: from around £34 billion in 1971 to £795 billion in 2006 (Tudor et al. 2011). Although the amount of indirect waste treated by the Landfill sector is more than that by the Recovery sector, the differences between them becomes smaller from scenario I to II. It gives an insight that the Landfill sector will be not a major solution for waste management in Australia (ABC NEWS 2018).

The comparative analysis between household consumption of B05 and D16 shows the effects of different patterns of household consumption on indirect waste generation in industrial sectors. The comparative analysis between B05 and D16 for scenarios I and II indicates the largest differences of indirect waste generation occur in the All other industry sector, which contains a series of service sectors including Accommodation and Food services, Rental, Hiring and Real Estate Services, Professional, Scientific and Technical Services, and Arts and Recreation Services (ABS 2008). It indicates that after satisfying the basic human demand for living products, people who spend more money on services, such as education (Smyth et al. 2010, Fagnani and Guimarães 2017), health (Thakur et al. 2015, Almeida et al. 2017), and tourism (Arbulú et al. 2015), can generate more indirect waste. The increase of indirect waste generation in the All other industry sector for scenarios I and II could be explained in part by the growth of food waste in the Food services sector: for example, Reynolds et al. 2015b found an increase in the number of meals eaten outside the home in the context of the increase of the income. For example, the increase of the amount of the UK household waste generation is partly related to a 2.1% increase in the number of meals eaten outside the home between 2012 and 2015 (The Environment, Food and Rural Affairs Committee 2017).

The negative numbers of indirect waste generation in the comparative analysis based on the same pattern of household consumption between scenarios I and II could indicate that more clean production technologies and environmental strategies have been applied in most industrial sectors to reduce the waste generation. For example, the Construction sector generated less waste in scenario II than scenario I, which can be partly attributed to the technology of Pre-Fabricated Construction (Sandanayake et al. 2016) and ‘Construction and demolition waste guide – recycling and re-use across the supply chain’

(Australian Government Department of Sustainability, Environment, Water, Population and Communities 2011). The only positive number of the differences for the indirect waste generation appears in the Mining sector. It illustrates that as the single largest producer of solid waste in Australia, the Mining sector has resulted in the cumulative solid waste legacy of mining due to the wide application of large-scale open cut mining (Worrall et al. 2009, Mudd 2010).

The correlation analysis shows that the differences of household consumption between B05 and D16 has strong nexus with the differences of indirect waste generation in scenarios I and II. It further indicates that the household consumption has significant effect on indirect waste generation (Sjöström and Östblom 2010, Suthar and Singh 2015).

The results of the sensitivity analysis indicate that the change of the amount of household waste generation in a reasonable range cannot dramatically affect the major economic activities and indirect waste generation. For example, the change in the amount of HW for D16 (The coefficient of variation is 0.7143.) has a slight significant change of the monetary inputs from the All other industry sector (The coefficient of variation is 5.5×10^{-5}.), and the amount of waste generation from the Manufacturing sector (The coefficient of variation is 2.7×10^{-5}). It also indirectly reflects that most of waste in the Australian economy caused by the Household consumption is generated in the supply chain, rather than at the household level. Therefore, the data of the amount of waste weighed from on-site audit only performs a benchmark value for the WIO analysis.

Finally, our application of WIO analyses the effect of different patterns of household consumption on indirect waste generation by incorporating different types of scenarios. This allows macro- and micro-economic data to be integrated with waste data. This quantitative method would benefit the study of effects of household consumption on waste management in a national scale. It could also be used to assist in the design of environmental policies for different households in terms of environmental impacts related to their different consumption and waste generation patterns.

This ability to investigate indirect waste generation from the perspective of different patterns of household consumption is particularly important when considering the rapidly changing demography of Australia, the UK and many other countries globally. The methods proposed in this paper allow the waste management implications of this demographic change to be investigated at a higher level of detail than under previous WIO or other traditional methods.

5. Conclusions

The novelty of this research is to analyse the indirect waste generation in the supply chain from the perspective of patterns of household consumption. We combine macro- and micro- economic and environmental data related to Australian industrial sectors, different patterns of household consumption (Mosaic data), and direct waste generation into the WIO model for exploring this nexus in two scenarios. This research has demonstrated it is possible to analyse indirect waste generation and treatment arising from household consumption, this is typically hidden within the Australian economic and waste data. However, the scale of the IO model (8 sector), and the aggregated waste data make this paper more of a proof-of-concept study than a detailed investigation.

Results show that indirect waste generation is hidden from the end-user of products and services. We find the level of indirect waste generation for B05 (couples without children who spend most of their time at the office) and D16 (couples without children who are retired and stay at home) is greater than that of direct waste generation for D16 and B05. 75% of Australian household waste generation is related to indirect waste generation. It indicates that the waste generated in the supply chain is much more than the waste generated in the household. Due to this result we encourage the consideration of waste management strategies that conduct waste minimisation across the supply chain, rather than just at the consumer level. The amount of indirect waste generated by B05 is more than that by D16. There are two reasons for this result: 1) B05 spends more time at the office and eat more food outside; and 2) B05 spends more money for their living. Both of them can generate more indirect waste from the supply chain. Policy-makers should levy extra fee for waste generation in terms of household consumption. Our Correlation analysis indicates a clear nexus between household consumption and indirect waste generation. This indicates that technologies and policies published by Australian governments and aimed at reducing waste generation should focus on the supply chain or upstream processes in addition to on-site disposal.

However, the patchy economic and waste data regarding household consumption and waste management are a significant hurdle for analysis. First, in relation to the accuracy of the research, although the data of waste generation from on-site collection have limited effects on the research findings, we could further enhance the accuracy with data of waste from more samples of different types of household. Second, if the base data can be matched to the same period(s), the modelling will obtain more accurate and useful results for policy-makers. Finally, this research does not intend to represent an entire class of people nationwide, but calculates for two large groups of the Australian population, how much waste will be indirectly generated in Australian industrial sectors due to their consumption and waste generation.

Indeed, a weakness of this paper is that the volumes of waste modelled have been presented and investigated in aggregate with no differentiation or waste composition analysis besides treatment destination. As Mmereki et al. (2016), states "the composition of solid waste varies greatly from country to country and changes significantly with time", this means that: 1) future changes to consumption and production will change the composition of the waste and thus environmental and economic impacts. 2) If this study was conducted in another geography and with other demographic groups the waste compositions will vary due to cultural and geographic factors. This complexity (between aggregated and disaggregated waste, destinations of waste, and cultural and geographic determinates) should be investigated in future research. A method to disaggregate generic waste volumes into component parts using IO tables has been proposed by Reynolds et al (2015a). In future work this method could be extended and linked with the scenarios presented in this paper, or compared with other geographies.

Furthermore, the IOT used in this study contains only one aggregated service sector (and only eight aggregated intermediate sectors in total). This aggregation means that differences in service sector consumption between B05 and D16 are not explored fully in our analysis, and the indirect waste generation differences cannot be explored fully. A disaggregated IOT and waste account, along with a full compositional audit of the waste would provide a much richer data source to model. A further weakness of the paper is that the IO tables it uses as a foundation are based on the assumption of domestic technology being identical to global technology (and vice versa). This has some major implications for our findings validation, as indirect waste generation will be embedded in both the global and Australian supply chains, and waste generation and production efficiency differences between supply chains is not currently taken into account.

With the above weaknesses in mind, the research presented here integrates the patterns of household consumption into a WIO model (albeit a model with only 8 intermediate sectors, and a single aggregated waste sector) . By using the micro-economic information of household consumption as the major driving force of indirect waste generation, it regards part of the operation of the supply chain as a function to generate waste in order to fulfil the different needs for human well-being. It is important from environmental management perspective to understand indirect waste generation with corresponding implication for the nexus between economy and environmental issues. This research can be used as a bridge between different future household consumption scenarios. Further studies’ directions based on this research for waste management are:

- Collect (disaggregated and detailed) waste data in terms of household types of Mosaic data to form a series of (detailed global or multiregional) WIO models to comprehensively explore the nexus between economic activities and waste generation caused by different types of household types, and

apply this method to analyse the indirect energy consumption and greenhouse gas emissions from different types of household consumptions.This research provides a method for obtaining more information regarding nexus between household consumption and indirect waste generation, allowing us to understand the effects of household consumption on indirect waste generated from industrial sectors. It is hoped this new capacity can 1) revitalize discussions around waste management and sustainable development from the perspective of household consumption, and 2) guide future data collection efforts.

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Supplementary Appendix

SA and Adelaide waste composistion

Sankey diagrams of additioanall scenarios

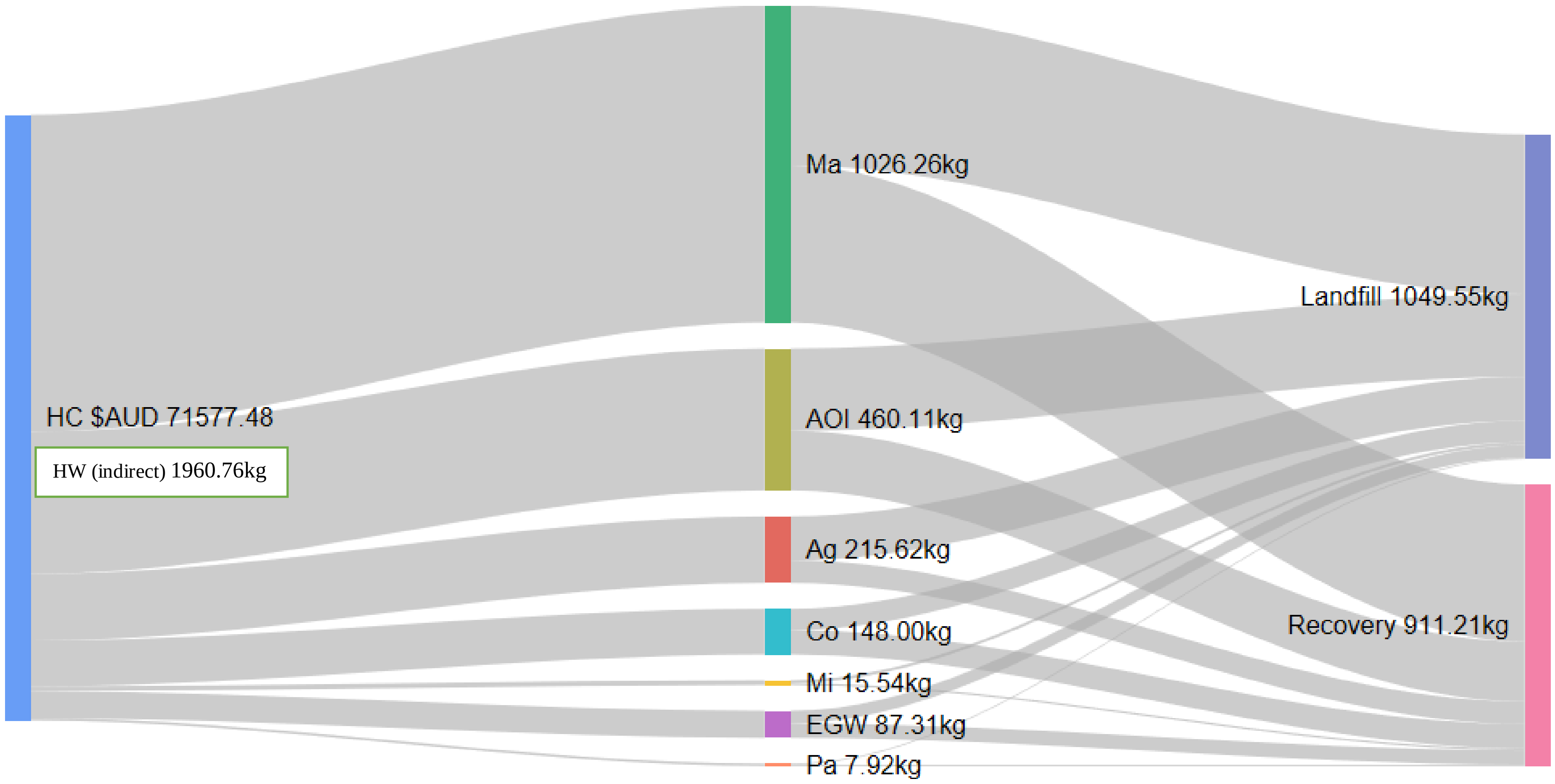

Fig. 2. Waste footprint of industrial sectors in Scenario II; indirect waste generation (industrial sectors) (middle) driven by the household of D16 (left) and treated by the Landfill and Recovery sectors (right). Note: Agriculture, forestry, and fishing = Ag; Mining = Mi; Manufacturing = Ma; Electricity, gas, and water = EGW; Waste management services = WMS; Construction = Co; Public administration = Pa; All other industry = AOI; Household consumption = HC.

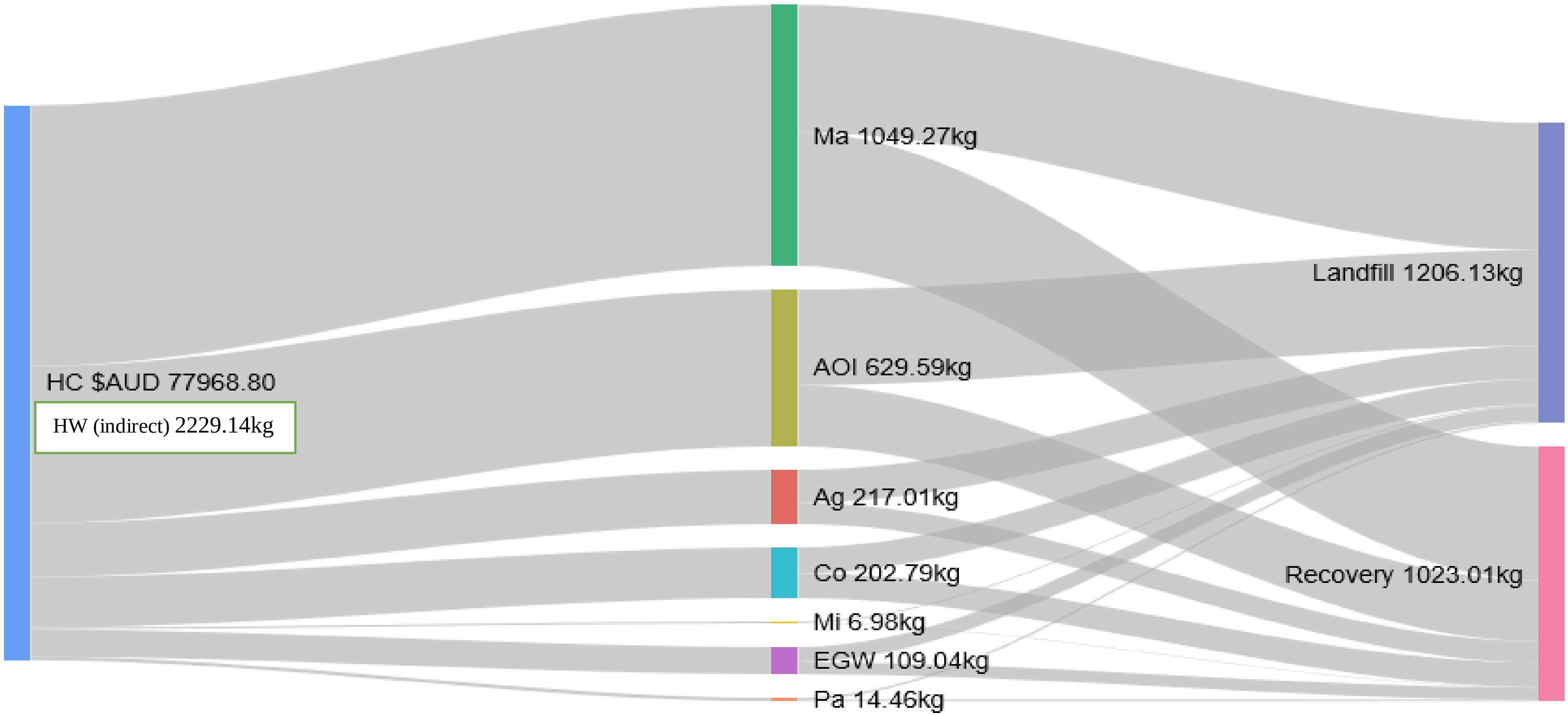

Fig. 3. Waste footprint of industrial sectors in Scenario I; indirect waste generation (industrial sectors) (middle) driven by the household of B05 (left) and treated by the Landfill and Recovery sectors (right). Note: Agriculture, forestry, and fishing = Ag; Mining = Mi; Manufacturing = Ma; Electricity, gas, and water = EGW; Waste management services = WMS; Construction = Co; Public administration = Pa; All other industry = AOI; Household consumption = HC.

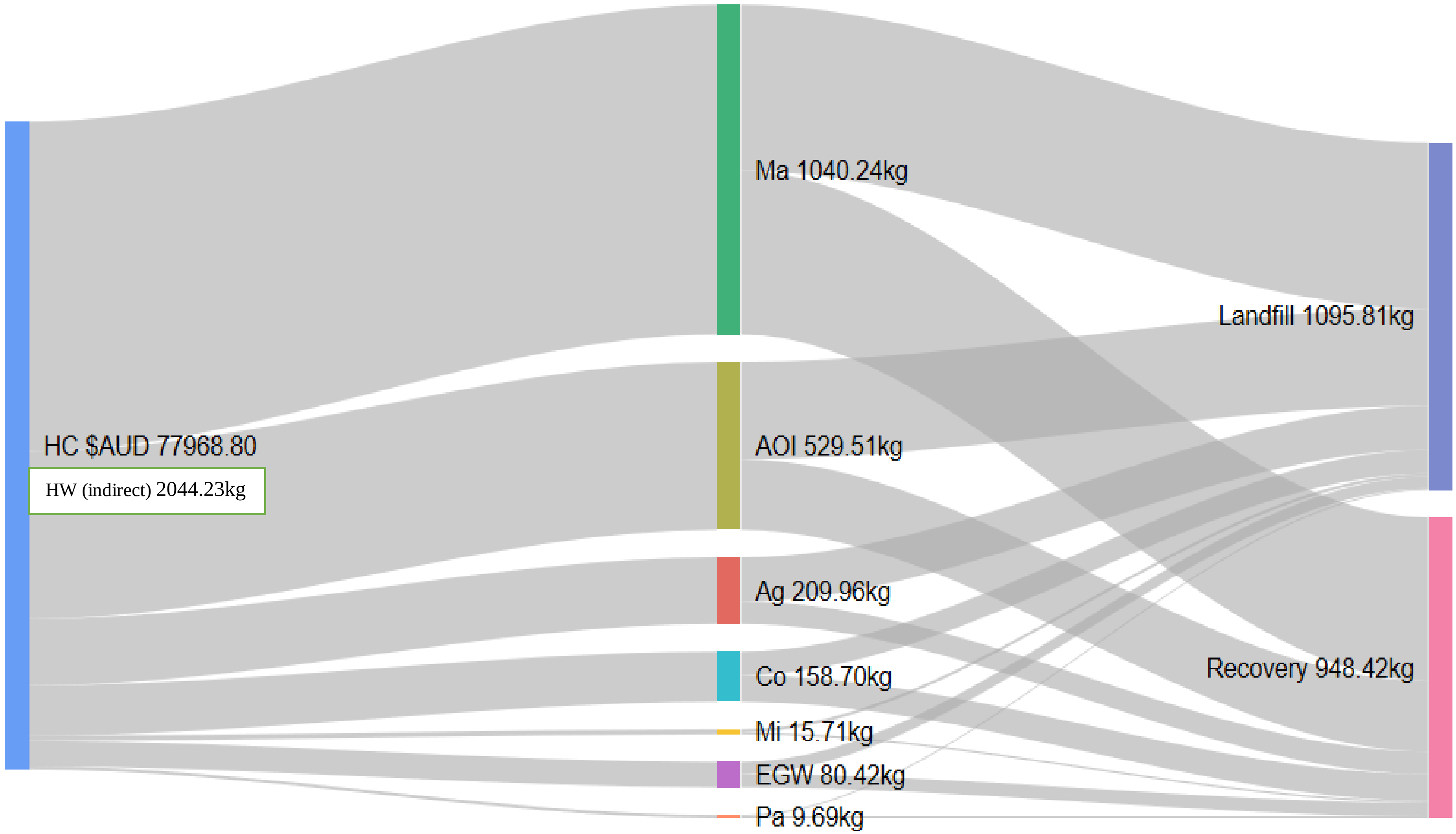

Fig. 4. Waste footprint of industrial sectors in Scenario II; indirect waste generation (industrial sectors) (middle) driven by the household of B05 (left) and treated by the Landfill and Recovery sectors (right). Note: Agriculture, forestry, and fishing = Ag; Mining = Mi; Manufacturing = Ma; Electricity, gas, and water = EGW; Waste management services = WMS; Construction = Co; Public administration = Pa; All other industry = AOI; Household consumption = HC.