# Input-Output Analysis of Waste Management

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**Abstract**

Any production activity emits waste, a proper treatment of which is the task of waste treatment. Goods producing- and waste treatment sectors are related to each other through the inter-sectoral flow of goods and wastes. We present an accounting framework termed Waste Input-Output (WIO) Table to describe this interdependence between goods producing and waste treatment sectors, and derive a model that is capable of analyzing the repercussion between waste emission and economic activity. We actually estimated a WIO Table for Japan, and applied the model to evaluating effects of alternative waste management options on the level of industrial output, waste emission, landfill consumption, and the emission of carbon dioxide. Empirical results indicate that regional deposal and sorting based on combustibleness are effective for reducing landfill consumption and $CO_2$ emission.

**keywords:** waste disposal, input-output analysis, LCA, regional disposal, waste heat

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# 1 Introduction

Any production activity emits waste of some type. This applies to household consumption (household production) and recycling of waste materials as well. Furthermore, almost any good has a potential to become waste with the elapse of time. Once emitted as residue, waste can never be "eliminated" because of the law of mass conservation, but can at most be converted into different forms with smaller environmental impacts. This conversion is carried out by waste treatment sectors (recycling, intermediate processing and final disposal).

Just as goods producing sectors (henceforth "goods" are understood to include services) are related to each other through the input-output stream of goods, goods producing- and waste treatment sectors are related to each other through an extended input-output stream that involves both goods and wastes. Goods producing sectors depend on waste treatment sectors for the treatment of wastes they emit. Waste treatment sectors, in turn, depend on inputs from goods producing sectors such as energy, chemicals, and machines for their activity. Recycling of waste materials further intensifies the complexity of this web of interdependence between goods producing and waste treatment sectors. Consideration of this interdependence would be vital to designing a waste management policy that is effective in reducing the overall environmental load that results from a given economic activity. In other words, a system-oriented approach is required. Attempts to deal with any one waste as a separate problem (the one problem-one solution approach is) is not only ineffectual but also usually just shifts the problem from one place or environment to another.

The Input-Output (henceforth, IO for short) table is a well-established accounting device for describing the interdependence among different sectors of an economy that results from the intersectoral stream of goods. The standard IO table, however, does not consider the interdependence between goods production and waste treatment sectors involving the stream of both goods and wastes.

We present a new accounting framework (Waste Input-Output, WIO for short) that is based on the basic idea of Nakamura [1] and extends the standard IO table to accommodate for this interdependence between goods producing and waste treatment sectors. The WIO serves two purposes. First, it provides an accounting system to describe the interdependence among production- and consumption sectors and waste treatment sectors of the economy in terms of the stream of goods and waste. Secondly, it provides a mathematical model that could be used for Life Cycle Assessment (LCA) of alternative waste management policy scenarios.

We illustrate the concept of WIO by use of the Japanese WIO table for 1995 that we developed, explain theoretical features of the WIO model, and show some results of its application to LCA of several waste management scenarios. It is for the first time that we present a Japanese WIO table for 1995, albeit in a consolidated form.

# 2 The Waste Input-Output Table

## 2.1 Mass balance and its implications

Fundamental to quantitative analysis of waste issues is the observation of mass balance condition, from which follow two important implications for the WIO. The first is the equality condition of supply of and demand for a particular waste:

$$\text{waste emission} = \text{recycling of waste} + \text{waste treatment}. \tag{1}$$

The level of waste emission and recycling is to a large extent determined by conditions of goods producing sectors. The level of waste treatment is then determined as the residual. In this sense, waste treatment has an inherently passive nature. In WIO, (1) plays a central role to determine the level of waste treatment.

The second implication is the fact that waste treatment is a conversion process of a give type of waste into different types of wastes:

$$\text{waste } A \xrightarrow{\text{waste treatment}} \begin{cases} \text{waste } B \\ \text{waste } C \\ \vdots \end{cases} \tag{2}$$

For instance, incineration converts garbage into ash, fly ash and flue gas. Combined with (1) it follows that a particular treatment of a waste may incur the subsequent treatment of secondary wastes. For instance, according to Japanese regulations fly ash has to be further processed to prevent leaching before it is landfilled.

## 2.2 Relationships to negative input method

As preparation for introducing the WIO, we find it useful first to look at the way by-products/and or scraps are statistically treated in the conventional IO table. In many IO tables including the Japanese table, a by-product and/or scrap (henceforth, by-product for short) is treated by the so-called "negative input method" (originally proposed by Richard Stone in 1955, and is often called the Stone method), whereby it is recorded as a negative input from the sector that produces it as the main product [2]. It is important to note that "by-products" here refer to those handled in the market with positive prices and exclude waste. In analogy with (1), the negative input method can then be represented in terms of the balance condition as

$$\text{generation of by-product} = \text{demand for by-product}. \tag{3}$$

Since waste (bads) is excluded by definition, the ex-post equality of supply and demand always holds. There is thus no room left for the generation of residue that has to be treated as waste. In the reality, however, a by-product can turn into waste depending on market conditions, and then has to be treated as such. Since (3) is not able to deal with this situation, it is not applicable to issues involving waste treatment.

The negative input method is often criticized for that depending on the level of final demand the output of the sector competing with the by-product of another sector could become negative, which is impossible. A negative output occurs because in (3) there is no device to prevent the supply of by-product from exceeding the positive demand for it. In reality, the excess supply of by-product is no longer a good, but becomes a waste (bad) and is handled by the waste treatment sector. The excess supply of by-product does not make the output of competing sector negative, but increases the activity of waste treatment sectors. This is exactly what (1) says. Neglect of this important adjustment mechanism of waste treatment results in the occurrence of unrealistic "negative output".

## 2.3 The Japanese WIO table for 1995

## 2.4 The non-square table

Table 1 shows the Japanese WIO table for 1995 in its consolidated form with 13 industries, 13 wastes, and 3 treatment processes (the original table captures 78 industrial sectors, 24 waste types, and 9 types of bulky waste)[3]. The upper panel corresponds to the conventional IO table except for a detailed description of waste treatment sector whereby it is distinguished by three treatment processes. All entries in this panel are measured in monetary units (billion yen).

The lower panel of Table 1 is specific to WIO, and describes the flow of waste among goods producing- and waste treatment sectors. In contrast to the upper panel referring to goods, the entries in this panel are measured in physical units (1000 tons). The *waste* × *industry* matrix shows the net emission of waste in industries, where net emission refers to the amount of gross emission minus that used as input. For instance, basic metal industries (MTL) emit, among other things, 2 million tons of dust and slag (*ash*) and 0.3 million tons of waste- oil, acid, and alkali (*oil*), while using 36 million tons of scrap metals (*mtl*) as input. Cement industry (CEM) turns out to be the largest user of ash, dust and slag (*ash*) because of the massive use of it as materials.

The row at the bottom refers to the emission of $CO_2$ (in 1000 ton-Carbon) that originates from the consumption of fossil fuels and lime stones [4], and methane from landfill site. In the conversion of the methane gas to carbon dioxide, the GWP100 value (= 21kg-$CO_2$eq/$CH_4$) was used. The emission of $CO_2$ released by the incineration of plastics and rubbers occurs as emission from the incineration sector.

The entries of waste into the final demand (FDM) column refer to the net waste emission from the final demand sector (consumption and investment). The first six waste items ranging from garbage to plant & animal waste correspond to municipal solid waste (MSW), which is mostly generated by household. The final demand sector is the sole generator of discarded durables such as automobiles and appliances (bulky waste).

The net emission from waste treatment sectors represents the outcome of relevant waste conversion processes. Incineration converts its waste feedstock into 3 million tons of ash. Shredding converts discarded durables (automobiles, appliances and other bulky waste) into several waste materials such as 3 million tons of metals, 1 million tons of wood waste, and 1.4 million tons of shredder dust. Note that while the *waste* $\times$ *treatment* matrix gives the outcome (output) of waste conversion, it does not, at least explicitly, give the amount of treatment (the input of feedstock). Given that landfilling is the final form of waste disposal, it involves no conversion process (we neglect leachate). This is the reason why the column referring to landfilling does not have any entry of waste except for $CO_2$ emission.

The WIO takes account of (2) in that it registers the outcome of waste conversion carried out by individual treatment processes. The last column of the lower panel gives the total amount of net emission (row sum) for each waste item, which corresponds to the amount of waste to be treated. For instance, the quantity of garbage that needs to be treated amounts to 16 million tons. Note that the row sum of the lower panel corresponds to (1).

While the WIO in Table 1 gives the amount of waste to be treated, it does not give how it should be *allocated* among each of the three treatment processes. This *allocation problem* does not occur in the pollution abatement model of Leontief [5][6], which is the pioneering application of IO to environmental issues. This is so because Leontief implicitly assumes a *one-to-one correspondence* between wastes and treatment processes. For instance, [5] deals with the simplest case of this correspondence consisting of a single pollutant and its abatement process. The Leontief model thus corresponds to the special case of WIO where the *waste* $\times$ *treatment* matrix is square and diagonal.

Faye Duchin [7] generalized the original Leontief model by allowing for the generation of treatment residues which were absent in the Leontief model. Still, the above-mentioned one-to-one correspondence holds to her model as well.

The assumption of one-to-one correspondence between waste and treatment is hardly applicable to the general case of multiple waste and treatment processes with which we are concerned. The non-squareness of WIO is the rule rather than the exception because in general the number of types of waste is much larger than that of waste treatment processes. Formally, this can be stated as follows. Let $\Theta$ be the set of goods being produced in an economy. Since any good has a potential to become a waste with time, the set of wastes would be as large as that of $\Theta$. On the other hand, the set of goods constituting waste treatment processes is nothing but a tiny subset $\theta$ of $\Theta$! Another reason for non-squareness is the fact that usually multiple treatment processes are available to each waste type. For instance, plastic waste can either be landfilled and/or incinerated.

Table 1: Waste IO Table for Japan 1995

| | goods producing sectors | | | | | | | | | | | | | waste treatment sectors | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AGR | MIN | FOD | WOD | CHE | CEM | MET | MEP | MCN | CNS | UTL | SRV | TRN | INC | LND | SHR | FDM | total |
| AGR | 1715 | 1 | 7660 | 709 | 142 | 1 | 0 | 0 | 154 | 136 | 0 | 1097 | 2 | 0 | 0 | 0 | 4199 | 15815 |
| MIN | 0 | 3 | 0 | 8 | 132 | 593 | 47 | 2 | 2 | 800 | 42 | 1 | 0 | 0 | 0 | 0 | 23 | 1654 |
| FOD | 1081 | 7 | 7267 | 123 | 276 | 27 | 1 | 41 | 286 | 202 | 7 | 6787 | 108 | 0 | 0 | 0 | 33773 | 49985 |
| WOD | 184 | 7 | 1305 | 7277 | 705 | 246 | 6 | 246 | 1300 | 4045 | 130 | 9808 | 725 | 0 | 0 | 0 | 3883 | 29867 |
| CHE | 920 | 31 | 1827 | 1342 | 13108 | 322 | 337 | 661 | 5419 | 2345 | 934 | 8133 | 3554 | 46 | 12 | 3 | 11333 | 50329 |
| CEM | 20 | 0 | 176 | 98 | 206 | 959 | 121 | 127 | 998 | 5609 | 17 | 401 | 3 | 0 | 0 | 0 | 965 | 9700 |
| MET | 0 | 0 | 0 | 0 | 33 | 13 | 1363 | 4673 | 215 | 2 | 0 | 3 | 0 | 0 | 0 | 0 | 176 | 6477 |
| MEP | 23 | 28 | 910 | 444 | 448 | 198 | 4 | 8790 | 9522 | 10368 | 29 | 867 | 105 | 0 | 0 | 0 | 3865 | 35600 |
| MCN | 84 | 12 | 175 | 86 | 67 | 36 | 0 | 125 | 40288 | 1837 | 27 | 7318 | 591 | 96 | 13 | 8 | 77856 | 128618 |
| CNS | 50 | 11 | 138 | 129 | 270 | 136 | 55 | 287 | 370 | 225 | 1141 | 4647 | 629 | 0 | 148 | 0 | 80030 | 88265 |
| UTL | 71 | 45 | 787 | 573 | 1412 | 357 | 323 | 875 | 1352 | 565 | 2303 | 5921 | 907 | -9 | 9 | 31 | 7760 | 23283 |
| SRV | 1500 | 207 | 6906 | 4028 | 7714 | 1422 | 807 | 4054 | 19789 | 14469 | 3557 | 67413 | 15075 | 0 | 0 | 7 | 282052 | 429001 |
| TRN | 728 | 408 | 1827 | 1305 | 1476 | 810 | 386 | 1144 | 2755 | 5107 | 529 | 17158 | 6460 | 104 | 66 | 0 | 24533 | 64796 |
| INC | 20001 | 3 | 3047 | -7561 | 871 | 111 | 229 | 1937 | 2311 | 3602 | 30 | 1778 | 246 | 0 | 0 | 1255 | 32776 | 60638 |
| LND | -5607 | 9188 | -1661 | 8202 | 5680 | -12688 | -32554 | 22557 | 12477 | 27401 | 8796 | 6783 | 511 | 2836 | 0 | 4895 | 20127 | 76942 |
| SHR | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7285 | 7285 |
| | net emission of waste | | | | | | | | | | | | | | | | | |
| grb | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6000 | 0 | 0 | 0 | 0 | 10000 | 16000 |
| ppr | 0 | 0 | 66 | -11460 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 101 | 17829 | 6536 |
| pls | 249 | 1 | 314 | 553 | -117 | 62 | 141 | 524 | 720 | 975 | 14 | 1236 | 144 | 0 | 0 | 229 | 3341 | 8386 |
| mtl | 2 | 1 | 24 | 730 | -234 | 7 | -35549 | 5013 | 9175 | 8424 | 11 | 306 | 21 | 0 | 0 | 3358 | 10679 | 1968 |
| gls | 0 | 0 | -4426 | 18 | 126 | -456 | 96 | 317 | 157 | 1758 | 56 | 4951 | 12 | 0 | 0 | 56 | 4561 | 7225 |
| wds | 19848 | 0 | 1454 | 2626 | 90 | 0 | 0 | 0 | 0 | 2818 | 0 | 0 | 0 | 0 | 0 | 1028 | 1023 | 28887 |
| ash | 0 | 4714 | 222 | 984 | 1627 | -11726 | 2089 | 15079 | 1786 | -9001 | 4757 | 39 | 5 | 2836 | 0 | 0 | 0 | 13412 |
| sld | -5710 | 4333 | 2333 | 7003 | 4006 | -894 | 320 | 1313 | 654 | 11750 | 3814 | 366 | 32 | 0 | 0 | 0 | 0 | 29319 |
| oil | 6 | 3 | 1376 | 155 | 850 | 90 | 368 | 1594 | 1831 | 87 | 20 | 988 | 160 | 0 | 0 | 0 | 0 | 7528 |
| cns | 0 | 139 | 23 | 33 | 204 | 341 | 211 | 655 | 463 | 14192 | 154 | 675 | 382 | 0 | 0 | 0 | 0 | 17472 |
| blk | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3775 | 3775 |
| atm | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5020 | 5020 |
| dst | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1377 | 0 | 1377 |
| CO2 | 5496 | 210 | 5513 | 5981 | 31340 | 23559 | 31053 | 9142 | 3528 | 4399 | 94678 | 21391 | 57073 | 3570 | 4816 | 104 | 36906 | 338759 |

See Tabel 3 for the classification of industries, and Table 2 for the classification of waste items.

Table 2: Allocation of waste to treatment

| | waste | incomplete sorting $S_0'$ incineration | landfill | shredding | complete sorting $S_1'$ incineration | landfill | shredding |
|---|---|---|---|---|---|---|---|
| grb | garbage | 0.90 | 0.10 | 0 | 1.00 | 0.00 | 0 |
| ppr | waste paper & textile | 0.93 | 0.07 | 0 | 1.00 | 0.00 | 0 |
| pls | waste plastics & rubber | 0.59 | 0.41 | 0 | 1.00 | 0.00 | 0 |
| mtl | metal scraps | 0.01 | 0.99 | 0 | 0.00 | 1.00 | 0 |
| gls | waste glass & ceramics | 0.03 | 0.97 | 0 | 0.00 | 1.00 | 0 |
| wds | plant & animal waste | 0.99 | 0.01 | 0 | 1.00 | 0.00 | 0 |
| ash | ash, dust & slag | 0 | 1 | 0 | 0 | 1 | 0 |
| sld | sludge | 0 | 1 | 0 | 0 | 1 | 0 |
| oil | waste oil, acid, & alkali | 1 | 0 | 0 | 1 | 0 | 0 |
| cns | construction waste | 0 | 1 | 0 | 0 | 1 | 0 |
| blk | bulky waste | 0 | 0 | 1 | 0 | 0 | 1 |
| atm | used automobile | 0 | 0 | 1 | 0 | 0 | 1 |
| dst | shredder dust | 0 | 1 | 0 | 0 | 1 | 0 |

Source of $S_0$: [8].

## 2.5 Allocation matrix and square WIO table

The non-square *waste* × *treatment* matrix of the WIO table can be converted to a square matrix by use of the *allocation matrix* $S$ that shows the allocation of each waste item to individual treatment processes when the waste is to be treated [1]. Its $i$ $j$ element $s_{ij}$ refers to the share of waste $j$ which is treated by process $i$. By definition, $\sum_i s_{ij} = 1$ holds. Recycling of a waste item reduces the activity of the treatment to which the waste would otherwise have been submitted.

Table 2 gives two examples of $S$ in its transposed form $S^\top$. Since the present case involves 13 waste items and 3 treatment processes, the corresponding $S$ is a 3 × 13 matrix. $S_1$ refers to a hypothetical case where combustible and incombustible wastes are completely sorted and no mixing up takes place in their treatment. Given a proper flue-gas treatment, the sorting of waste in this way would contribute to minimizing the consumption of landfill capacity, which is a scarce resource in Japan.

Even though incineration has a high priority in the Japanese MSW treatment, from technical and institutional reasons the actual sorting of waste is not complete in the above sense. In the reality, small portions of incombustible wastes like metals and glass get mixed up in incinerator. Furthermore, many Japanese municipalities including the metro Tokyo have adopted the policy *in principle* not to incinerate waste plastics.

The $S_0$ in Table 2 gives our estimates of the representative allocation matrix in Japan for 6 waste items (garbage to plant & animal waste), which constitute a significant portion of MSW. The portion of the estimates corresponding to MSW is based on the survey data of MSW for several Japanese

Table 3: Net disposal of waste under different sorting schemes

| | AGR | MIN | FOD | WOD | CHE | CEM | MET | MEP | MCN | CNS | UTL | SRV | TRN | INC | LND | SHR | FDM | total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | incomplete sorting | | | | | | | | | | | | | | | | | |
| INC | 19856 | 3 | 2922 | -7575 | 873 | 112 | 276 | 1937 | 2306 | 3558 | 30 | 7277 | 246 | 0 | 0 | 1268 | 28776 | 61866 |
| LND | -5462 | 9188 | -1536 | 8216 | 5678 | -12689 | -32600 | 22557 | 12481 | 27446 | 8796 | 7284 | 511 | 2836 | 0 | 4882 | 18657 | 76245 |
| SHR | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8795 | 8795 |
| | complete sorting | | | | | | | | | | | | | | | | | |
| INC | 20103 | 4 | 3210 | -8127 | 823 | 153 | 508 | 2118 | 2552 | 3880 | 34 | 8223 | 305 | 0 | 0 | 1358 | 32194 | 67337 |
| LND | -5709 | 9187 | -1824 | 8768 | 5728 | -12729 | -32833 | 22377 | 12236 | 27123 | 8792 | 6338 | 452 | 2836 | 0 | 4792 | 15240 | 70774 |
| SHR | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8795 | 8795 |

AGR: agriculture, fishery, forestry, MIN: mining , FOD: foods, feeds, tobacco. WOD: woods, paper, printing, publishing.

CHE: chemicals, coal & petroleum products, plastics, rubber, and leather. CEM: glass, cement, stone & clay. MET: basic metals.

MEP: metal products. MCN: machinery. CNS: construction & civil engineering. UTL: utilities. SRV: service. TRN: transport.

INC: incineration. LND: landfill. SHR: shredding.

municipalities [8]. As for the portion from industrial sources, we assumed complete sorting. About one to three percent of incombustibles such as metals and glass get mixed up with combustibles and find their way into incinerator. On the other hand, about 40% of plastic waste ends up in the landfill in spite of its combustibleness.

Multiplication of the $3 \times 13$ matrix $S_0$ from the left of the $13 \times 18$ matrix of the lower panel (except for the last row referring to $CO_2$) of Table 1 gives the $3 \times 18$ matrix in the upper panel of Table 3. In the converted WIO matrix waste treatment processes occur as row elements, whereas prior to the conversion it was waste items that occurred as row elements. Replacing the *waste* $\times$ *sectors* matrix of Table 1 by this *treatment* $\times$ *sectors* matrix yields a squared version of WIO table. Recall that in Table 1 CEM occurred as the single largest user of *ash*. Since *ash* is allocated to landfill by $S$, it occurs in Table 3 as the negative input to CEM of LND in the amount of 12.7 million tons. Adding up the row elements of the *treatment* $\times$ *sectors* matrix, we obtain the activity level of each treatment process, which was not available in the non-square version of WIO in Table 1. The allocation matrix is thus an indispensable component of the WIO accounting system.

Conversion of the non-square matrix by $S_1$ in place of $S_0$ yields the matrix in the lower panel of Table 3. Compared to the matrix in the upper panel obtained from $S_0$, the level of incineration increases from 28.8 million tons to 21.2 million tons while the level of landfilling declines from 18.7 million tons to 15.2 million tons. Use of different allocation matrices changes not only the volume of waste allocated to each treatment, but also its composition. As we shall see below, the performance of treatment processes can significantly be affected by a change in waste composition.

# 3 The WIO model

## 3.1 The linear model

Denote by $X_{ij}$, $(i = 1,13,\ j = 1,16)$ the elements of the inter-industry matrix in the upper panel of Table 1, by $W_{ij}$, $(i = 1,13,\ j = 1,16)$ the elements of the net-emission matrix in the lower panel, by $f_X$ the column of final demand referring to goods, by $f_W$ the column of final demand referring to waste emission, by $X$ the $13 \times 1$ column of output level, and by $Z$ the $3 \times 1$ column of the level of waste treatment. We then have

$$X_i = \sum_{j=1}^{16} X_{ij} + f_{X_i},\ i = 1,\cdots,13, \tag{4}$$

$$W_k = \sum_{j=1}^{16} W_{kj} + f_{W_k},\ k = 1,\cdots,13, \tag{5}$$

$$Z_l = \sum_{j=1}^{16} \left( \sum_k s_{lk} \left(W_{kj} + f_{W_k}\right) \right),\ l = 1,2,3. \tag{6}$$

Let $a_{ij}^X$, $a_{ij}^Z$, $g_{kj}^X$ and $g_{kj}^Z$ be the input and net-emission coefficients give by

$$a_{ij}^X = X_{ij}/X_j,\ (i,j=1,\cdots,13), \tag{7}$$

$$a_{il}^Z = X_{ij}/Z_j,\ (i=1,\cdots,13,\ l=1,\cdot,3), \tag{8}$$

$$g_{ij}^X = W_{ij}/X_j,\ (i=1,\cdots,13,\ j=1,\cdots,13), \tag{9}$$

$$g_{il}^Z = W_{ij}/Z_l,\ (i,j=1,\cdots,13,\ l=1,\cdot,3). \tag{10}$$

(4) and (6) can then be rewritten as

$$X_i = \sum_{j=1}^{13} a_{ij}^X X_j + \sum_{m=1}^{3} a_{im}^Z Z_m + f_{X_i},\ i=1,\cdots,13, \tag{11}$$

$$Z_l = \sum_{k=1}^{13} S_{lk}\left(\sum_{j=1}^{13} g_{kj}^X + \sum_{m=1}^{3} g_{km}^Z + f_{W_k}\right),\ l=1,2,3. \tag{12}$$

Using the matrix notation $A_X := [a_{ij}^X]$, $A_Z := [a_{ij}^Z]$, $G_X := [g_{ij}^X]$, and $G_Z := [g_{ij}^Z]$, these equations can be represented by

$$\begin{pmatrix} X \\ Z \end{pmatrix} = \begin{pmatrix} A_o & A_z \\ SG_o & SG_z \end{pmatrix}\begin{pmatrix} X \\ Z \end{pmatrix} + \begin{pmatrix} f_X \\ S f_W \end{pmatrix}. \tag{13}$$

Provided the input-and emission coefficients *remain* constant, and the relevant matrices are invertible, we could solve (13) for $X$ and $Z$, and obtain

$$\begin{pmatrix} X \\ Z \end{pmatrix} = \begin{pmatrix} I-A_o & -A_z \\ -SG_o & I-SG_z \end{pmatrix}^{-1}\begin{pmatrix} f_X \\ S f_W \end{pmatrix}. \tag{14}$$

The inverse matrix in the right hand side of (14) corresponds to the well known Leontief inverse matrix in IO analysis. Using (14) we could analyze economic and environmental effects of alternative scenarios with regard to life style ($f_X$ and $f_W$), technology ($A$, $G$), and institution ($S$).

For instance, effects of the introduction of a new recycling technology in an industry sector can be implemented by replacing the column vector of input- and emission coefficients of that sector by the one representing the new technology. Similarly, the introduction of a new waste treatment technology can be implemented by introducing a new column vector of input- and emission coefficients referring to that technology.

Environmental loads associated with economic activity can easily be analyzed, provided simple fixed coefficients approximate the association. For instance, let $e_X$ and $e_Z$ be the emission of $CO_2$ from fossil fuel origin per unit of output and treatment activity, and $f_E$ be the direct emission from final demand. We then have

$$\text{total emission of } CO_2 = e_X X + e_Z Z + f_E. \tag{15}$$

To the extent that the linearity assumption is acceptable, extensions of this method to other substances such as $NO_x$ are straightforward.

Table 3.1 gives the squared matrix of input-and emission coefficients, which correspond to the expression inside the first square brackets in the right hand side of (13). The emission coefficients of $CO_2$ are obtained analogous to the other emission coefficients. Table 5 then gives the Leontief inverse matrix, the $i-j$ element of which refers to the amount of $i$-th output or activity that is directly and indirectly required to satisfy a unit of final demand for $j$. Unique to WIO is the elements referring to the direct and indirect demand for waste treatment given by the three rows at the bottom of Table 5. For instance, the satisfaction of one billion yen of final demand for food induces 130 tons of incineration and 70 tons of landfill. As for direct requirements, Table 3.1 shows that a unit output of the food industry *saves* incineration by 60 tons while consumes landfill by 80 tons. Consideration of indirect effects thus turns the food industry from net saver to net user of incineration.

## 3.2 Nonlinearity of waste treatment technology

### 3.2.1 Passive nature of waste treatment

In waste management, it is usual to characterize waste by its composition of combustibles, water, and ash. These are parameters of great importance in waste management that have profound effects on the performance of waste treatment. For instance, the extent to which a given volume of waste is reduced by incineration depends on its composition of ash, and the latter depends on the degree waste is separated before entering the incinerator. Another example is incineration with power generation from waste heat. An increased material recycling of waste paper and plastics reduces the proportion of combustible waste entering into the incinerator, and lowers the calorific value of waste heat. This may reduce the amount of power obtained from waste heat, and could even make the incinerator fuel dependent. In other words, the waste treatment sector has inherently passive nature in the sense that it is required to adjusts its treatment processes to whatever composition and quantity of waste generated by industry and household.

As these examples suggest, waste management policy can affect input- and emission coefficients of the waste treatment sector by altering the composition of waste allocated to individual treatment processes. In other words, the WIO model has a non-linear nature in the sense that its coefficients can be affected by a change in waste management policy.

The WIO model remains linear in so far as the characteristics of waste allocated to each of the treatment processes are fixed. When these characteristics are altered, however, the coefficients of the model may also change, and the linearity may no longer hold. This point is important because the scenario analysis conducted below is concerned with the alteration of waste management policy. Consideration of this intrinsically non-linear nature of waste treatment is another distinguishing feature of the WIO model.

In Section 2.5 above, we saw that complete sorting of waste as represented by $S_1$ increases the

Table 4: The input-and emission coefficients matrix of WIO: $S_0$

| | AGR | MIN | FOD | WOD | CHE | CEM | MET | MEP | MCN | CNS | UTL | SRV | TRN | INC | LND | SHR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AGR | 0.108 | 0.000 | 0.153 | 0.024 | 0.003 | 0.000 | 0.000 | 0.000 | 0.001 | 0.002 | 0.000 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 |
| MIN | 0.000 | 0.002 | 0.000 | 0.000 | 0.003 | 0.061 | 0.007 | 0.000 | 0.000 | 0.009 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| FOD | 0.068 | 0.004 | 0.145 | 0.004 | 0.005 | 0.003 | 0.000 | 0.001 | 0.002 | 0.002 | 0.000 | 0.016 | 0.002 | 0.000 | 0.000 | 0.000 |
| WOD | 0.012 | 0.004 | 0.026 | 0.243 | 0.014 | 0.025 | 0.001 | 0.007 | 0.010 | 0.046 | 0.006 | 0.023 | 0.011 | 0.000 | 0.000 | 0.000 |
| CHE | 0.058 | 0.019 | 0.037 | 0.045 | 0.259 | 0.033 | 0.052 | 0.019 | 0.042 | 0.027 | 0.040 | 0.019 | 0.055 | 0.001 | 0.000 | 0.000 |
| CEM | 0.001 | 0.000 | 0.004 | 0.003 | 0.004 | 0.099 | 0.019 | 0.004 | 0.008 | 0.064 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 |
| MET | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 | 0.210 | 0.131 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| MEP | 0.001 | 0.017 | 0.018 | 0.015 | 0.009 | 0.020 | 0.001 | 0.246 | 0.073 | 0.118 | 0.001 | 0.002 | 0.002 | 0.000 | 0.000 | 0.000 |
| MCN | 0.005 | 0.007 | 0.003 | 0.003 | 0.001 | 0.004 | 0.000 | 0.004 | 0.310 | 0.021 | 0.001 | 0.017 | 0.009 | 0.002 | 0.000 | 0.001 |
| CNS | 0.003 | 0.006 | 0.003 | 0.004 | 0.005 | 0.014 | 0.008 | 0.008 | 0.003 | 0.003 | 0.049 | 0.011 | 0.010 | 0.000 | 0.002 | 0.000 |
| UTL | 0.004 | 0.027 | 0.016 | 0.019 | 0.028 | 0.037 | 0.050 | 0.025 | 0.010 | 0.006 | 0.098 | 0.014 | 0.014 | 0.000 | 0.000 | 0.004 |
| SRV | 0.095 | 0.125 | 0.138 | 0.134 | 0.153 | 0.147 | 0.124 | 0.114 | 0.152 | 0.164 | 0.152 | 0.158 | 0.232 | 0.000 | 0.000 | 0.001 |
| TRN | 0.046 | 0.247 | 0.037 | 0.044 | 0.029 | 0.084 | 0.060 | 0.032 | 0.021 | 0.058 | 0.023 | 0.040 | 0.100 | 0.002 | 0.001 | 0.000 |
| INC | 1.264 | 0.002 | 0.061 | -0.252 | 0.017 | 0.011 | 0.035 | 0.054 | 0.018 | 0.041 | 0.001 | 0.004 | 0.004 | 0.000 | 0.000 | 0.143 |
| LND | -0.354 | 5.561 | -0.033 | 0.273 | 0.112 | -1.309 | -5.022 | 0.633 | 0.096 | 0.311 | 0.376 | 0.016 | 0.008 | 0.046 | 0.000 | 0.557 |
| SHR | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| CO2 | 0.347 | 0.127 | 0.110 | 0.199 | 0.620 | 2.430 | 4.790 | 0.256 | 0.027 | 0.050 | 4.045 | 0.050 | 0.880 | 0.058 | 0.063 | 0.012 |

See Tabel 3 for the classification of industries.

Table 5: The Leontief inverse matrix of WIO

| | AGR | MIN | FOD | WOD | CHE | CEM | MET | MEP | MCN | CNS | UTL | SRV | TRN | INC | LND | SHR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AGR | 1.140 | 0.004 | 0.208 | 0.039 | 0.009 | 0.005 | 0.003 | 0.003 | 0.006 | 0.007 | 0.003 | 0.009 | 0.004 | 0.000 | 0.000 | 0.000 |
| MIN | 0.001 | 1.003 | 0.001 | 0.001 | 0.004 | 0.069 | 0.011 | 0.003 | 0.002 | 0.014 | 0.003 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 |
| FOD | 0.096 | 0.012 | 1.193 | 0.016 | 0.015 | 0.011 | 0.007 | 0.008 | 0.012 | 0.011 | 0.006 | 0.025 | 0.010 | 0.000 | 0.000 | 0.000 |
| WOD | 0.031 | 0.022 | 0.058 | 1.335 | 0.038 | 0.053 | 0.016 | 0.026 | 0.036 | 0.079 | 0.022 | 0.042 | 0.031 | 0.000 | 0.000 | 0.000 |
| CHE | 0.112 | 0.064 | 0.097 | 0.103 | 1.372 | 0.081 | 0.110 | 0.070 | 0.108 | 0.072 | 0.076 | 0.045 | 0.100 | 0.001 | 0.000 | 0.001 |
| CEM | 0.004 | 0.003 | 0.007 | 0.007 | 0.008 | 1.113 | 0.028 | 0.012 | 0.016 | 0.074 | 0.006 | 0.003 | 0.003 | 0.000 | 0.000 | 0.000 |
| MET | 0.002 | 0.005 | 0.006 | 0.006 | 0.005 | 0.009 | 1.267 | 0.222 | 0.028 | 0.028 | 0.003 | 0.002 | 0.002 | 0.000 | 0.000 | 0.000 |
| MEP | 0.010 | 0.032 | 0.036 | 0.033 | 0.022 | 0.040 | 0.007 | 1.335 | 0.148 | 0.168 | 0.015 | 0.011 | 0.011 | 0.000 | 0.000 | 0.000 |
| MCN | 0.019 | 0.024 | 0.018 | 0.014 | 0.012 | 0.017 | 0.008 | 0.016 | 1.460 | 0.042 | 0.011 | 0.033 | 0.025 | 0.002 | 0.000 | 0.002 |
| CNS | 0.008 | 0.026 | 0.011 | 0.014 | 0.015 | 0.023 | 0.008 | 0.020 | 0.013 | 1.013 | 0.060 | 0.016 | 0.017 | 0.000 | 0.002 | 0.001 |
| UTL | 0.016 | 0.044 | 0.034 | 0.040 | 0.051 | 0.060 | 0.080 | 0.058 | 0.034 | 0.028 | 1.118 | 0.024 | 0.028 | 0.000 | 0.000 | 0.004 |
| SRV | 0.202 | 0.273 | 0.287 | 0.282 | 0.296 | 0.295 | 0.264 | 0.274 | 0.345 | 0.309 | 0.252 | 1.241 | 0.353 | 0.001 | 0.001 | 0.003 |
| TRN | 0.081 | 0.301 | 0.083 | 0.088 | 0.066 | 0.146 | 0.103 | 0.083 | 0.067 | 0.107 | 0.050 | 0.064 | 1.135 | 0.002 | 0.001 | 0.001 |
| INC | 1.444 | 0.009 | 0.327 | -0.280 | 0.030 | 0.013 | 0.049 | 0.082 | 0.039 | 0.046 | 0.006 | 0.011 | 0.007 | 1.000 | 0.000 | 0.143 |
| LND | -0.310 | 5.610 | -0.061 | 0.366 | 0.196 | -1.032 | -6.277 | -0.216 | 0.127 | 0.311 | 0.464 | 0.046 | 0.049 | 0.046 | 1.001 | 0.565 |
| SHR | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |

See Table 3 for the classification of industries.

volume of incineration. It is important to notice that this increase is associated with a change in the composition of waste entering into and leaving the incineration process as well. Under $S_1$, the calorific value of incinerating waste per unit increases due to the inclusion of all waste plastics, and the generation of residue per unit declines due to the exclusion of incombustibles. Provided it is possible to use waste heat for power generation, more power could be obtained per unit of waste under $S_1$ than under $S_0$. The landfill consumption of incineration may also decline because of the decline in the ash content of waste feedstock.

In order to take account this non-linear nature of waste treatment in the WIO model, we need to resort to the chemistry and engineering of waste treatment. What is needed is not economic but engineering model of individual treatment processes describing the quantitative relationships between characteristics of waste feedstock, inputs of utilities, chemicals, specification of the equipment, and outputs. Let $F_Z$ be a set of these engineering sub-models which are relevant to the WIO. The algorithm of WIO can then be given by Figure 1. Starting from given values of $A_X$, $G_X$ (technology of gods producing sectors), final demand $(f)$, allocation matrix $S$, and the *initial value* of net waste emission $W_0$, the submodel $F_Z$ determines the coefficients of waste treatment $A_Z$, $G_Z$. Combined with the coefficients of goods producing sectors, they determine the level of output and treatment as well as the associated net emission of waste $W$. Since $W$ may differ from the starting value $W_0$, we replace the latter by the former, and re-compute $A_Z$, $G_Z$. The process iterates until $W$ clears a convergence criterion.

### 3.2.2 The engineering model of Tanaka and Matsuto

Professors Nobutoshi Tanaka and Toshihiko Matsuto of Hokkaido University developed a computer based engineering model of waste treatment technologies, which could assist municipal waste managers in designing optimal combinations of alternative technologies under given local restrictions and policy objectives [8]. This model describes the behavior of individual treatment processes under alternative waste compositions. For instance, the model enables us to obtain the amount of electricity and residue generated from waste feedstock of a given composition by operating the incinerator of a given specification. In the following, we use the model of Tanaka and Matsuto as a engineering submodel of waste treatment.

As an example for illustrating the non-linear nature of WIO, we consider effects of alternative sorting options on the input coefficients of waste incineration process. In Japan, there are about 2000 public MSW incinerators and 5000 private incinerators operated by waste management firms. These incinerators differ widely in terms of size and the way waste heat is utilized. In Table 6, the panel termed *Control* shows the composition as of 1995 of incinerators by three major types based on size and heat utilization. About 34% of them were equipped with power generation from waste heat, whereas more than half the total capacity consisted of small batch type incinerators with no

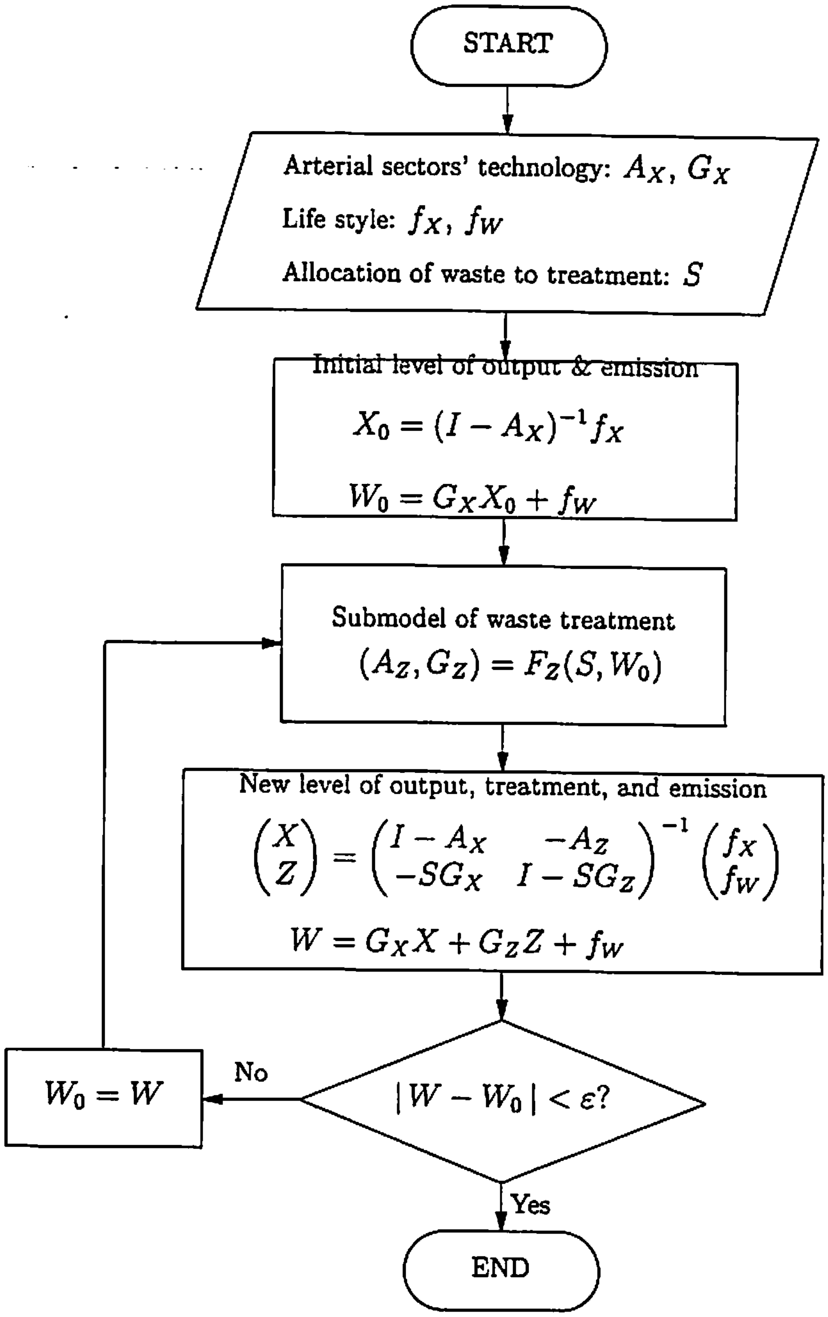


Figure 1: Algorithm of WIO

energy recovery facilities. Responsible for the presence of many small incinerators is the principle that MSW should be disposed within the boundary of each municipality. In Japan, there are more than three thousand municipalities!

Table 6: Composition of incinerators

| scenario/incinerator types | plant size t/d | share of capacity | plants |
|---|---|---|---|
| *Control*: current state as of 1995 | | | |
| 1. full continuous with power generation | 483 | 0.343 | 231 |
| 2. full continuous without power generation | 177 | 0.144 | 264 |
| 3. non-full continuous | 26 | 0.513 | 6441 |
| Total | | 1.000 | 6936 |
| *Regional*: Regional treatment of both MSW and industrial waste | | | |
| 1. full continuous with power generation | 500 | 1 | 650 |

Source of *Control*: [9].

Table 7 shows the capacity weighted mean of input coefficients of three incineration processes under alternative sorting and disposal options. (A) gives the weighted input coefficients under $S_0$, with the weights given by *share of capacity* in *Control* of Table 6. Note that they correspond to the input coefficients of incineration in Table 3.1. (B) differs from (A) in that is it was obtained using the allocation matrix $S_1$ that corresponds to complete sorting, while the weights remain the same as (A). Note that electricity input changes from -.0001 to -.0004 because of the increased power generation that results from the increased calorific value of waste feedstock. The input of landfill (emission of residue) slightly declines from 0.0468 to 0.046 due to the decrease in the ash content of waste feedstock.

(C) is an extreme case of regional disposal where all the incinerators of types 2 and 3 are replaced by those of type 1 as is given by *Regional* in the bottom of Table 6. The allocation matrix is the same $S_1$ as in (B). In this scenario, replacement of a large number of small incinerators by large ones decreases the number of operating incinerators to 10% of *Control*. It then follows that waste has to be transported over longer distances as before to reach the nearest incinerator. We assume that the transportation requirement of a unit of waste increased to 4 times the present value. We find that electricity obtained from a ton of waste increases 15 times that of (B), and that the emission of residue per ton of incineration further declines by 2 kg from 46 kg to 44 kg. This decline in landfill consumption is due to the fact that the incinerator of type 1 has smaller ignition loss (this takes a smaller value for larger incinerators) and is equipped with the melting and solidification facility that reduces the weight as well as volume of the residue.

Table 7: Input coefficients of incineration under alternative scenarios

| Allocation matrix disposal | (A) $S_0$ control | (B) $S_1$ control | (C) $S_1$ regional |
|---|---|---|---|
| AGR | 0.0000 | 0.0000 | 0.0000 |
| MIN | 0.0000 | 0.0000 | 0.0000 |
| FOD | 0.0000 | 0.0000 | 0.0000 |
| WOD | 0.0000 | 0.0000 | 0.0000 |
| CHE | 0.0008 | 0.0008 | 0.0008 |
| CEM | 0.0000 | 0.0000 | 0.0000 |
| MET | 0.0000 | 0.0000 | 0.0000 |
| MEP | 0.0000 | 0.0000 | 0.0000 |
| MCN | 0.0016 | 0.0016 | 0.0020 |
| CNS | 0.0000 | 0.0000 | 0.0000 |
| UTL | -0.0001 | -0.0004 | -0.0061 |
| SRV | 0.0000 | 0.0000 | 0.0000 |
| TRN | 0.0017 | 0.0017 | 0.0068 |
| INC | 0.0000 | 0.0000 | 0.0000 |
| LND | 0.0468 | 0.0460 | 0.0438 |
| SHR | 0.0000 | 0.0000 | 0.0000 |

See Tabel 3 for the classification of industries.

# 4 Application

## 4.1 Scenarios etc.

We now turn to empirical application of the WIO to evaluating economic and environmental effects of three alternative waste management scenarios with respect to regional disposal and sorting. Scenario 1 refers to the effect of complete sorting as given by $S_1$ under the current composition of incinerator types, whereas Scenario 2 refers to that of regional disposal with the current sorting pattern given by $S_0$. Finally, Scenario 3 refers to the combined effect of both complete sorting and regional disposal.

Actual analysis is carried out by substituting the relevant coefficient values into (14) and comparing the solution with that obtained under the default settings that serves as *Control* in the following analysis. For instance, we obtain the solution relevant to Scenario 2 by replacing the coefficients vector of incinerator by (C) in Table 7 while keeping $S$ at $S_0$. The additional replacement of $S_0$ by $S_1$ yields the solution of Scenario 3. *Control* refers to the solution of (14) with the input coefficients (A) in Table 7 and $S_0$.

Common to waste disposals in Japan, Denmark and Switzerland is the high proportion (around 3 to 1) of incineration relative to landfilling. The opposite applies to the US and Germany where the ratio is around 1 to 3. It is noteworthy that in Denmark since 1997 landfilling of "waste suitable for incineration" is prohibited [10]. As for the proportion of incinerator types, however, Denmark differs from Japan in that each MSW incinerator is equipped with facility for recovering waste heat.

The last scenario thus corresponds to the "Danish Model".

Table 8 shows the computation results in terms of the rate of change relative to *Control* in percentage. The term "net emission" refers to the emission of waste net of recycling. This is the amount that needs to undergo waste treatment. We use the total sum of sectoral gross output (equal to sales value up to changes in inventory) and total employment as proxies for overall economic costs associated with each Scenario. Recall that in our evaluation we keep the level of final demand constant, and obtain the level of production and disposal that is required for its satisfaction. An increase (decrease) in the total gross output then implies that we need to produce more (less) to satisfy the same level of final demand, and hence a decline (an increase) in the level of overall productivity. An analogous interpretation applies to employment as well.

## 4.2 Results

Sorting of combustibles and non-combustibles (Scenario 1) increases incineration by 8.5%, ash by 0.5%, and $CO_2$ by 0.4%, but reduces landfill consumption by 6.4% in weight and by 17.3% in volume. The increase in $CO_2$ is mainly due to the incineration of the part of waste plastics that was previously landfilled, since landfilled plastics are not supposed to decompose. Sorting, however, could also contribute to the reduction of $CO_2$ by increasing the quantity of waste power generation because it raises the calorific value of waste feedstock.

In fact, sorting reduces the quantity of commercial power generation by 0.1%, and the associated output of mining, petroleum & coal by 0.035%. The increase in $CO_2$ by 0.38% should thus be interpreted as the result of canceling out of these mutually opposite effects. Given that the additionally obtained waste heat is not fully utilized under the current composition of incinerators, the net effect was the increase in emission. The total of sectoral gross output and employment respectively decreases by 0.005% and 0.002%. Sorting leads to a marginal increase in overall productivity.

We now turn to Scenario 2 which is characterized by effective utilization of waste heat, whereas the pattern of sorting remains mixed as in *Control*. Even though the calorific value of waste feedstock remains unchanged, its effective utilization substitutes commercial power generation by 1.4% and reduces $CO_2$ emission by 0.4%. While regional disposal increases transport requirement by 0.5%, the associated increase in $CO_2$ emission due to fuel consumption is more than offset by power generation from waste heat. Reduction of commercial power generation reduces the emission of fly ash from coal firing power stations. Combined with the conversion of incineration residue into molten slag, this reduces landfill consumption by 0.3% in weight and 0.8% in volume.

Incinerators of the type considered in this scenario are quite capital intensive and require substantially higher amount of expenditure for repair and maintenance per activity than the average type considered in Scenario 1. Combined with the increase demand for transport vehicles, this leads to the increase in machinery output by 0.03%, and metal output by 0.01%. The latter is responsible for the increased emission of waste oil, acid and alkali by 0.03%. When it comes to macro economic costs, gross output is increased by 0.01% and employment by 0.04%. This marginal decline in overall labor productivity implies the increasing share of industrial sectors with lower labor productivity such as transport in the economy.

Finally, we consider Scenario 3, which is a hybrid of Scenarios 1 and 2. Its effect of saving landfill consumption exceeds that of Scenario 1 due to the factor mentioned above. While the $CO_2$ reducing effect of Scenario 2 is mitigated by the increased incineration of waste plastics and rubber, it is still -0.16%. As for overall productivity, there is no sigh of decline in terms of gross output, whereas in terms of employment we find the same level of decline as in Scenario 2.

Landfill capacity is a scare resource in Japan. The saving of its consumption should be pursued with the highest priority while keeping consistency with the reduction of $CO_2$ emission from fossil fuel origins. Our result indicates that Scenario 3 is the one that is best suited to this objective. In other words, the "Danish model" is effective in reducing landfill consumption and $CO_2$ emission while being cost neutral in terms of total gross output.

## 5 Concluding Remarks

In closing the paper we point out current limitations of the WIO and future directions for research. The analysis in this paper has been static, and no aspect of the dynamic process, where goods get converted into waste, was considered. Proper consideration of this dynamic aspect is of great importance for analyzing issues of durable waste such as buildings, structures, automobiles, and appliances. At the moment, the WIO is a "open model" because there is no link between final demand (consumption and investment) for durables and the accumulation and discarding process of durables over time. Closing of this link is an important step toward dynamic extension of the WIO model.

While economists have developed several "dynamic input-output models", which describe the accumulation and decaying process of durables, they did not consider any aspect of waste. In fact, in these models decayed durables simply "evaporate" and disappear from the scene of interest. Furthermore, any good including durables is measured only in monetary units and physical aspects of it are no considered.

From the point of view of a "good", what matters for a durable is its performance in its totality as a product. Once this durable is converted into waste, however, what matters is no longer its totality but its composition (metals, plastics, hazardous materials etc) and the easiness with which it can be decomposed. Since the IO table provides information on the composition of a product via its input coefficients, what is left for the WIO will be to keep the trace of this information in the accumulation and decaying process of the product.

Table 8: Effects of Alternative Waste Management Scenarios

Rate of change in % relative to *Control*

| scenario<br>disposal<br>allocation matrix | 1<br>*Control* [a]<br>$S_1$ | 2<br>Regional<br>$S_0$ | 3<br>Regional<br>$S_1$ |
|---|---|---|---|
| sectoral output | | | |
| AGR | -0.001 | 0.000 | -0.001 |
| MIN | -0.035 | -0.037 | -0.084 |
| FOD | 0.000 | 0.002 | 0.001 |
| WOD | -0.003 | 0.003 | -0.003 |
| CHE | 0.010 | 0.038 | 0.046 |
| CEM | -0.021 | -0.002 | -0.025 |
| MET | -0.004 | 0.016 | 0.012 |
| MEP | -0.006 | 0.010 | 0.003 |
| MCN | 0.006 | 0.033 | 0.041 |
| CNS | -0.027 | -0.016 | -0.047 |
| UTL | -0.100 | -1.443 | -1.863 |
| SRV | -0.002 | 0.010 | 0.007 |
| TRN | 0.003 | 0.519 | 0.564 |
| net emission of waste | | | |
| grb | 0.000 | 0.000 | 0.000 |
| ppr | 0.000 | 0.002 | 0.001 |
| pls | -0.003 | 0.020 | 0.018 |
| mtl | -0.004 | 0.010 | 0.005 |
| gls | -0.007 | -0.006 | -0.016 |
| wds | -0.001 | -0.001 | -0.003 |
| ash | 0.474 | -0.624 | -0.201 |
| sld | -0.013 | -0.017 | -0.035 |
| oil | 0.006 | 0.028 | 0.035 |
| cns | -0.026 | -0.012 | -0.042 |
| waste treatment/ effluents | | | |
| incineration | 8.466 | -0.001 | 8.465 |
| landfill: weight | -6.429 | -0.331 | -6.792 |
| landfill: volume | -17.265 | -0.783 | -18.067 |
| $CO_2$ | 0.384 | -0.438 | -0.162 |
| macro economic cost | | | |
| gross output | -0.005 | 0.010 | -0.001 |
| employment | -0.002 | 0.037 | 0.036 |

a: *Control* corresponds to *scenario* 1 with $S_1$ replaced by $S_0$

See Tabel 3 for the classification of industries, and Table 2 for that of waste items.

The easiness of decomposing durables depends on the way they are designed, and constitutes one important factor of a new paradigm of product design termed EcoDesign and/or Design for Environment (DFE). The empirical analysis in this paper has been limited to the so-called End of Pipe (EOP) case where waste treatment takes care of whatever waste generated by given level of production and consumption. EcoDesign and/or DFE represent a substantial departure from EOP because it could dramatically change the way products are designed, used, and even owned. While a preliminary analysis of the recycling of electrical appliances by use of WIO is available [11], the consideration of EcoDesign aspects within the framework of WIO is yet to be initiated.

The scenarios in this paper are "hand-made" in the sense that they were derived in a rather ad-hoc way. We obtained for each scenario the associated level of effluents and landfill consumption, and used them to evaluate the scenarios. We could have proceeded the other way round by first setting up objective functions (for instance, minimization of landfill consumption) and solving for the model subject to constraints referring to final demand, available treatment capacity and so on. This will represent the re-formulation of WIO as a optimization model.

The last point is concerned with the extension of WIO over space. In this paper we have not considered any aspect of space, treated Japan as a single spatial unit except for the ad-hoc consideration of waste transportation associated with regional disposal, and ignored any impacts of Japanese imports on the waste emission in foreign countries. A systematic analysis of waste transport requires explicit consideration of regional aspects, which could be facilitated by incorporating regional IO tables into the WIO system. In Japan, for instance, the government publishes regional IO tables on regular basis.

Extension of WIO outside the national boundary will be an important step toward understanding the global link between trade and waste flow. Just like the case of regional extension within the national boundary, here too, we can make use of the existing body of public data system. The data system relevant for the present case is "international IO table', which describes the inter-industry flow of goods and services among trading countries. The first international IO table was the US-Japan table for 1985. Since then, a number of international IO tables have been developed in Japan including the tables for EU-Japan, Taiwan-Japan, and Korea-Japan, among others. Once their national WIOs were available for the group of countries concerned, we would be able to develop its international counterpart by exploiting the international interdependence provided by the international IO table. Extension over time and space consist future directions for research of WIO.

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