DEVELOPMENT AND EVALUATION OF AN MODEL FOR ESTIMATING MATERIAL AND ENERGY RECOVERY FROM LANDFILLED WASTE

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Abstract : Relandfill activity, which means digging up landfill waste and recovering resources, can remove the material having been landfilled, and will free up the land to be reused as new landfill space. We have extended the WIO model for environmental assessment including re-landfill activity. As a part of this work, we have estimated landfill consumption and CO_2 emission based on 4 kinds of scenarios with 2 types of melting furnaces.

Key Words : *Waste Input-Output Analysis, landfilled waste*

1 Introduction

Waste disposal with production and consumption activities is translated into environmental emission after appropriate treatment. In Japan, most of municipal waste are separated and go to incineration system. Incineration residue is mainly landfilled. Under our geographical condition, we have very limited space for landfill, and it is difficult to find new space for final disposal. Fig.1 shows residual capacity of landfill site in Japan. The final disposal space residual years of final disposal is increasing because of reduction of waste generation by depression and nationwide spread of waste separation. However the situation around us about capacity of final disposal space is still serious. It is important for us to reduce quantity of final disposal and to save existing final disposal space.

However more conservation of landfill site seems to be difficult only in existing treatment. Under these conditions, recovering of material and energy from final disposal space is promoted by material industry, which plays a key role.(Fig.2)

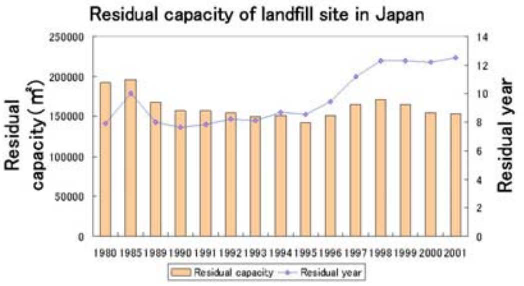

Fig. 1: Remained capacity of landfill

Relandfill activity, which means digging up landfill waste and recovering resources, can remove the material having been landfilled, and will free up the land to be reused as new landfill space. Recently relandfill activity examined in Japan(ex. Maki town, Niigata prefecture and Kameyama city, Mie prefecture etc.) is that gasification-melting furnace system receives waste including municipal waste, incinerator ash and landfill waste. Metals contained in the wastelike aluminium, copper and iron, can be recovered as mixed metal and slag through that system. Waste is generated from the production activities of industries, and the consumption activities of household

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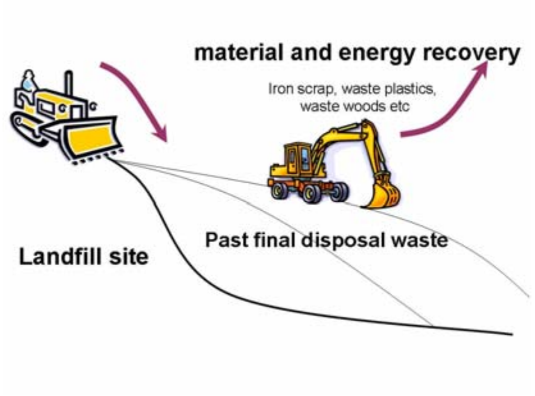

Fig. 2: Material and energy recovery

economies. The waste generated in industrial sectors is managed in waste treatment sectors. However, the goods produced by industrial sectors are indispensable to the activity of waste treatment sectors. Waste treatments create relations of interdependence between production sectors and waste treatment sectors. The waste Input-Output table (WIO)(Nakamura and Kondo(2002)) analyzes the relations of such interdependence. However, a static model like WIO is unsuitable for the analysis of durables with several years of life, for example, a building. Yokoyama(2004) presented a dynamic extension of the WIO focussing on the construction industry.

However, in many methods of environmental assessment by using input-output model, final disposal site is not considered to be an object of material recovery. The purpose of this study is the development of methods to evaluate environmental burden and analysis economic effects considering with relandfill activity.

2 Material and energy recovery model from landfill waste

2.1 The Model

This model mainly follows Waste Input-Output model(WIO). WIO, which was developed by Nakamura and Kondo(2002), is based on SNA input-output table and extended from the view point of material recycling, energy recovery and landfill consumption. WIO table has the information of waste material flow between sectors, and describes inter-relationship between production sectors and waste treatment sectors. Yokoyama(2004) extended WIO which is a static model dynamically.(Fig.3)

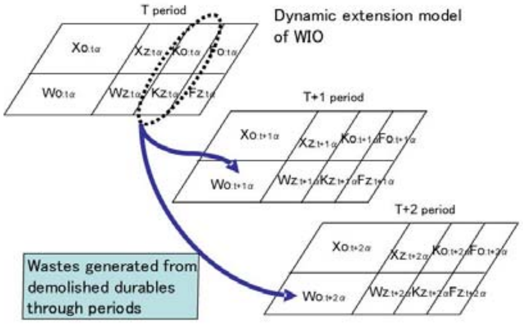

Fig. 3: Dynamic extension of Waste Input-Output Table

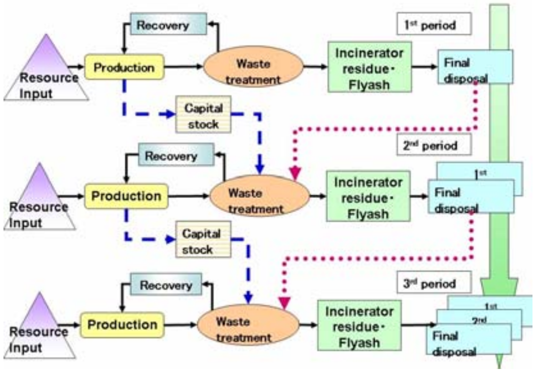

Fig. 4: Material recovery from landfill model

2.2 Symbols

This model mainly follows Waste Input-Output model. Here $\mathbf{X}_{0:t} = \{X_{0:ij:t}\}^{1)}$ (N times N matrix with N equal

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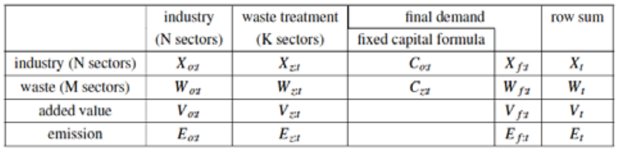
1) $\mathbf{X}$ refers to the matrix which uses the inside of $\{\}$ as an element; $\hat{\mathbf{X}}$ refers to the diagonalized matrix of $\mathbf{X}$; and $\mathbf{X}^\top$ refers to the transposition of $\mathbf{X}$.

to the number of industrial sectors) refers to the amount of the output of the i-th sector that is used by the j-th sector as input and $\mathbf{X}_{z:t} = \{X_{z:ij:t}\}$($N$ times K matrix with K equal to the number of waste treatment sectors) refers to the amount of the output of the i-th sector that is used by the j-th waste treatment sector as input at t term.

$\mathbf{W}_{0:t} = \{W_{0:ij:t}\}$($M$ times N matrix with M equal to the number of waste types) refers to the amount of the output of the i-th waste net recycling that is emitted by the j-th industrial sector, and $\mathbf{W}_{z:t} = \{W_{z:ij:t}\}$($M$ times K matrix) refers to the amount of the i-th waste generated by the j-th waste treatment sector at t term.

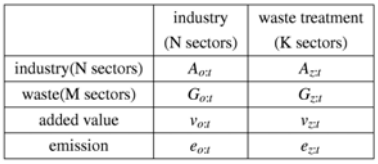
The final demand sector demands $\mathbf{X}_{f:t} = \{X_{f:ij:t}\}$ of the output of industrial sectors, and emits $\mathbf{W}_{f:t} = \{W_{f:ij:t}\}$ of waste and the fixed capital stock sector demands $\mathbf{C}_{0:t} = \{C_{0:i:t}\}$ of the output of i-th industrial sectors, and $\mathbf{C}_{z:t} = \{C_{z:i:t}\}$ represents fixed i-th waste into the capital stock.

Table.1 Dynamic extended waste input-output table



	industry (N sectors)	waste treatment (K sectors)	final demand		row sum
			fixed capital formula		
industry (N sectors)	$X_{o:t}$	$X_{z:t}$	$C_{o:t}$	$X_{f:t}$	X_t
waste (M sectors)	$W_{o:t}$	$W_{z:t}$	$C_{z:t}$	$W_{f:t}$	W_t
added value	$V_{o:t}$	$V_{z:t}$		$V_{f:t}$	V_t
emission	$E_{o:t}$	$E_{z:t}$		$E_{f:t}$	E_t

Table.2 Input coefficient tabel



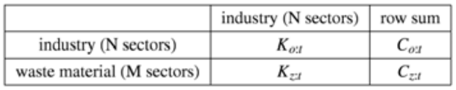
	industry (N sectors)	waste treatment (K sectors)
industry(N sectors)	$A_{o:t}$	$A_{z:t}$
waste(M sectors)	$G_{o:t}$	$G_{z:t}$
added value	$v_{o:t}$	$v_{z:t}$
emission	$e_{o:t}$	$e_{z:t}$

Table.1 refers to the input-output table with waste management and describs the relations of interdependence between industrial sectors and waste management sectors, and Table.2 refers to the input coefficients table for dynamic extended Waste Input-Output analysis. The dynamic Leontief model describs the relations of interdependence between sections through periods. However, in the dynamic Leontief model, activities of waste treatment sections and recycling are not considered. In this study, we consider about the circulation between the production sectors and waste treatment sectors with time lag.

$\mathbf{K}_t = \{K_{ij:t}\}$ refers to the conventional fixed capital matrix (N times N matrix). However, The conventional fixed capital matrix is considered only about production sectors. To accumulate commodities means that the wastes constituting goods are also accumulated. Therefore, it is necessary to consider about material flow from demolished durables.

Therefore, it is necessary to extend the conventional fixed capital matrix, and to create an extended fixed capital matrix, $\tilde{\mathbf{K}}$ ($(N+M)$ times N matrix). The extended fixed capital matrix is defined as $\tilde{\mathbf{K}}_t := [\mathbf{K}_{0:t}, \mathbf{K}_{z:t}]^\top$. $\mathbf{K}_{0:t} = \{K_{0:ij:t}\}$ refers to the accumulation of material goods i to industrial sector j; $\mathbf{K}_{z:t} = \{K_{z:ij:t}\}$ refers to the accumulation of waste material i used by industrial sector j at t term.

Table.3 Extended Fixed Capital Matrix



	industry (N sectors)	row sum
industry (N sectors)	$K_{o:t}$	$C_{o:t}$
waste material (M sectors)	$K_{z:t}$	$C_{z:t}$

$\tilde{\mathbf{A}}_{k:t}$ is defined as $\tilde{\mathbf{A}}_{k:t} := [\mathbf{X}_{0:t}, \mathbf{W}^-_{0:t}]^\top \hat{\mathbf{X}}_t^{-1}$. $\mathbf{W}^-_{0:t}$ (Z times N matrix) refers to the amount of recycling of waste i used by industrial section j. Extended fixed capital matrix $\tilde{\mathbf{K}}_t$ is defined as $\tilde{\mathbf{K}}_t := \tilde{\mathbf{A}}_{k:t}\mathbf{K}_t = [\mathbf{X}_{0:t}, \mathbf{W}^-_{0:t}]^\top \hat{\mathbf{X}}_t^{-1}\mathbf{K}_t$.

Since the fixed capital matrix is described in quantity terms, it is necessary to create a coefficient, $\tilde{\mathbf{B}}_t$. The extended fixed capital coefficient is defined as $\tilde{\mathbf{B}}_t := [\mathbf{B}_{0:t}, \mathbf{B}_{z:t}]^\top = [\mathbf{X}_{0:t}, \mathbf{W}^-_{0:t}]^\top \hat{\mathbf{X}}_t^{-1}\mathbf{K}_t\hat{\mathbf{X}}_t^{-1}$. $\mathbf{B}_{0:t} = \{B_{0:ij:t}\}$ refers to the accumulation of goos j to the production sector i, $\mathbf{B}_{z:t} = \{B_{z:ij:t}\}$ refers to the accumulation of waste j to the production sector i.

Table.3 describes the extended fixed capital matrix which refers to the the accumulation of capital goods to industrial section, $K_{o:t}$ and the accumulation of waste material to industrial section, $K_{z:t}$. Next, it is necessary to consider what kind of waste will generate from demolished capital stock in future. We must consider about the proportion of wastes generated from durables.

Therefore here we define the waste conversion matrix, $\mathbf{T}$, which refers to the proportion of wastes generated from durables. Waste conversion matrix $\mathbf{T}$ is defined as $\mathbf{T} := [\mathbf{T}_0, \mathbf{T}_z]^\top$. $T_{0:ij}$ refers to refers to the proportion of wastes j generated from demolished durables i, $T_{z:ij}$ refers to the proportion of wastes j recovered from waste material i constituting durables. This matrix is variable through periods. Table.4 describes the waste conversion matrix. In case where goods designed by DFE or Eco-design spread, T_{0t} will change, and T_{zt} depends on the sorting technology.

Table.4 Waste Conversion Matrix T

	waste (M sectors)
industry (N sectors)	T_{0t}
waste material (M sectors)	T_{zt}

2.3 Waste generation

we can represent wastes generated from each industry, $\mathbf{W}_{0:t}$ as the sum of $\mathbf{W}_{0n:t}$, which refers to the waste associated with production, $\mathbf{W}_{0k:t}$, that refers to the waste generated from discarded capital stock and $\mathbf{W}_{0r:t}$ refers to the waste material.

To consider material and energy recovery from landfill site, we need to modify the definition of waste generation $W_{0:t}$. $W_{0:t}$ is the sum of wastes with production activity, wastes generated from discarded durables and waste material recovered from landfill.

Waste generated from each industry is as follows.

$$\begin{aligned} W_{o:t} &= W_{on:t} + W_{or:t} + W_{ok:t} \\ &= \beta_t \hat{X}_t - B_z \Delta \hat{X}_{t+1} + \gamma_t \alpha \sum^{t-1} e_i^\top X_i \\ &\quad + T^\top \tilde{B} \hat{\delta}_{t-1,t} \Delta \hat{X}_t + T^\top \tilde{B} \hat{\delta}_{t-2,t} \Delta \hat{X}_{t-1} \\ &\quad\quad + T^\top \tilde{B} \hat{\delta}_{t-3,t} \Delta \hat{X}_{t-2} + \cdots \end{aligned} \tag{1}$$

γ_t refers to the content rate of waste material, α refers to the rate of digging up from past landfill. Life-time matrix $\boldsymbol{\delta}_{\mathbf{t-i,t}}$ refers to the rate by which the capital stock fixed at $t-i$ period is discarded at t period. This matrix consider when capital stock is discarded. Furthermore, $\mathbf{S} = \{S_{ij}\}$ (K times M matrix) refers to the matrix that allocates wastes to corresponding treatments. The model is based on the following balance equation for the supply and demand of goods production and waste treatment.

$$\begin{bmatrix} \tilde{A}_0 & 0 & \cdots & A_z & 0 & \cdots \\ -B_0 & \tilde{A}_0 & \ddots & 0 & A_z & \ddots \\ \vdots & \ddots & \ddots & \vdots & \ddots & \ddots \\ \tilde{W}_{0;1} & \tilde{W}_{0;2} & \cdots & SG_z & 0 & \cdots \\ -SB_z & \tilde{W}_{0;1} & \ddots & 0 & SG_z & \ddots \\ \vdots & \ddots & \ddots & \vdots & \ddots & \ddots \end{bmatrix} \begin{bmatrix} X_t \\ X_{t-1} \\ \vdots \\ Z_t \\ Z_{t-1} \\ \vdots \end{bmatrix} + \begin{bmatrix} X_{f:t} \\ X_{f:t-1} \\ \vdots \\ SW_{f:t} \\ SW_{f:t-1} \\ \vdots \end{bmatrix} = \begin{bmatrix} X_t \\ X_{t-1} \\ \vdots \\ Z_t \\ Z_{t-1} \\ \vdots \end{bmatrix}$$

Where $\tilde{A}_0 = A_0 + B_0$, $\tilde{W}_{0;1} = S\beta + SB_z + ST^\top \tilde{B} \hat{\delta}_{t-1,t}$, $\tilde{W}_{0;2} = ST^\top \tilde{B} [\hat{\delta}_{t-2,t} - \hat{\delta}_{t-1,t}]$.

The above equations reflect time as in the case of waste at t term which was generated from capital stock existing before t term.

The first term on the left hand side of equation refers to the path of technology through which the final demand sector X_f and waste discharge W_f are realized with given set of technology, institution and life style. This system of equations could be solved for production of the artery sector and activity level of of the vein sector of t term to $t-2$ term, where the technology, fixed capital coefficient and final demand are given.

For simplicity, let us transform this balance equation into the following forms.

$$[I - A_t^*]^{-1} X_f^* = X_t^*. \tag{2}$$

This system of equations can be solved for production and waste treatment sector, where the technology, fixed capital coefficient and final demand are given.

In environmental emission, landfill consumption $E_{l:t}$ is defined as the quantity that deducted $E_{q:t}$ from the sum of $E_{p:t}$ and $E_{r:t}$. $E_{q:t}$ is the quantity of landfill waste dug up, $E_{p:t}$ is landfill consumption with production activity, and $E_{r:t}$ is landfill consumption with material and energy recovery activity.

$$\begin{aligned} E_{l:t} &= e_{l:t} \top X_t + E_{r:t} - E_{q:t} && (3) \\ &= e_{l:t} \top [I - A_t]^{-1} X_{f:t} + E_{r:t} - E_{q:t} && (4) \end{aligned}$$

3 Scenario Analysis

By using this model, 2 scenarios are considered. First is about waste treatment, second is about mixture rate of wastes.

In the first scenario, two types of melting furnace treatment options are considered. First is fluid bed melting furnace system and second is shaft melting furnace system. In second scenario, two types of wastes for melting furnace are considered. One scenario is considering the case landfill wastes are re-treated by only melting furnace system and the other is the case mixed wastes are re-treated. In the case of latter, calorie shortage of wastes doesn't need to be assumed. The control scenario is assumed no re-landfill activity.

3.1 Settings

To consider re-landfill activity, we need some settings of WIO table. At first, we added 2 activities "re-landfill" and "gasification melting furnace" in waste treatment sector. Secondly, we added 8 kinds of wastes: "iron scrap: from landfill" "aluminum scrap: from landfill" "recovered metal" "slag" "re-landfill waste" "waste soil" "retreatment waste" "tiles and stones". These additional information make it possible to consider the effects of re-landfill activities.

In Japan, 40,633,227t waste are incinerated and 9,949,281t waste are landfilled in 2001. According to prestudy of JESC, we have assumed that 994,928t waste are re-landfilled, which equal to 10*wt*% of landfill waste in 2001.

Components of landfilled wastes are as follows. According to reports of JESC, a half of components is soil, a quarter is impropriety wastes for incineration, residue is the waste to re-treated.

Calorie shortage of wastes in fluid bed furnace requires heavy oil input for assistance. Re-landfill activity has been assumed similar activity with landfill activity from the view point of input energy, resources etc.

Melting furnace melts the dewatered and dried sludge by exposing it to the high temperature combustion air. By making melted slag out of the sludge, the furnace achieves more volume reduction, as well as the stabilisation of heavy metals in the slag. Therefore, the slag can be beneficially used.

Fig.5 shows the material flow of mixed waste by fluidized bed melting furnace system. Fluidized bed melting furnace combusts the sludge by fluidizing the sand within the furnace with the hot air heated from the bottom with limestone, activated carbon, heavy oil, chelate agent, cement and water.

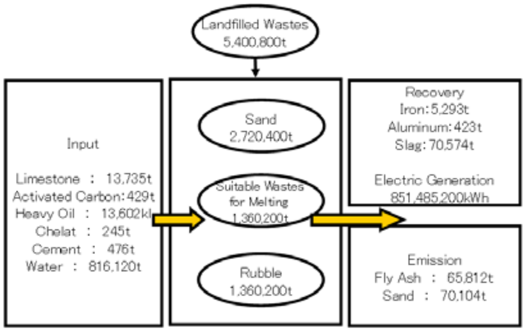


Fig. 5: The material flow of mixed waste by fluid bed furnace

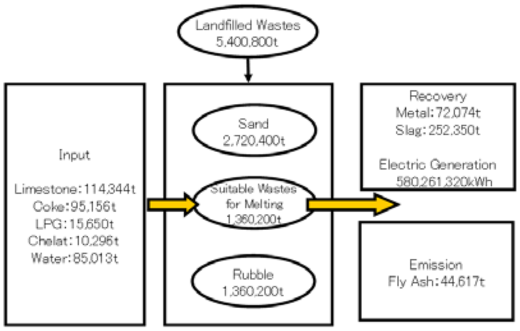


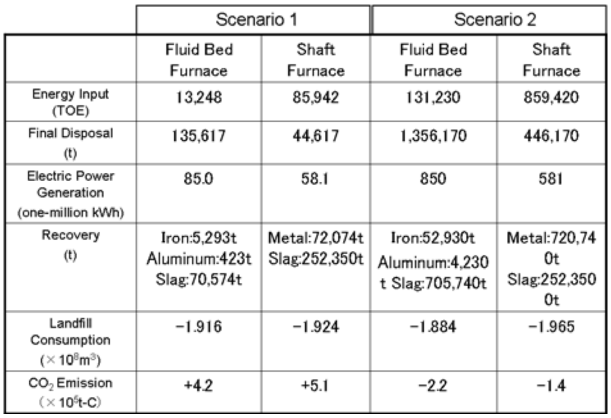
Fig. 6: The material flow of mixed waste by shaft furnace

Fig.6 shows the material flow of mixed waste by shaft melting furnace system. Waste treatment by shaft melting furnace system requires coke, limestone, water, LPG and chelate agent and generate electric power by residual heat. Metal and slag are recovered from treated wastes and generate fly ash as waste to landfill. In this system, characteristics include that calorie shortage of wastes doesn't need to be assumed for input of coke as fuel.

3.2 Results and discussion

Table.5 shows the results of scenario analysis. In the view point of energy input, shaft furnace system needs

Table.5 Results of Scenarios



	Scenario 1		Scenario 2	
	Fluid Bed Furnace	Shaft Furnace	Fluid Bed Furnace	Shaft Furnace
Energy Input (TOE)	13,248	85,942	131,230	859,420
Final Disposal (t)	135,617	44,617	1,356,170	446,170
Electric Power Generation (one-million kWh)	85.0	58.1	850	581
Recovery (t)	Iron:5,293t Aluminum:423t Slag:70,574t	Metal:72,074t Slag:252,350t	Iron:52,930t Aluminum:4,230t Slag:705,740t	Metal:720,740t Slag:252,3500t
Landfill Consumption (×$10^8 m^3$)	−1.916	−1.924	−1.884	−1.965
CO_2 Emission (×10^5t-C)	+4.2	+5.1	−2.2	−1.4

coke for melting, so it needs six times or more compared with the fluid bed furnace. Fig.7 shows the change rate of landfill consumption. The difference between shaft furnace and fluid bed furnace is that the former generate less sand than latter, so that latter generates only one-third of the former about landfill. Comparing between scenarios, shaft furnace fluid bed furnace has the ability of volume reduction than shaft furnace. Increase in the mixture ratio of municipal waste brings a decrease in the volume reduction ratio in the fluid bed furnace and an increase effects in the shaft furnace system.

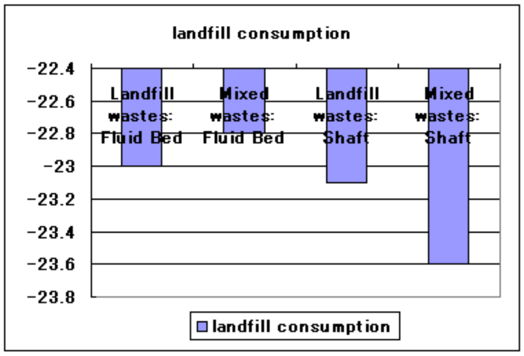


Fig. 7: Change Rate (%)- landfill consumption -

Fig.8 shows the change rate of CO_2 emission. Significant decline in the level of CO_2 emission of under scenario 2. Comparing between scenarios, fluid bed furnace emits less CO_2 than shaft furnace. In addition, reduction of CO_2 emission can be seen in both furnace system when the mixture rate of municipal wastes increases.

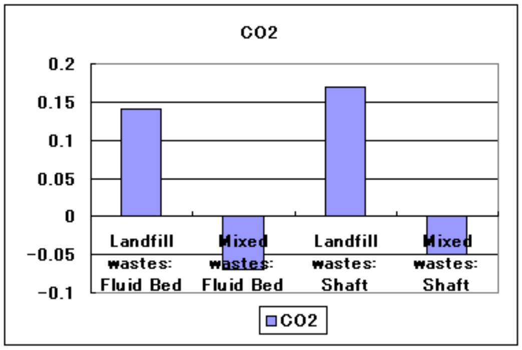


Fig. 8: Change Rate (%)- CO_2 Emission -

4 Conclusion

In this work, we have extended the WIO model for environmental assessment including re-landfill activity, which means digging up landfill wastes; recovery of resources and energy by the gasification melting furnace, and saving remaining landfill capacity. As a part of this work, we have estimated landfill consumption and CO_2 emission based on 4 kinds of scenarios with these types of melting furnaces.

In the view point of landfill consumption, each gasification melting furnace can decrease the volume of waste, and saving existing landfill space. Shaft furnace seems to have more potential for decreasing volume of wastes because of less emission than fluid bed furnace.

In this work, we have indicated that re-landfill activity is effective for sustainable management of landfill sites. However, assessed landfilled waste components were limited. There are currently more than 300 waste incineration plants in operation in Japan with a total capacity exceeding 50 million tons/a. Municipal solid waste incineration produces residues which contain toxic heavy metals. Landfills containing such residues are therefore potentially hazardous. The recovery of energy for heat and power production is dependent on local conditions and in particular on the national waste management strategy and landfill policy.

More detailed information about contents of landfill wastes will make it possible to evaluate the effects of re-landfill activity.

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