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Life Cycle Assessment on Food Waste Treatment Systems
- biogasification and composting -

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ABSTRACT

A case study of foodwaste treatment was conducted to compare the impacts of four scenarios: *incineration, incineration after biogasification, biogasification followed by composting, and composting*. Potential contributions to climate change, acidification, consumption of landfill and human toxicity were assessed. Characterization of human toxicity caused by metals and PCDD/DF was performed by three multimedia fate models. Scenarios with a biogasification process showed lower impact on climate change and human toxicity. The ranking of four scenarios on human toxicity varied depending on the characterization models applied. The steady state models placed high priority on emission of heavy metals to farmland, whereas the dynamic model estimated the emission of PCDD/DF from the incineration process as more significant.

INTRODUCTION

More than 90% of foodwaste from households in Japan is incinerated. Concerns on PCDD/DF emission from incineration plants and demands to seek a more resource-efficient society have led to the development and adoption of foodwaste recycling systems, namely composting and biogasification. In this study, an LCA of foodwaste treatment is conducted to compare the potential impacts of these systems.

METHODOLOGY

The functional unit

The functional unit is a treatment of 1 ton of model waste. The 'model waste' indicates a mixture of 0.8 ton of foodwaste and 0.2 ton of woodwaste, which has suitable moisture for composting and biogasification. 'Treatment' is specified as 'to remove the waste from the waste generation site, reduce its undesired properties in accordance with environmental regulations, and release the residue to the environment in a stable form.'

The scenarios investigated and the system boundaries

The scenarios investigated are: 1) incineration, 2) biogasification before incineration, 3) biogasification followed by composting and 4) composting (see Figure 1). Only the impacts caused by operation phase are considered. Other phases, such as construction of facilities, are not included. Material recycling (composting) and energy recovery (biogasification, waste power generation) are handled by expanding the system boundary with a synthesized fertilizer subsystem and a power generation subsystem. The synthesized fertilizer subsystem consists of a fertilizer production process [1] and a decomposition of fertilizer in the farmland process. An assumption was made that the compost replaces the synthesized fertilizer, which has the same amount of nitrogen. The assumption was also made that the power generation subsystem has the typical power source configuration used in Japan.

Data collection and calculation procedures

Inventory data were collected from local governments and facility manufacturers. Literature data, statistics and model estimates were used to fill the data gaps [2]. The amount of PCDD/DF emitted from incineration was estimated based on the assumed concentration and the volume of emission gas calculated from the waste composition.

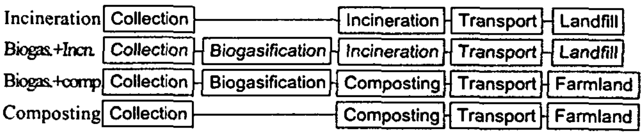

Figure 1. Scenarios investigated

Selection of impact categories, inventory items and characterization models

In the LCIA phase, characterization, normalization and weighting were performed. The impact categories and the corresponding inventory items selected for this study are shown in Table I. Global Warming Potential (100 years) and Acidification Potential were used as characterization factors for climate change and acidification. It was assumed that CO2 from biomass does not contribute to global warming. To cope with the expected model uncertainties, the characterization of human toxicity was performed by three models [2,3,4,5] (see Table II). For each toxic substance, these models calculate a characterization factor expressed in the unit of ' kg of reference substance (1,4-dichlorobenzene) emitted to air.'

Normalization values and weighting method

In the normalization step, total annual emissions in Japan, as shown in Table I, were selected as reference values. The reference values for human toxicity include the impact of PCDD/DF and heavy metals, but the impact of other toxic substances, such as benzene and PM, are not included. The 'Distance to Target' method (annual emission per target emission as weighting factors) was used for the weighting of the normalized results. For this study, we determined a set of target emissions that should be achieved by 2010, considering international treaties, government targets and industry action programs.

Table I. Impact categories and corresponding substances with annual emission and target emission

Impact category	Substance	Annual emission	Target emission	Unit
Climate change	CO2, CH4, N2O	1231(1997)	1057(-6% from 1990 level)	million ton-CO2eq
Acidification	SOx	1400(1990)	1400(same as 1990)	1000 ton-SO2
	NOx	2840(1990)	2130(-25% from 1990)	1000 ton-NO2
Consumption of landfill		81.0(1996)	40.5(-50% from 1996)	million m^3
Human toxicity	PCDD/DF (air)	2900(1998)	635 (-90% from 1997)	g-TEQ
	Heavy Metals	see [2]	(-30% from 1997)	

Table II. Characterization models for human toxicity

Type of the model	Region of first emission	Spacial scale	Time scale
USES-LCA [3]	Europe	Globally nested	Infinite (steady state)
Dynamic USES-LCA [4]	Europe	Globally nested	20, 100, 500 years
Mackay-Japan (developed for this study) [2]	Japan	Regional	Infinite (steady state)

RESULTS AND DISCUSSION

Climate change (Fig. 2)

Biogasification collects biomass energy more efficiently than conventional waste power generation; this efficiency results in a lower GHG emission for the scenarios with biogasification. Although the avoidance of chemical fertilizers reduces the GHG emission by 33 kg-CO2eq/ton-waste, the composting process requires more energy than it saves, making the composting scenario inferior reagarding climate change.

Acidification (Fig. 3)

In all of the scenarios, the collection processes have a significant impact on acidification. However, the differences among the four scenarios within this process are rather small and do not influence the ranking. The amount of waste incinerated determines the results of acidification.

Consumption of landfill

0.04 m3/ton of landfill is consumed in the scenarios with incineration, while no amount of landfill is required for the scenarios with composting.

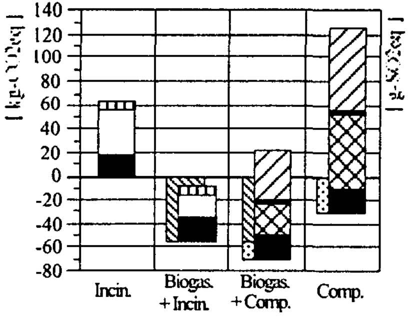

Figure 2. Indicator values for climate change

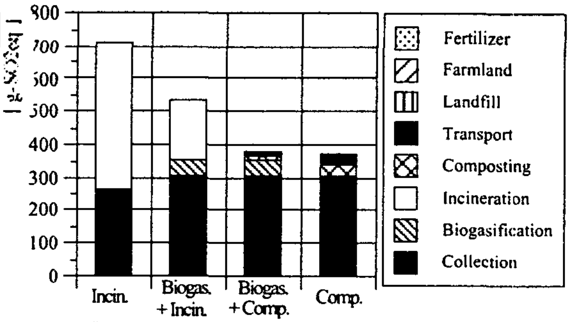

Figure 3. Indicator values for acidification

Human toxicity caused by PCDD/DF (Fig. 4)

The ranking of the four scenarios was consistent through all three characterization models. Assuming a current representative incineration plant (3.1 ng-TEQ/Nm3: median value for 1998), the incineration scenario was the worst in human toxicity caused by PCDD/DF. The two scenarios without incineration had much lower impact. When the regulation (<0.1 ng-TEQ/Nm3) on new incineration facilities, in effect from 2002, is achieved, the impact of the incineration scenario will be reduced to the same level as that of the composting scenario. However, it should be noted that this estimate might be too optimistic because the diffusive emission of incineration residues during transportation and landfilling was not considered.

Human toxicity caused by metals (Fig. 5)

As for human toxicity caused by metals, the results of characterization vary significantly depending on the choice of characterization model. While the steady state models (i.e. Mackay-Japan and USES-LCA) place higher priority on emission to farmland than on emission to air, the dynamic model (dynamic USES-LCA, 100-year time frame) estimates that both pathways have the same order of significance. This is caused by the difference in the time frames of the models. In the steady state models, the heavy metals emitted to farmland are exposed to individuals through a soil-water-fish-man pathway. On the other hand, in the dynamic model, most of the heavy metals will remain in the soil for the time frame of 100 years.

Sensitivity analysis for human toxicity (Fig. 6)

Fig. 6 shows the sensitivity of the impact on human toxicity with respect to the choice of characterization model and the variation in key parameters (Table III). The results were more sensitive to the choice of model than to the variations in the parameters. In the steady state models, the emission of heavy metals to farmland is more important, whereas in the dynamic model, the emission of PCDD/DF from incineration is more influential. In contrast, scenarios with biogasification show lower impact than the corresponding scenario without biogasification throughout the three models.

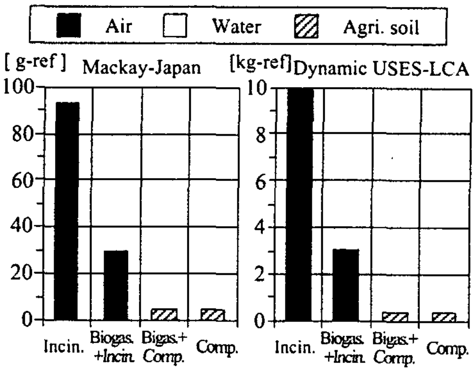

Figure 4. Indicator values for human toxicity by PCDD/DF

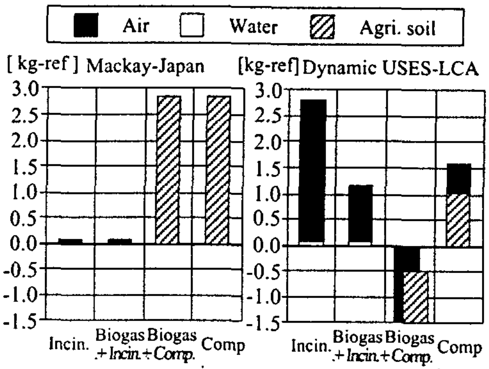

Figure 5. Indicator values for human toxicity by metals

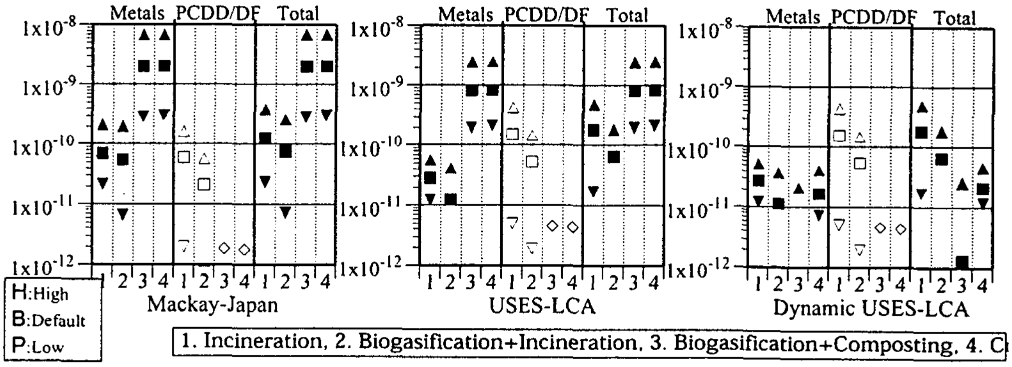

Figure 6. Results of Sensitivity analysis for human toxicity (normalized by annual emission in Japan)

Table III. Parameter values for sensitivity analysis in human toxicity

Scenarios	Heavy metals in model waste [mg/kg-wet]							PCDD/DF in stack gas	
	Cd	Cr	Cu	Pb	Hg	Zn	As	[ng-TEQ/Nm3]	
High	0.372	8.24	29.8	44.7	0.114	96.8	0.689	8.6	mean for 1998
Default	0.117	4.65	12.3	9.49	0.0372	30.1	0.223	3.1	median for 1998
Low	0.0186	2.214	0.149	0.372	0.0186	0.0372	0.0372	0.1	new facility after 2002

Results of normalization and weighting

The results of normalization and weighting for each impact category are shown in Table IV. The differences of normalized values between the maximum and minimum scenarios suggest that consumption of landfill has relative importance to climate change and acidification. While the difference for human toxicity is nearly equal to those for climate change and acidification in the dynamic model, human toxicity has more importance in the steady state models. This may be explained by the lower coverage of annual emission on metals. Data on the amount of metals emitted to soil in low (background level) concentrations are usually difficult to obtain. This is because they are not considered as influential, contrary to the estimation of the steady state models. The inconsistency between available normalization values and adopted characterization models should be addressed in order to make normalization a helpful procedure to interpret the results across impact categories.

Table IV. Results of normalization and weighting [x10^{-10}]

Scenario	Climate change	Acidification	Consumption of landfill	Human toxicity *1		Human toxicity *2		Human toxicity *3	
				Metals	PCDD/DF	Metals	PCDD/DF	Metals	PCDD/DF
Incineration	0.50/0.59	2.10/2.97	4.97/9.93	0.59/0.84	0.61/2.80	0.28/0.40	0.95/4.35	0.28/0.39	0.98/4.46
Biogas.+Incinr.	-0.08/-0.09	1.59/2.25	4.97/9.93	0.44/0.62	0.20/0.89	0.12/0.18	0.30/1.38	0.11/0.16	0.31/1.42
Biogas.+comp.	0.16/0.19	1.13/1.59	0.00/0.00	18.4/26.3	0.04/0.17	8.07/11.5	0.05/0.21	-0.03/-0.05	0.05/0.21
Composting	1.02/1.19	1.09/1.54	0.00/0.00	18.6/26.6	0.04/0.17	8.27/11.8	0.04/0.20	0.17/0.24	0.04/0.20
Max. - Min.	1.10/1.28	1.01/1.43	4.97/9.93	18.2/26.0	0.58/2.64	8.14/11.63	0.91/4.15	0.31/0.44	0.93/4.26

[normalized score / weighted score] *1: Mackay-Japan, *2: USES-LCA, *3: Dynamic USES-LCA

CONCLUSION

The integration of a biogasification process to the incineration or composting scenario yields an efficient recovery of biomass energy which lowers the potential contribution to climate change and acidification. In the case of a transition from the incineration scenario to the incineration after biogasification scenario, the reduction in the amount of incineration lowers the emission of PCDD/DF which in turn reduces the impact on human toxicity.

Compared to the incineration of the model waste (or the biogasification residue), composting reduces the contributions to consumption of landfill, acidification and human toxicity caused by PCDD/DF; on the other hand, the effects on climate change and human toxicity caused by metals are increased.

Depending on the model adopted, the characterization results for the emission of metals to farmland varied significantly; this variation leads to different rankings of the four scenarios. In the valuation of toxic substances, it is important to note the uncertainties of environmental fate models, the incompleteness of normalization values and the inconsistency between the characterization model and normalization values.

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