Reduction of Industrial Waste and CO_2 Emission:

Evidence from Microdata linked with the Input-Output Table Japan

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1. Introduction

"Reduce, Reuse and Recycle" (3R) of municipal and industrial wastes is both necessary for resource management and urgent for one of the major social issues on scarce space area for waste disposal. According to "Discharge and Treatment of Industrial Waste" by the Ministry of Environment (MOE), recycled industrial waste has increased from 38% of the total discharge in 1990 to 51% in 2004, and final disposal has decreased from 23% to 6% for the same period. Incorporating establishment data by the industrial waste survey for 2005 (the Ministry of Economy, Trade and Industry, METI) into the 2000 Input-Output Table Japan, we obtain that direct and indirect repercussions of waste discharges by production of goods and services.

There are at least two reservations on the 3R for wastes and reducing CO_2 emission. Firstly, the METI's industrial waste survey reports that most of intermediately treated wastes are transferred to industrial waste disposers. It depends on how the industrial waste disposer treats their wastes (inputs). Secondly, CO_2 emissions from fossil fuels may increase with higher recycling rate, as our previous result on paper recycling shows.

Most of the commodities are not designed for reducing industrial waste and CO_2 emissions from its materials (indirect repercussions). Our detail estimates provide useful information necessary to reduce commodity's waste discharges from upstream sectors. Furthermore, we must assess CO_2 emissions of the entire economic systems depending on volumes of recycled inputs, disposition to landfill, or heat recovery.

2. Survey

Waste management analyses using an input-output table have been accumulated in Japan. We would like to introduce here some examples of waste management analysis.

KEO Research Group for Environmental Issues (1996) has constructed the *Input-Output Table for Environmental Analysis* that describes energy and waste flow in accompanying tables. To conduct recycle flow of industrial wastes, they have segmentalized the input-output table and made scenario analyses.

The research group centered on Prof. Nakamura in Waseda University has focused on municipal and industrial wastes and developed the *Waste Input-Output Table* (WIO) (Kondo *et al.* 2002, Nakamura and Kondo 2002a, 2002b, 2006a, 2006b, Kondo and Nakamura 2004, 2005, Takase *et al.* 2005, Nakamura and Nakajima 2005 among others). Waste management services by municipal and industrial waste are described as endogenous sectors in the WIO. They have also estimated not only lifecycle environmental load of technologies but their lifecycle cost.

Kagawa *et al.* have conducted the national and regional input-output model for waste analysis (Kagawa et al. 2003, 2004).

However, there have been no previous cases in which the microdata of the industrial waste survey and the input-output table are linked as this study.

3. Data

The industrial classification of the industrial waste survey for 2005 (METI) is based on the eleventh revision of the Japan Standard Industrial Classification (JSIC). Thus the classification is consistent with the industrial classification of *Census of Manufactures* 2005 (METI). The comparison between the value of manufactured goods shipments of the industrial waste survey and that of the *Census of Manufactures* is as follows.

Table 1

The industrial waste survey covers not only manufactures but also coal mining, electricity and town gas. Below tabulates the shipment value of the industrial waste survey and the output of the *Extended Input-Output Table* 2005 (METI) in these three industries.

Table 2

Using the ratio by industry of shipment value of the industrial waste survey to that of the *Census of Manufactures* or the *Extended Input-Output Table*, the industrial waste discharge, the recycled waste, the intermediately treated waste and the final disposal of sampling establishments are expanded.[1] On the other side, the expanded industrial waste data is reported in the industrial waste survey. According to table 3, the expanded waste discharge in the industrial waste survey (112,518,000 tons) is less than the estimates using the *Census of Manufactures* (137,673,640 tons) and the *Extended Input-Output Table* (120,990,481 tons).

Table 3

To allocate consistently value by establishment of the industrial waste survey to activities of the input-output table, we must consider 1) adjustment of sector definition and 2) difference of survey period.

The bridge table between industries of the *Census of Manufactures* and activities of the input-output table is prepared in the *Input-Output Table*. Using the bridge table, we can allocate the shipment value of the industrial waste survey to the output by activity of the input-output table. However, the eleventh revision of JSIC must be converted into the tenth revision, because the bridge table in the latest benchmark input-output table, the *Input-Output Table* 2000 is based on the tenth revision of JSIC.

We have assessed the industrial waste data on the basis of the shipment value of the *Census of Manufactures* in 2005. Although the latest benchmark year of the input-output table is 2000, we have utilized only the input-output structure, input coefficients in 2000. The price adjustment based on the deflator of the *Extended Input-Output Table* 2005 is required, because the price index in this study is not 2005-base but 2000-base.

Shipment value : **x_IO =T_io * Ccmio * T_jsc * Cjsc * sZc**
Waste discharge : **w_IO =T_io * Ccmio * T_jsc * Cjsc * Wt**
Intermediately treated waste : **v_IO =T_io * Ccmio * T_jsc * Cjsc * Vt**
Recycled waste : **u_IO =T_io * Ccmio * T_jsc * Cjsc * Ut**
Final disposal : **t_IO =T_io * Ccmio * T_jsc * Cjsc * Tt**

sZc : Shipment value by industry of the industrial waste survey
Wt : Waste discharge by industry of the industrial waste survey
Vt : Intermediately treated waste by industry of the industrial waste survey

[1] Note that the industrial waste discharge is not always proportional to the shipment value.

Ut : Recycled waste by industry of the industrial waste survey
Tt : Final disposal by industry of the industrial waste survey
Cjsc : Matrix converting the 11-th revision of JSIC into the 10-th
T_jsc : Matrix converting the JSIC into the industrial classification of the *Census of Manufactures*
Ccmio : Matrix converting the industrial classification of the *Census of Manufactures* into the basic sector classification of the input-output table
T_io : Matrix converting the basic sector classification of the input-output table into the squared sector classification (399 sectors)
x_IO : Output by activity of the input-output table
w_IO : Waste discharge by activity of the input-output table
v_IO : Intermediately treated waste by activity of the input-output table
u_IO : Recycled waste by activity of the input-output table
t_IO : Final disposal by activity of the input-output table

The industrial waste discharge, intermediately treated waste, recycled waste and final disposal per unit of output are calculated by following two methods. The one method (method 1) is the industrial waste data converted into the classification of the input-output table (w_IO, v_IO, u_IO, t_IO) is divided by the shipment value converted in a similar way (x_IO). The shipment value is evaluated by the 2000-base price index (x_IO_2000price). *j* denotes 37 kinds of wastes (table 4).

e_w[,j]＝w_IO[,j]/x_IO_2000price, j=1,...,37

e_v[,j]=v_IO[,j]/x_IO_2000price, j=1,...,37
e_u[,j]=u_IO[,j]/x_IO_2000price, j=1,...,37
e_t[,j]=t_IO[,j]/x_IO_2000price, j=1,...,37

e_w : Waste discharge per unit of production by activity of the input-output table
e_v : Intermediately treated waste per unit of production by activity of the input-output table
e_u : Recycled waste per unit of production by activity of the input-output table
e_t : Final disposal per unit of production by activity of the input-output table
x_IO_2000price : Converted output by activity of the input-output table at 2000 price

Table 4

The another method (method 2) is the industrial waste data converted into the classification of the input-output table (w_IO, v_IO, u_IO, t_IO) is divided by the output of the *Input-Output Table* 2000 (x). Using the method, the industrial waste data (w_IO, v_IO, u_IO, t_IO) equal to total direct and indirect repercussions calculated by the input-output table.

e_w[,j]＝w_IO[,j]/x, j=1,...,37

e_v[,j]＝v_IO[,j]/x, j=1,...,37

e_u[,j]＝u_IO[,j]/x, j=1,...,37

e_t[,j]＝t_IO[,j]/x, j=1,...,37

x : Output by activity of the input-output table at 2000 price

If the ratio by activity of the converted shipment value is evaluated by the 2000-base price index (x_IO_2000price) to the output of the *Input-Output Table* 2000 (x) runs from 0.5 to 1.5, we have adopted the method 1. Otherwise we have chosen the method 2.

For CO_2 emission by activity of the input-output table, we have used the *Input-Output Table for Environmental Analysis* 2000 (Nakano, Hayami, Nakamura and Suzuki (forthcoming))

4. Model

4.1. Repercussions

The input coefficient, input coefficient matrix, final demand vector and waste discharge per unit of output matrix are defined as

$$a_{ij} = \frac{X_{ij}}{x_j}, \quad \mathbf{A} = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix}, \quad \mathbf{f} = \begin{pmatrix} f_1 \\ \vdots \\ f_n \end{pmatrix}, \quad \mathbf{E} = \begin{pmatrix} e\_w_1 & & 0 \\ & \ddots & \\ 0 & & e\_w_n \end{pmatrix}$$ respectively.

The direct repercussion is as follows.

$$\textit{Direct repercussion}: \ \mathbf{Ef}$$

The indirect repercussions are calculated by the following equation.

$$\textit{Indirect repercussion}: \ \mathbf{E}\left(\mathbf{A}\mathbf{f} + \mathbf{A}^2\mathbf{f} + \cdots\right) = \mathbf{EA}\left(\mathbf{I} - \mathbf{A}\right)^{-1}\mathbf{f}$$

Thus the total repercussions are as the following.

$$\mathbf{E}\left(\mathbf{f} + \mathbf{A}\mathbf{f} + \mathbf{A}^2\mathbf{f} + \cdots\right) = \mathbf{E}\left(\mathbf{I} - \mathbf{A}\right)^{-1}\mathbf{f}$$

The factors of the matrix **E** will be replaced by the intermediately treated waste, the recycled waste, the final disposal or CO_2 emission per unit of output as needed.

4.2. Scenario Analysis

In this study, we have simulated utilization of scrap and slag in the iron and steel sector and fly ash in the electricity sector. Our model is based on KEO Research Group for Environmental Issues (1996). The main object of the study is treated as a sub sector and the rest of sectors are classified into main sectors.

Table 5

Table 6

Table 7

4.2.1. Production Function

The production processes of 389 main sectors are described by perfect complementary production functions. The production function of the *n*-th main sector is as follows.

$$x_n^1 = \min\left[\frac{1}{a_{i,n}^{11}} X_{i,n}^{11}, \frac{1}{a_{l,n}^{21}} X_{l,n}^{21}, \frac{1}{a_{m,n}^{31}} X_{m,n}^{31}\right]$$

$x_n^1, X_{i,n}^{11}, X_{l,n}^{21}$ and $X_{m,n}^{31}$ denote the output of the *n*-th main sector, the intermediate input of the *i*-th main sector, that of the *l*-th main product in the sub sector, and that of the *m*-th by-product in the sub sector, respectively. The *m*-th by-product output of the *n*-th main sector is calculated by the following equation.

$$X_{m,n}^{41} = a_{m,n}^{41} x_n^1$$

$a_{m,n}^{41}$ denotes output coefficient of the *m*-th by-product in the *n*-th main sector. The production processes in 14 out of 16 sub sectors are described by perfect complementary production functions. The production function of the *n*-th sub sector is as follows.

$$z_n = \min\left[\frac{1}{a_{i,n}^{12}} X_{i,n}^{12}, \frac{1}{a_{l,n}^{22}} X_{l,n}^{22}, \frac{1}{a_{m,n}^{32}} X_{m,n}^{32}\right]$$

$z_n, X_{i,n}^{12}, X_{l,n}^{22}$ and $X_{m,n}^{32}$ denote the output of the *n*-th sub sector, the intermediate input of the *i*-th main sector, that of the *l*-th main product in the sub sector, and that of the *m*-th by-product in the sub sector, respectively. The *m*-th by-product output of the *n*-th sub sector is calculated by the following equation.

$$X^{42}_{m,n} = a^{42}_{m,n} z_n$$

$a^{42}_{m,n}$ denotes generation coefficient of the *m*-th by-product in the *n*-th main sector. The production processes in 2 out of 16 sub sectors are described by production function with perfect complementary and perfect substitution. Petroleum refinery products, blast furnace gas, coke oven gas and converter gas are described as perfectly substitutive intermediate inputs in the production function of the electricity sector. The other intermediate inputs are perfect substitutive goods.

$$z_{ele} = \min\left[\frac{1}{a^{12}_{i,ele}} X^{12}_{i,ele}, \frac{1}{a^{22}_{l,ele}} X^{22}_{l,ele}, \frac{1}{a^{32}_{m,ele}} X^{32}_{m,ele}, \right.$$
$$\left. \lambda^{22}_{pet,ele} X^{22}_{pet,ele} + \lambda^{32}_{bla,ele} X^{32}_{bla,ele} + \lambda^{32}_{cok,ele} X^{32}_{cok,ele} + \lambda^{32}_{con,ele} X^{32}_{con,ele} \right]$$

z_{ele}, $X^{22}_{pet,ele}$, $X^{32}_{bla,ele}$, $X^{32}_{cok,ele}$ and $X^{32}_{con,ele}$ denote the output of the electricity sector, the intermediate input of the petroleum refinery products, that of the blast furnace gas, that of the coke oven gas, and that of the converter gas, respectively. The *m*-th by-product output of the electricity sector is calculated by the following equation.

$$X^{42}_{m,ele} = a^{42}_{m,ele} z_{ele}$$

In the production function of the private power generation sector, petroleum refinery products, blast furnace gas, coke oven gas, converter gas, electric furnace gas and pulp black liquor are described as perfectly substitutive intermediate inputs. The other intermediate inputs are perfect substitutive goods.

$$z_{pri} = \min\left[\frac{1}{a^{12}_{i,pri}} X^{12}_{i,pri}, \frac{1}{a^{22}_{l,pri}} X^{22}_{l,pri}, \frac{1}{a^{32}_{m,pri}} X^{32}_{m,pri}, \lambda^{22}_{pet,pri} X^{22}_{pet,pri} + \lambda^{32}_{bla,pri} X^{32}_{bla,pri} \right.$$
$$\left. + \lambda^{32}_{cok,pri} X^{32}_{cok,pri} + \lambda^{32}_{con,pri} X^{32}_{con,pri} + \lambda^{32}_{eleg,pri} X^{32}_{eleg,pri} + \lambda^{32}_{pul,pri} X^{32}_{pul,pri} + \lambda^{32}_{was,pri} X^{32}_{was,pri} \right]$$

z_{pri}, $X^{22}_{pet,pri}$, $X^{32}_{bla,pri}$, $X^{32}_{cok,pri}$, $X^{32}_{con,pri}$, $X^{32}_{eleg,pri}$, $X^{32}_{pul,pri}$ and $X^{32}_{was,pri}$ denote the output of the private power generation sector, the intermediate input of the petroleum refinery products, that of the blast furnace gas, that of the coke oven gas, that of the converter gas, that of the electric furnace gas, that of the pulp black liquor, and that of the waste tire, respectively. The *m*-th by-product output of the private power generation sector is calculated by the following equation.

$$X^{42}_{m,pri} = a^{42}_{m,pri} z_{pri}$$

4.2.2. Outlet Structure

The outlet structure of the main sector is designated by the equation below.

$$\mathbf{A}^{11}\mathbf{x}^{1} + \mathbf{A}^{12}\mathbf{z} + \mathbf{f}^{1} + \mathbf{ex}^{1} + \mathbf{im}^{1} = \mathbf{x}^{1}$$

The outlet structure of the main product in the sub sector is designated by the equation below.

$$\mathbf{A}^{21}\mathbf{x}^{1} + \mathbf{A}^{22}\mathbf{z} + \mathbf{B}^{24}\mathbf{y} + \mathbf{f}^{2} + \mathbf{ex}^{2} + \mathbf{im}^{2} = \mathbf{x}^{2}$$

$\mathbf{B}^{24}$ denotes the matrix whose factors are 0 and 1. $\mathbf{y}$ denotes the vector whose factors are substitutable variables

$$(X^{22}_{pet,ele}, X^{32}_{bla,ele}, X^{32}_{cok,ele}, X^{32}_{con,ele}, X^{22}_{pet,pri}, X^{32}_{bla,pri}, X^{32}_{cok,pri}, X^{32}_{con,pri}, X^{32}_{eleg,pri}, X^{32}_{pul,pri}, X^{32}_{was,pri}),$$

the stock change of iron and steel scrap, iron and steel scrap, blast furnace slag and fly ash, and three variables (D^1, D^2, D^3) in the scenario equations mentioned later. The outlet structure of the by-product in the sub sector is described by the equation below.

$$\mathbf{A}^{31}\mathbf{x}^{1} + \mathbf{A}^{32}\mathbf{z} + \mathbf{B}^{34}\mathbf{y} + \mathbf{f}^{3} + \mathbf{ex}^{3} + \mathbf{im}^{3} = \mathbf{x}^{3}$$

$\mathbf{B}^{34}$ denotes the matrix whose factors are 0 and 1. The generation structure of the by-product in the sub sector is described by the equation below.

$$-\mathbf{A}^{41}\mathbf{x}^{1} - \mathbf{A}^{42}\mathbf{z} - \mathbf{f}^{4} = -\mathbf{x}^{3}$$

$\mathbf{A}^{41}$ and $\mathbf{A}^{42}$ denote the generation coefficient matrixes. The relationship between $\mathbf{z}$ and $\mathbf{y}$ is described by the following equations derived from the production functions.

$$z_{ele} = \lambda^{22}_{pet,ele} X^{22}_{pet,ele} + \lambda^{32}_{bla,ele} X^{32}_{bla,ele} + \lambda^{32}_{cok,ele} X^{32}_{cok,ele} + \lambda^{32}_{con,ele} X^{32}_{con,ele}$$

$$z_{pri} = \lambda^{22}_{pet,pri} X^{22}_{pet,pri} + \lambda^{32}_{bla,pri} X^{32}_{bla,pri} + \lambda^{32}_{cok,pri} X^{32}_{cok,pri} + \lambda^{32}_{con,pri} X^{32}_{con,pri} + \lambda^{32}_{eleg,pri} X^{32}_{eleg,pri} + \lambda^{32}_{pul,pri} X^{32}_{pul,pri} + \lambda^{32}_{was,pri} X^{32}_{was,pri}$$

4.2.3. Scenario

We have assumed that the allocation ratios $(\beta^1, \beta^2, \beta^3)$ of blast furnace gas, coke oven gas and converter gas for power generation use to the electricity sector are constant.

$$D^1 = X^{32}_{bla,pri} + X^{32}_{bla,ele}$$

$$D^2 = X^{32}_{cok,pri} + X^{32}_{cok,ele}$$

$$D^3 = X^{32}_{con,pri} + X^{32}_{con,ele}$$

$$X^{32}_{bla,ele} = \beta^1 D^1$$

$$X^{32}_{cok,ele} = \beta^2 D^2$$

$$X^{32}_{con,ele} = \beta^3 D^3$$

The relationship between $\mathbf{z}$ and $\mathbf{y}$ is described by the following equation derived from the scenario above.

$$\mathbf{B}^{52}\mathbf{z} = \mathbf{B}^{54}\mathbf{y}$$

$\mathbf{B}^{52}$ denotes the matrix whose factors are 0 and 1, and $\mathbf{B}^{52}$ denotes the matrix whose factors are λ^k_{ij}, β, 0, 1, -1. The activity of the sub sector and the main product of the sub sector except for the hot rolled steel sector and cement sector is one-to-one relation. The correspondence relationship between the three activities of the hot rolled steel sector and the main product of the hot rolled steel sector is described as follows.

$$z_{hota} = \alpha^1 x^2_{hot}$$

$$z_{hotb} = \alpha^2 x^2_{hot}$$

Similarly, the correspondence relationship between the three activities of the cement sector and the main product of the cement sector is described as follows.

$$z_{cema} = \alpha^3 x^2_{cem}$$

$$z_{cemb} = \alpha^4 x^2_{cem}$$

The balance of gross output between activities and main products of sub sectors is designated by the following equation.

$$\mathbf{G}\mathbf{x}^2 = \mathbf{z}$$

$\mathbf{G}$ denotes the matrix whose factors are α, 0, 1. In this study, we have prepared simple scenarios changing α. Eliminating $\mathbf{z}$ in the equations above,

$$\mathbf{A}^{11}\mathbf{x}^1 + \mathbf{A}^{12}\mathbf{G}\mathbf{x}^2 + \mathbf{f}^1 + \mathbf{ex}^1 + \mathbf{im}^1 = \mathbf{x}^1,$$
$$\mathbf{A}^{21}\mathbf{x}^1 + \mathbf{A}^{22}\mathbf{G}\mathbf{x}^2 + \mathbf{B}^{24}\mathbf{y} + \mathbf{f}^2 + \mathbf{ex}^2 + \mathbf{im}^2 = \mathbf{x}^2,$$
$$\mathbf{A}^{31}\mathbf{x}^1 + \mathbf{A}^{32}\mathbf{G}\mathbf{x}^2 + \mathbf{B}^{34}\mathbf{y} + \mathbf{f}^3 + \mathbf{ex}^3 + \mathbf{im}^3 = \mathbf{x}^3,$$
$$\mathbf{A}^{41}\mathbf{x}^1 + \mathbf{A}^{42}\mathbf{G}\mathbf{x}^2 - \mathbf{x}^3 + \mathbf{f}^4 = \mathbf{0},$$
$$-\mathbf{B}^{52}\mathbf{G}\mathbf{x}^2 + \mathbf{B}^{54}\mathbf{y} = \mathbf{0}.$$

The equation system is designated as follows.

$$\begin{pmatrix} \mathbf{A}^{11} & \mathbf{A}^{12}\mathbf{G} & \mathbf{0} & \mathbf{0} \\ \mathbf{A}^{21} & \mathbf{A}^{22}\mathbf{G} & \mathbf{0} & \mathbf{B}^{24} \\ \mathbf{A}^{31} & \mathbf{A}^{32}\mathbf{G} & \mathbf{0} & \mathbf{B}^{34} \\ \mathbf{A}^{41} & \mathbf{A}^{42}\mathbf{G} & -\mathbf{I} & \mathbf{0} \\ \mathbf{0} & -\mathbf{B}^{52}\mathbf{G} & \mathbf{0} & \mathbf{B}^{54} \end{pmatrix} \begin{pmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \\ \mathbf{x}^3 \\ \mathbf{y} \end{pmatrix} + \begin{pmatrix} \mathbf{f}^1 \\ \mathbf{f}^2 \\ \mathbf{f}^3 \\ \mathbf{f}^4 \\ \mathbf{0} \end{pmatrix} + \begin{pmatrix} \mathbf{ex}^1 \\ \mathbf{ex}^2 \\ \mathbf{ex}^3 \\ \mathbf{0} \\ \mathbf{0} \end{pmatrix} - \begin{pmatrix} \mathbf{im}^1 \\ \mathbf{im}^2 \\ \mathbf{im}^3 \\ \mathbf{0} \\ \mathbf{0} \end{pmatrix} = \begin{pmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \\ \mathbf{x}^3 \\ \mathbf{0} \\ \mathbf{0} \end{pmatrix}$$

The import coefficients m_i^1, m_i^2, m_i^3 are defined by

$$m_i^1 = \frac{im^1}{\sum_j X_{ij}^{11} + \sum_j X_{ij}^{12} + f_i^1},$$

$$m_i^2 = \frac{im^2}{\sum_j X_{ij}^{21} + \sum_j X_{ij}^{22} + f_i^2},$$

$$m_i^3 = \frac{im^3}{\sum_j X_{ij}^{31} + \sum_j X_{ij}^{32} + f_i^3}.$$

Using the import coefficients,

$$\left(\begin{array}{c|c|c|c} (\mathbf{I}-\hat{\mathbf{M}}^1)\mathbf{A}^{11} & (\mathbf{I}-\hat{\mathbf{M}}^1)\mathbf{A}^{12}\mathbf{G} & \mathbf{0} & \mathbf{0} \\ \hline (\mathbf{I}-\hat{\mathbf{M}}^2)\mathbf{A}^{21} & (\mathbf{I}-\hat{\mathbf{M}}^2)\mathbf{A}^{22}\mathbf{G} & \mathbf{0} & (\mathbf{I}-\hat{\mathbf{M}}^2)\mathbf{B}^{24} \\ \hline (\mathbf{I}-\hat{\mathbf{M}}^3)\mathbf{A}^{31} & (\mathbf{I}-\hat{\mathbf{M}}^3)\mathbf{A}^{32}\mathbf{G} & \mathbf{0} & (\mathbf{I}-\hat{\mathbf{M}}^3)\mathbf{B}^{34} \\ \hline \mathbf{A}^{41} & \mathbf{A}^{42}\mathbf{G} & -\mathbf{I} & \mathbf{0} \\ \hline \mathbf{0} & -\mathbf{B}^{52}\mathbf{G} & \mathbf{0} & \mathbf{B}^{54} \end{array}\right) \left(\begin{array}{c} \mathbf{x}^1 \\ \hline \mathbf{x}^2 \\ \hline \mathbf{x}^3 \\ \hline \mathbf{y} \end{array}\right) + \left(\begin{array}{c} (\mathbf{I}-\hat{\mathbf{M}}^1)\mathbf{f}^1 + \mathbf{ex}^1 \\ \hline (\mathbf{I}-\hat{\mathbf{M}}^2)\mathbf{f}^2 + \mathbf{ex}^2 \\ \hline (\mathbf{I}-\hat{\mathbf{M}}^3)\mathbf{f}^3 + \mathbf{ex}^3 \\ \hline \mathbf{f}^4 \\ \hline \mathbf{0} \end{array}\right) = \left(\begin{array}{c} \mathbf{x}^1 \\ \hline \mathbf{x}^2 \\ \hline \mathbf{x}^3 \\ \hline \mathbf{0} \\ \hline \mathbf{0} \end{array}\right).$$

$\hat{\mathbf{M}}^1, \hat{\mathbf{M}}^2$ and $\hat{\mathbf{M}}^3$ denote the matrix whose diagonal factors are the import coefficients and non-diagonal factors are 0. Solving $\mathbf{x}^1, \mathbf{x}^2, \mathbf{x}^3$ and $\mathbf{y}$,

$$\left(\begin{array}{c} \mathbf{x}^1 \\ \hline \mathbf{x}^2 \\ \hline \mathbf{x}^3 \\ \hline \mathbf{y} \end{array}\right) = \left(\begin{array}{c|c|c|c} \mathbf{I}-(\mathbf{I}-\hat{\mathbf{M}}^1)\mathbf{A}^{11} & -(\mathbf{I}-\hat{\mathbf{M}}^1)\mathbf{A}^{12}\mathbf{G} & \mathbf{0} & \mathbf{0} \\ \hline -(\mathbf{I}-\hat{\mathbf{M}}^2)\mathbf{A}^{21} & \mathbf{I}-(\mathbf{I}-\hat{\mathbf{M}}^2)\mathbf{A}^{22}\mathbf{G} & \mathbf{0} & -(\mathbf{I}-\hat{\mathbf{M}}^2)\mathbf{B}^{24} \\ \hline -(\mathbf{I}-\hat{\mathbf{M}}^3)\mathbf{A}^{31} & -(\mathbf{I}-\hat{\mathbf{M}}^3)\mathbf{A}^{32}\mathbf{G} & \mathbf{I} & -(\mathbf{I}-\hat{\mathbf{M}}^3)\mathbf{B}^{34} \\ \hline -\mathbf{A}^{41} & -\mathbf{A}^{42}\mathbf{G} & \mathbf{I} & \mathbf{0} \\ \hline \mathbf{0} & \mathbf{B}^{52}\mathbf{G} & \mathbf{0} & -\mathbf{B}^{54} \end{array}\right)^{-1} \left(\begin{array}{c} (\mathbf{I}-\hat{\mathbf{M}}^1)\mathbf{f}^1 + \mathbf{ex}^1 \\ \hline (\mathbf{I}-\hat{\mathbf{M}}^2)\mathbf{f}^2 + \mathbf{ex}^2 \\ \hline (\mathbf{I}-\hat{\mathbf{M}}^3)\mathbf{f}^3 + \mathbf{ex}^3 \\ \hline \mathbf{f}^4 \\ \hline \mathbf{0} \end{array}\right).$$

Multiplying the solution by the matrix **E**, we can obtain emissions of industrial wastes and CO_2 under the scenario.

5. Repercussions of industrial wastes discharge and CO_2 emission

Using the database constructed, direct and indirect repercussions of industrial wastes discharge and CO_2 emission by production of goods and services are calculated. We introduce here some calculation examples of repercussions; mobile phone and motor vehicle.

The direct and indirect repercussions of waste discharges per unit of mobile phone production are approximately 7.1kg. The physical weight share of recycled waste to the total discharge and that of final disposal is 69.2% and 5.1%, respectively. The similar repercussions by one unit of motor vehicle production are approximately 1.4 tons.

96.9% of the total discharges are recycled or intermediately treated and 3.1% of them are disposed to landfill.

Three major wastes directly and indirectly discharged by mobile phone production are waste acid (16.3%), iron and steel slag (9.7%) and inorganic sludge except for rotten stone (9.1%). About half of waste acid discharge and about 20% of inorganic sludge except for rotten stone are intermediately treated. The waste with the largest discharge related to motor vehicle production is iron and steel scrap (28.0%). The second largest is iron and steel slag (21.5%) and the third is waste casting sand (7.4%). Almost all wastes induced by motor vehicle production are recycled.

Indirect repercussions of waste discharge, intermediately treated waste, recycled waste and final disposal per unit of mobile phone production account for more than 95% of the total. On the other hand, indirect repercussions of waste discharge and recycled waste by one unit of motor vehicle production account for approximately 80%.

CO_2 emission directly and indirectly induced per unit of mobile phone production is approximately 44.5kg-CO_2 (direct repercussion: 4.0% and indirect repercussion: 96.0%). The similar emission by one unit of motor vehicle production is approximately 5.4tons-CO_2 (direct repercussion: 1.9% and indirect repercussion: 98.1%).

Table 8

Table 9

6. Concluding Remarks

We have linked the microdata from the industrial waste survey (METI) with the input-output table and constructed 37 industrial wastes database as accompanying table for the *Input-Output Table for Environmental Analysis*. As a result, direct and indirect repercussions of industrial wastes by production of goods and services could be traced. It is confirmed that the database also serves as useful information for scenario analyses of recycling processes.

The database is not without issue. Because the coverage of the industrial waste survey is limited to coal mining, manufacturing, electricity and gas industry, we should collect waste data for other industries. We will solve these issues and make more scenario analyses of recycling and CO_2 emission for the future.

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Tables

Table 1: The value of manufactured goods shipments in 2005

Statistics	Scope	Value (million JPY)
Industrial waste survey	sampling establishments	123,158,487
Census of Manufactures by commodity	all establishments	229,935,599
Census of Manufactures by industry	all establishments	236,271,585

Table 2: The shipment value of coal mining, electricity and town gas in 2005

Statistics	Scope	Value (million JPY)
Industrial waste survey	sampling establishments	10,822,138
Extended Input-Output Table		17,399,915

Table 3: The expanded industrial waste data (unit: ton)

Magnification factor	Discharge	Intermediately treated	Recycled	Final disposal
Industrial waste survey (original)	89,025,197	7,920,714	76,995,827	4,108,656
Industrial waste survey (expansion)	112,518,000	11,906,000	94,987,000	5,635,000
Census of Manufactures by industry	137,673,640	23,115,588	107,153,563	7,404,488
Extended Input-Output Table	120,990,481	24,617,622	91,059,078	5,313,780

Table 4: Classification of industrial waste

Cinders (except coal)	Wastepaper	Slag (iron and steel)
Cinders (coal)	Chips and sawdust	Slag (ferroalloy)
Inorganic sludge (except rotten stone)	Waste textile	Slag (copper)
Inorganic sludge (rotten stone)	Animal and vegetable remnants	Mining waste (except aluminum dross)
Organic sludge	Waste animal-solidified	Mining waste (aluminum dross)
Mixed sludge (except rotten stone)	Waste rubber	Demolition debris
Mixed sludge (rotten stone)	Iron and steel scrap	Animal manure
Waste mineral oil	Non-ferrous metal scrap	Animal carcasses

Waste chlorinated solvent	Glass	Soot and dust (except fly ash)
Waste acid	Ceramics	Soot and dust (fly ash)
Waste alkali	Concrete	Processed material for the disposal of industrial wastes
Thermo-plastics	Waste casting sand	
Waste tire	Slag (except iron and steel, ferroalloy, copper)	

Table 5: Activity of sub sector

1	Pig iron	
2	Crude steel (converters)	Conventional activity
3	Crude steel (converters, alternative)	High utilization ratio of iron and steel scrap (market)
4	Crude steel (electric furnaces)	
5	Hot rolled steel (converters)	Utilization of crude steel (converters)
6	Hot rolled steel (converters, alternative)	Utilization of crude steel (converters, alternative)
7	Hot rolled steel (electric furnaces)	Utilization of crude steel (electric furnaces)
8	Granulated blast furnace slag	
9	Cement (portland)	
10	Cement (granulated blast furnace slag)	
11	Cement (fly ash)	
12	Electricity	
13	Private power generation	
14	Petroleum refinery product	
15	Coal product	
16	Lime stone	

Table 6: Main product of sub sector

1	PIG IRON	
2	CRUDE STEEL (CONVERTERS)	
3	CRUDE STEEL (CONVERTERS,	

	ALTREVATIVE)	
4	CRUDE STEEL (ELECTRIC FURNACES)	
5	HOT ROLLED STEEL	
6	GRANULATED BLAST FURNACE SLAG	
7	CEMENT	
8	ELECTRICITY	
9	PRIVATE POWER GENERATION	
10	PETROLEUM REFINERY PRODUCT	
11	COAL PRODUCT	
12	LIME STONE	

Table 7: By-product of sub sector

1	BLAST FURNACE SLAG	Raw material of gRANULATED BLAST FURNACE SLAG
2	BLAST FURNACE GAS	
3	COKE OVEN GAS	
4	CONVERTER GAS	
5	ELECTRIC FURNACE GAS	
6	IRON AND STEEL SCRAP (IN-PLANT)	
7	IRON AND STEEL SCRAP (MARKET)	

8	FLY ASH	
9	PULP BLACK LIQUOR	
10	WASTE TIRE	

Table 8: Direct and indirect repercussions by one unit production of mobile phone

[redacted]

Table 9: Direct and indirect repercussions by one unit production of motor vehicle

[redacted]