CHEMICAL ENGINEERING TRANSACTIONS
VOL. 61, 2017
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Petar S Varbanov, Rongxin Su, Hon Loong Lam, Xia Liu, Jiří J Klemeš

ISBN 978-88-95608-51-8; **ISSN** 2283-9216
DOI: 10.3303/CET1761003

Environmental and Economic Evaluation of Pre-Disaster Waste Management

Tomohiro Tabata[a*], Yohei Wakabayashi[a], Tsai Peii[a], Takashi Saeki[b]

[a]Kobe University, 3-11 Tsurukabuto, Nada-ku, Kobe city Hyogo 657-8501 Japan
[b]Toyama Prefectural University, 5180 Kurokawa, Isumi city, Toyama 939-0398 Japan
tabata@people.kobe-u.ac.jp

Disaster waste management should be conducted in an environmentally and economically friendly manner, although disaster waste should be demolished and removed as soon as possible after a natural disaster. The aim of this study was to develop methods to conduct environmental and economic evaluation of pre-disaster waste management. A disaster waste management system consists of processes such as transportation, storage and separation at primary and secondary temporary storage sites, incineration, crushing, landfilling and recycling. Firstly, environmental and economic intensity data for each process was created via interview and literature surveys. Then, proposed methods was applied to the disaster waste management related to the 2016 Kumamoto Earthquakes, which occurred in Kumamoto Prefecture, Japan as the case study. Our results indicate that CO_2 emission, SO_x emission and cost from this disaster waste management method were 390 – 630 kt, 2,500 – 3,000 t and 630–710 kUSD. In particular, the SO_x emission from such corresponded to 29 – 35 % of total annual SO_x emission in Kumamoto Prefecture. This result revealed that the impact on regional air pollution via managing disaster waste is considerable.

1. Introduction

Disaster waste components are vast and comprise debris such as wood, concrete, glass and tsunami debris. If a natural disaster such as an earthquake were to occur, plenty of disaster waste would be generated. For example, the Great East Japan Earthquake that occurred in March 2011 generated approximately 31 Mt of disaster waste (Ministry of Environment, 2016), which corresponds to approximately 65 % of total annual municipal solid waste (MSW) generation in Japan.

Disaster waste should be demolished and removed as soon as possible after a natural disaster, so re-establishment and reconstruction of the affected area can begin. However, the environmental burden and cost derived from disaster waste treatment should not be disregarded. Target 12.5 of the sustainable development goals (SDGs; United Nations (2015)) states waste generation should be substantially reduced by 2030 via prevention, reduction, recycling and reuse. Target 12.5 of the SDGs also covers the environmental impacts from waste management. Basing on the SDGs' perspective, waste management should be conducted in an environmentally and economically friendly manner even though the disaster waste. In addition, disaster waste management should be conducted at low cost, with the goal of having enough funding to re-establish and reconstruct an affected area and to support disaster victims by saving on disaster waste management costs. If local municipalities conduct an evaluation of pre-disaster waste management from these perspectives, it will be effective for them to utilize environmental and economic evaluation methods that can grasp an entire disaster waste management system. Life cycle assessment (LCA) and life cycle cost (LCC) methods are valid and feasible as evaluation methods of such.

Local municipalities of many countries including Japan have instituted pre-disaster waste management plans for future natural disasters. Numerous studies related to the disaster waste management exist in several research fields. For example, Pereira and Lee (2016) conducted environmental and economic evaluations by focusing on energy recovery from the disaster waste generated by the Great East Japan earthquake. Tabata et al. (2016b) developed a model to estimate the disaster waste derived from consumer durables, taking into

Please cite this article as: Tabata T., Wakabayashi Y., Peii T., Saeki T., 2017, Environmental and economic evaluation of pre-disaster waste management, Chemical Engineering Transactions, 61, 31-36 DOI:10.3303/CET1761003

account possessions and weight of consumer durables. Pramudita et al. (2014) discussed methods for construction of a transportation network for disaster debris if a Tokyo inland earthquake were to occur. Onan et al. (2015) created a decision-making tool to estimate disaster waste and to investigate transportation networks and the location of temporary storage sites. Lorca et al. (2015) presented a decision-making tool that optimizes and balances the financial and environmental costs, duration of removal operations, landfill usage and amount of recycled materials generated.
However, few studies have evaluated environmental burden and cost considering the entire disaster waste management system. Moreover, few integrated evaluation methods consider disaster waste transportation network, spatial location, and storage and treatment capacity of temporary storage sites and treatment plants. To date, local municipalities have no evaluation methods to estimate environmental burden and cost if current pre-disaster waste management plans were put into practice. They also have no methods to propose alternative plans if the current plans had low effectiveness. To solve such issues, Tabata et al. (2016a) developed evaluation methods utilizing LCA and LCC and conducted environmental and economic evaluation of the disaster waste derived from specific kinds of home appliances (refrigerators, washing machines, air-conditioners and TV sets) in a small town. The aim of the current study is to develop methods to conduct environmental and economic evaluation of an integrated pre-disaster waste management system for a large region. In this study, environmental and economic intensity data of disaster waste treatment processes was created and a case study for actual disaster waste management to achieve our target was conducted.

2. Methods

2.1 Concept of a disaster waste management system

Figure 1 shows the flow of disaster waste management. Firstly, disaster waste is transported from an affected area to a primary temporary storage sites and stored. Then, the stored disaster waste is transported to a secondary temporary storage site, where the disaster waste is classified and separated into several kinds of waste such as waste and concrete. Bulky waste is crushed. Finally, the classified waste is incinerated and/or landfilled or recycled. Recycling enables the utilization of wood as fuel and of other wastes as secondary materials. The disaster waste management system was defined as follows: an integrated system in which disaster waste management flows from upstream (generation) to downstream (treatment). By thinking of disaster waste management as an integrated system, LCA and LCC methods is able to apply to disaster waste management.

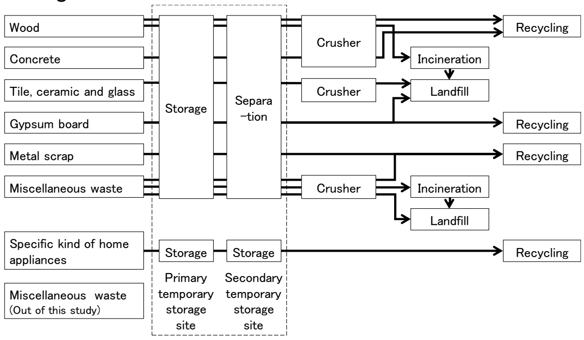

Figure 1: Flow of disaster waste management, amended from Kumamoto Prefecture (2016).

2.2 Creation of Environmental and Economic Intensity data

The environmental burden and cost of each process are calculated by multiplying the transportation or treatment volume of disaster waste with the intensity data. Overall environmental burden and cost are calculated by aggregating the results for each process. Our created intensity data includes CO_2, SO_x, NO_x and PM emissions and cost. CO_2 affects global climate change, and other environmental burdens affect regional air pollution. The targeted processes in this study were transportation, storage and separation at primary and secondary temporary storage sites, incineration, crusher and landfill. The intensity data was created the following procedure:

(1) Transportation

Environmental intensity data was applied from the LCA software “MiLCA”, released by JEMAI (2014). 4 t trucks were assumed to utilize for transportation from a primary temporary storage site to a secondary temporary storage site. 10-t trucks were utilized for transportation from a secondary temporary storage site to a treatment plant was also assumed to utilize. The average monthly truck leasing cost of lease companies was applied as economic intensity data.

(2) Primary and secondary temporary storage sites

The regression formulas for light oil usage and cost presented in Tabata et al. (2016a) was revised. Then, intensity data was calculated by multiplying light oil usage and cost data, as calculated using Eqs (1) and (2), with environmental burden intensity and usage fee of light oil (JEMAI, 2014). By using the above equations, local municipalities will be able to evaluate the environmental burden and cost of setting up these temporary storage sites. Although above equations was created basing on interview survey from seven local municipalities affected by the Great East Japan Earthquake, detail data in related with utilities usage and cost can not acquire for time constraint. Etherealizing above formulas for better analysis is our future research.

$$O = 0.027A \tag{1}$$

$$C = 0.00070A - 0.0051Dummy \tag{2}$$

where O: light oil usage per tonne of disaster waste [L/t], A: land area of the temporary storage site [ha], C: cost per tonne of disaster waste [USD/t] and *Dummy*: existence or non-existence of tsunami debris dummy (Yes=1, No=0).

The environmental burden and cost at a secondary temporary storage site determined by using Eqs (1) and (2) might be overestimated comparing to the same results for a primary temporary storage site, as the land area of a secondary temporary storage site is much greater than that of a primary temporary storage site. For example, the average land areas of primary and secondary temporary storage sites are 1.2 ha and 98 ha (Kumamoto Prefecture, 2016). Moreover, the larger the temporary storage site is, the lower the utility usage and cost of the temporary storage site per unit of land area are. This concept is known as economics of scale. In this study, the environmental burden and cost at a secondary temporary storage site was assumed that thinking of the scale of economics comes into effect, and these value was calculated using the six-tenths-rule from the economics of scale concept, as follows (Green and Perry, 2008).

$$I_2 = \left(A_2 \times A_1^{-1}\right)^{0.6} \times I_1 \tag{3}$$

where I_1: environmental and economic intensity data of primary temporary storage site [kg/t or kg/tkm or USD/t], I_2: environmental and economic intensity data of secondary temporary storage site [kg/t or kg/tkm or USD/t], A_1: land area of primary temporary storage site [ha] and A_2: land area of secondary temporary storage site [ha]. Unit tkm means tonne-kilometre.

(3) Treatment plants including incineration, crushing and landfilling

The intensity data of MSW incineration plants and landfills was applied presented by Tabata et al. (2011). Utility usage data (electricity, gas and water) of industrial waste incineration plants and crushers was collected based on interview surveys with employees of industrial waste treatment companies in Japan. Then, intensity data was calculated by multiplying utility usage and cost data with environmental burden intensity and usage fee for each utility (JEMAI, 2014).

2.3 2016 Kumamoto Earthquakes and its disaster waste management

The 2016 Kumamoto Earthquakes occurred in the northern area of Kumamoto Prefecture, Japan in April 2016. This Prefecture is located on the western side of Japan (32.8031° N and 130.7079° E) (Figure 2). It has a population of approximately 1,800,000, a land area of 7,409 km^2, and approximately 800,000 dwellings. When the 2016 earthquakes hit this region, their maximum magnitude was 7.3 and the number of deaths and damaged dwellings caused by them were 181 and approximately 190,000. The generated disaster waste from these earthquakes was approximately 3,160 kt, and accounted for most of the total disaster waste generated in 2016 in the northern area of the Kumamoto Prefecture. Kumamoto Prefecture (2016) has established 66 primary temporary storage sites and 1 secondary temporary storage site to store and separate the disaster waste (Figure 2). Kumamoto Prefecture (2016) decided to treat the disaster waste via the disaster waste management plan shown in Figure 1. The plan is to treat the disaster waste inside and/or outside this Prefecture, with the goal of completing the disaster waste treatment within 2 y.

In this study, environmental burden and cost according to the disaster waste management of the disaster waste generated by the 2016 Kumamoto Earthquakes was estimated. The disaster waste was classified into eight categories (Figure 1) based on information from the Kumamoto Prefecture (2016) and interview surveys with employees in the Kumamoto Prefectural office. Miscellaneous waste was out of this study because waste content was unknown. All of the disaster waste was assumed to treat inside Kumamoto Prefecture. In this

Prefecture, 21 MSW incineration plants and 12 landfills operate (Figure 2), as do a number of industrial waste incineration plants and crushers. The disaster waste treatment processes is following as shown in Figure 1; transportation, storage and separation at primary and secondary storage sites, incineration at MSW incineration plants and/or industrial waste incineration plants, crusher, landfill and recycling (including fuel utilization of wood and resource utilization of other waste). Combustibles were assumed to treat, considering the redundant capacity of incineration plants (Tsai et al., 2015). Transportation distances was also calculated using Google Earth.

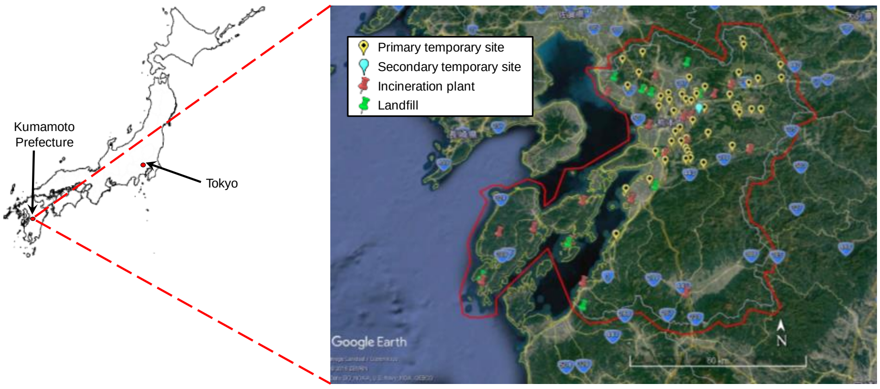

Figure 2: Location of temporary storage sites and MSW treatment plants (The red line delineates Kumamoto Prefecture)

3. Results and discussions

3.1 Intensity data of disaster waste treatment

Table 1 shows the part of the intensity data that was created in this study. Intensity data related to the treatment of specific types of home appliances, recycling of wood for fuel utilization and recycling of other waste were applied, as reported by Tabata et al. (2016a), Tabata and Okuda (2012) and Kobayashi et al. (2009). The intensity data for recycling is only CO_2 emission, with the creation of other environmental burden and cost a goal for future research.

Table 1: Environmental and economic intensity data

	Transportation (via 10 t truck)	Temporary storage site	Incineration		Crusher	Landfill
			For MSW	For industrial waste		
Unit	(tkm)	(t)	(t)	(t)	(t)	(t)
CO_2 (kg)	0.13	2.21×10^{-4}	906	807	51.1	79
SO_x (kg)	6.32×10^{-6}	4.4E-08	5.41×10^{-1}	8.82×10^{-2}	4.84×10^{-3}	4.40×10^{-2}
NO_x (kg)	1.09×10^{-5}	3.86E-07	6.26×10^{-1}	3.52×10^{-1}	2.04×10^{-2}	1.42×10^{-1}
PM (kg)	6.68×10^{-5}	1.78E-23	6.23×10^{-3}	1.36×10^{-14}	3.16×10^{-16}	3.22×10^{-3}
Cost (USD)*	–	1,370	1,570	1,590	450	1,070
Ash (t)	–	–	0.12	0.12	–	–

*1 USD = 113.34 JPY (18.01.2017).

3.2 LCA and LCC results of disaster waste management based on the 2016 Kumamoto Earthquakes

Figure 3 (a) shows the results of CO_2 emission. Environmental burden and cost was estimated for the following two cases to consider the length of time involved in treatment: Case 1 means that combustibles were incinerated at the MSW incineration plants and Case 2 means that combustibles were incinerated at MSW and industrial waste incineration plants. Resultantly, CO_2 emission was 390 – 630 kt. Incineration was the dominant process that resulted in CO_2 emission. A reduction effect in CO_2 emission via utilization of wood for fuel compensated for approximately 34 – 46 % of total CO_2 emission. Comparing the two cases, Case 2 had approximately 38 % less CO_2 emission than Case 1 did. This means that intensity data of industrial waste incineration plant is smaller than one of MSW waste incineration plant. In addition, for Case 1, it will take 2.4 y to treat the combustibles completely; yet, Kumamoto Prefecture has set their goal to complete the disaster waste treatment to within 2 y.

It will be difficult to achieve their target, unless industrial waste incineration plants are utilized. These results revealed that utilization of industrial waste incineration plants is advantageous regarding CO_2 emission and length of treatment time.

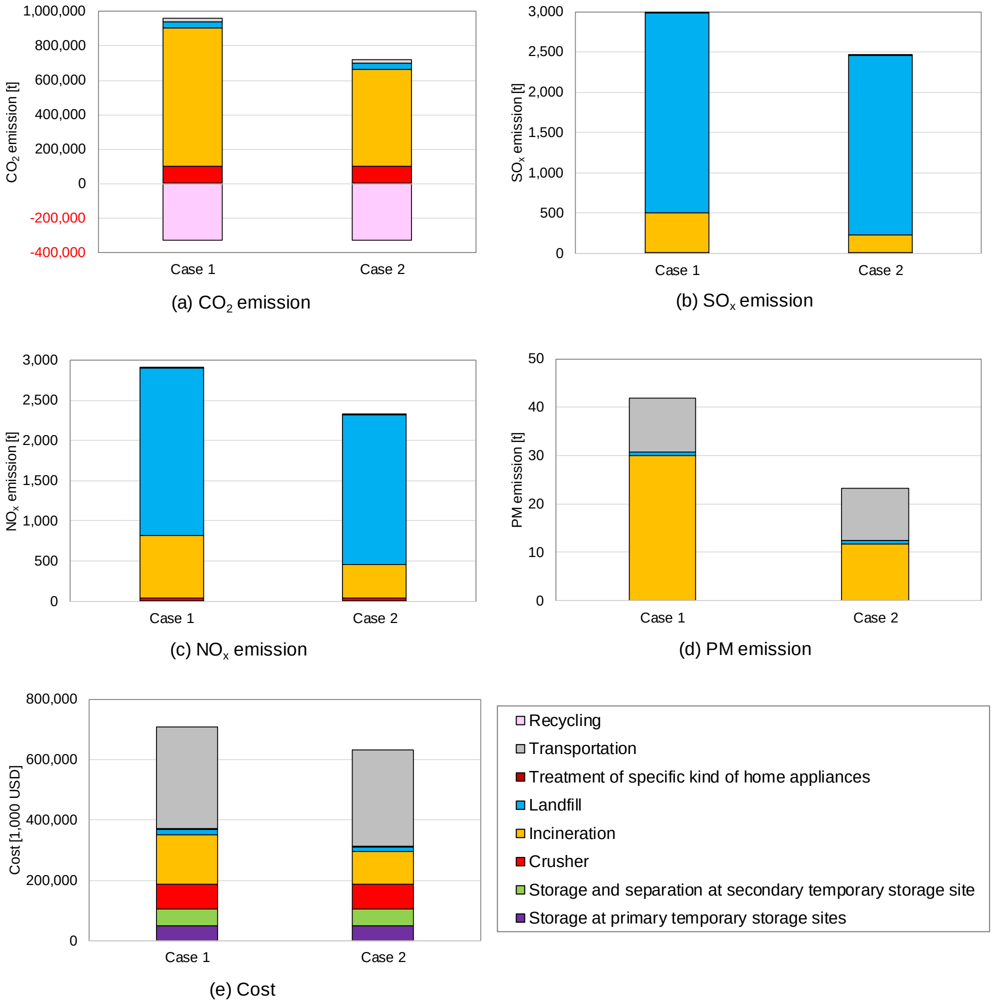

Figure 3: Results of Environmental burden and cost

Figure 3 (b) to (e) also shows the results of SO_x, NO_x and PM emissions and costs. Resultantly, SO_x emission, NOx emission, PM emission and cost were 2,500 – 3,000 t, 2,300 – 2,900 t, 20 – 40 t and 630 – 710 kUSD. Landfill was the dominant process in SO_x and NO_x emissions, whereas transportation and incineration were the dominant processes in PM emission and cost. All of the results revealed that Case 2 has less environmental burden and cost than Case 1 does.

Finally, the degree of impact on CO_2 and SO_x emissions. Regarding CO_2 emission was discussed. The estimated amount corresponded to only 3 – 5 % of total annual greenhouse gas emission in Kumamoto Prefecture. The impact on CO_2 emission via treating the disaster waste was quite small. On the other hand, for SO_x emission, the estimated amount corresponded to 29 – 35 % of total annual SO_2 emission in Kumamoto Prefecture. This impact is considerable from the viewpoint of regional air pollution. Local municipalities should investigate disaster waste management plans that perfectly recycle the waste.

4. Conclusions

The aim of this study was to develop methods to conduct environmental and economic evaluation of pre-disaster waste management. In this study, intensity data of disaster waste treatment processes was created. Analysis of the disaster waste management of waste from the 2016 Kumamoto Earthquakes was also conducted as a case study. The intensity data should be improve the data quality by examining our results. However, the environmental burden and cost was clarified in this disaster waste management. The degree of impact of environmental burden was revealed. Methods that proposed in this study are useful if local municipalities investigate pre-disaster waste management plans for future natural disasters. Moreover, by using our methods, local municipalities can deem the environmental and economic appropriateness of their post-disaster waste management plans. To determine what is correct in and/or ways to improve their plans is possible for local municipalities. These methods should be useful for them regarding their disaster management plans.

Acknowledgments

This research was supported by the Environmental Research and Technology Development Fund (3K143015).

References

Green D. W. and Perry R. H., 2008, Perry's Chemical Engineers' Handbook, Eighth Edition. McGraw-Hill Professional, Tokyo, Japan, 2704 ps. ISBN: 978-0071422949.

Kobayashi K., Isobe T., Tahara M., Inoue T., 2009, Analysis of building waste treatment in view of environmental load reduction. Journal of Environmental Engineering, Architectural Institute of Japan, 74, 97–104, doi: 10.3130/aije.74.97.

Kumamoto Prefecture, 2016, Disaster waste management plan for 2016 Kumamoto Earthquakes (ver.1), <www.pref.kumamoto.jp/kiji_16209.html> accessed 18.01.17. [in Japanese]

JEMAI (Japan Environmental Management Association for Industry), 2014. MiLCA, <www.milca-milca.net> accessed 18.01.17. [in Japanese]

Lorca Á., Çelik M., Ergun Ö., Keskinocak P., 2015, A decision-support tool for post-disaster debris operations. Procedia Engineering, 107, 154–167

Ministry of Environment, 2016, Disaster waste information site, <kouikishori.env.go.jp/en/> accessed 18.01.17. [in Japanese]

Onan K., Ülengin F., Sennaroğlu B., 2015, An evolutionary multi-objective optimization approach to disaster waste management: A case study of Istanbul, Turkey. Expert Systems with Applications, 42, 8850–8857, doi: 10.1016/j.eswa.2015.07.039.

Pereira J.-P., Lee L., 2016, Economic and environmental benefits of waste-to-energy technologies for debris recovery in disaster-hit Northeast Japan. Journal of Cleaner Production, 112, 4419–4429, 10.1016/j.jclepro.2015.05.083.

Pramudita P., Taniguchi E., Qureshi A-G., 2014, Location and routing problems of debris collection operation after disasters with realistic case study. Procedia - Social and Behavioral Sciences, 125, 445–458, doi: 10.1016/j.sbspro.2014.01.1487.

Tabata T., Hishinuma T., Ihara T., Genchi Y., 2011, Life cycle assessment of integrated municipal solid waste management systems, taking account of climate change and landfill shortage trade-off problems, Waste Management & Research, 29, 423–432, doi: 10.1177/0734242X10379493.

Tabata T., Okuda T., 2012, Life cycle assessment of woody biomass energy utilization: Case study in Gifu Prefecture, Japan, Energy, 45, 944–951, doi: 10.1016/j.energy.2012.06.064.

Tabata T. Wakabayashi Y., Tsai P., Saeki T., 2016a, Environmental and economic evaluation of pre-disaster plans for disaster waste management: Case study of Minami-Ise, Japan. Waste Management, in press, doi: 10.1016/j.wasman.2016.12.020.

Tabata T., Zhang O., Yamanaka Y., Tsai P., 2016b Estimating potential disaster waste generation for pre-disaster waste management. Clean Technologies and Environmental Policy, 18, 1735–1744, doi: 10.1007/s10098-016-1160-9.

Tsai P., Saeki T., Tabata T., 2015, Analysis of the redundant capacities of waste incineration plants and the possibility of wide- area disposal in Japan: the case of great earthquake at the Nankai trough. Proceedings of the 10th conference on sustainable development of energy, water and environmental systems, Croatia, Dubrovnik, SDEWES2015.0947, 1–7

United Nations, 2015, SDGs.:. Sustainable Development Knowledge Platform, <sustainabledevelopment. un.org/sdgs > accessed 18.01.17.