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ELEMENTARY STUDY ON EVALUATION OF ENVIRONMENTAL LOADS AND COSTS FOR WASTE TREATMENT SYSTEM IN BANGKOK

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It is very important for waste to be controlled and appropriately treated in a waste treatment system because of its impact on the environment. This study quantitatively evaluates the current waste treatment system and suggests countermeasures based on their impact on reducing the environmental and treatment costs in order to solve waste treatment problems in Bangkok, Thailand. Evaluation models are applied to estimate the treatment and environmental costs in the current waste treatment system.

This study shows that the contribution of carbon dioxide and methane gases from the current waste treatment system in Bangkok, Thailand to the greenhouse effect is large. Using the baseline scenario as a standard, the study provides a quantitative measure of the reduction in environmental costs that can be achieved by applying the countermeasure scenarios.

Key Words: *environmental cost, greenhouse gas, treatment cost, waste treatment flow*

1. INTRODUCTION

In Thailand and in many other developing countries, when it comes to waste management, the collection of waste constitutes the main countermeasure and treatment, and there are few cases where intermediate treatment or final disposal is appropriately conducted (*see* Fig. 1). It is very important that waste be controlled and appropriately handled in a waste management system because of its impact on the environment[1), 2)]. However, there are budgetary restrictions associated with the cost of treatment. Thus, it is necessary to quantitatively evaluate the impacts on the environment and to evaluate the suitability of a current treatment system, in relation to the costs associated with it. This study quantitatively evaluates and reviews the current waste treatment system and the respective countermeasures, based on their impacts and their effectiveness in reducing the environmental load, in order to solve the waste treatment problem in Bangkok, Thailand.

Fig. 1 Sanitary landfill site located in northeast area of Thailand

2. WASTE TREATMENT IN THAILAND

(1) Waste-related laws and organizations

The Improvement and Conservation of National Environmental Quality Act was instituted in

Thailand in 1975 to counter the escalating environmental problems caused by the country's rapid industrialization and urbanization. However, this law was not effective in achieving improvements, and it was abolished in 1992. Thailand now has environmental regulations under the Enhancement and Conservation of National Environmental Quality Act, which corresponds to the Environment Basic Law[3]. In addition, it was announced that recycling businesses should be prioritised in The Ninth National Economic and Social Development Plan. Furthermore, it was suggested in the same plan that at least 30% of waste should be separated, collected, and recycled. The main features of The Ninth National Economic and Social Development Plan are shown in Table 1[3].

Table 1 Main contents of The Ninth National Economic and Social Development Plan (Master Plan)

Goal	Guideline
The generation of municipal solid waste will be decreased to less than 1.0kg/parson/day.	An efficient system of the municipal solid waste treatment has to be established including the collection, transportation, intermediate treatment, and final disposal.
The recycling rate for municipal solid waste in Thailand will be increased to more than 15%.	The generation of municipal solid waste has to be controlled, and recycling and reusing have to be promoted.
All municipal solid wastes in Bangkok area will be managed.	The private-sector initiative to operation of municipal solid waste treatment system has to be utilized.
The sanitary management of municipal solid waste will be surely executed, and appropriate treatment system will be given.	The participation of private organization and citizens on the municipal solid waste treatment system has to be promoted.

(2) Waste and recycling

In Thailand, waste is divided into five categories: municipal solid waste, infectious waste, industrial hazardous waste, industrial non-hazardous waste, and hazardous waste. Municipal solid waste constitutes about 67% of all waste, and about 30% of municipal solid waste comes from Bangkok and surrounding cities[3].

Municipal solid waste in the areas around Bangkok is collected from garbage collection points specified by the administration, or from each households or facilities. Subsequently, via relay stations or temporary repositories, the waste is transported to disposal sites. Valuable resources in the waste collected at the relay stations or the temporary repositories are collected by waste pickers, who then sell these resources to second-hand shops. The second-hand shops then sell them to recycling facilities. However, a lot of recyclable waste is still left in the waste, and according to the data from the urban areas, the approximate percentage of recycled waste from recyclable waste is 18% for glass, 28% for paper, 14% for plastic, and 39% for metals. In the areas surrounding Bangkok, about 18% of industrial hazardous waste is reused and recycled. On the other hand, about 80% of industrial non-hazardous waste is recycled[4].

In Thailand, there are an estimated 1000 or more repository sites. At those sites, only 104 facilities were built properly with state funds. Also, many of these facilities are located in city centres [4].

3. EVALUATION MODEL OF WASTE TREATMENT SYSTEM

To handle waste treatment problems, the following points need to be examined:

(i) Rate of treatment costs as a whole in the current waste treatment system.

(ii) Emission rate of substances, such as carbon dioxide, methane and dinitrogen monoxide as well as final disposal amount of waste which contribute to the environmental load in current waste treatment processes.

(iii) Reduction of treatment costs and environmental load, and the suppression effect following the adoption of a countermeasure currently under consideration.

(1) Previous studies

There have been many attempts at creating environment assessment models of a waste treatment system by use of Life Cycle Assessment (LCA) or similar processes. For example, in the 1970s, Clark (1978)[5] reviewed a modelling method to optimise a waste collection method, predict the shortest route of collection and locate the optimal landfill sites. These models were based on detailed analyses of each process. On the other hand, Greenberg et al. (1976)[6] compared an alternative to a waste treatment system from the viewpoint of economics. Typical of the research conducted in the 1990s are the following: a detailed modelling of the economics of material recycling and its environmental loads[7]; and a wider modelling of the cost of alternatives of waste treatment including acceptability to residents, environmental loads and ease of operation and maintenance[8]. Additional research by Wu Ji et al. (1996)[9] and recently by Matsuto et al. (2005)[10] includes development of models to estimate CO_2 emission, energy consumption and disposition costs based on material flow in the waste treatment system. As described later, the model proposed in this study is based on the LCA model proposed by Wu Ji et al.

(1996)[9] and Matsuto et al. (2005)[10].

(2) Evaluation model procedure

In this study, evaluation models of waste treatment systems are applied to quantitatively evaluate environmental loads and treatment costs. These models can assess environmental impacts and treatment costs. The final objective of this research is to study a waste treatment system which comprehensively optimises environmental costs and treatment costs. To be more precise, the following evaluation models are applied to assess waste treatment systems based on their environmental impact:

(i) Setting up a waste treatment flow in a target area.
(ii) Dividing a waste treatment flow into three phases: collection and transport, intermediate treatment, and final disposal.
(iii) Estimating relevant work situations such as the distance travelled by collection vehicles, operating conditions, and amount of waste in each phase.
(iv) Estimating fuel consumption, required personnel, and treated amount of waste based on estimated operating conditions in each phase.
(v) Calculating environmental load and treatment costs in each phase by multiplying estimated fuel consumption, required personnel, and treated amount of waste in each phase by emission factors such as emissions per unit of substances that have an associated environmental load or labour costs.
(vi) Determining environmental loads and treatment costs in the overall waste treatment flow by adding environmental loads and treatment costs calculated in each phase.

It should be noted that a very large number of assumptions would be required for the input values for the evaluation model. However, we have used values based on on-site surveys described in literature[9), 10)] as well as on interviews with responsible persons at the facilities. To set the annual treatment cost, we assume a facility lifetime of 20 years, because the construction cost of facilities is one of the treatment costs.

(3) Emission factors

The amount of given activities are multiplied by an environmental load emission factor to determine final environmental loads. Since the unit for the environmental load emission factor is activity, the emission factor is very useful and convenient to estimate environmental loads. For example, the expression to calculate CO_2 emitted from fuels such

Table 2 Differences in emission factors between Japan and Thailand

Fields		Japan	Thailand
Electricity	($kg\text{-}CO_2/kWh$)	0.473	0.640
Heavy oil	($kg\text{-}CO_2/L$)	2.585	3.080
Light oil	($kg\text{-}CO_2/L$)	2.713	2.700
Civil works	($kg\text{-}CO_2/1{,}000yen$)	5.647	17.160
Building works	($kg\text{-}CO_2/1{,}000yen$)	4.400	6.750
Automobile manufacture	($kg\text{-}CO_2/1{,}000yen$)	3.150	4.770

as gasoline is as follows:

CO_2 emission factor (kg-C/MJ) = Carbon contents (kg-C/kg/L/Nm^3)/Per unit calorific value (MJ/kg/L/Nm^3)

According to the Ministry of the Environment of Japan, the estimated emission factor of CO_2 from gasoline in Japan is 2.32kg-CO_2/L. In addition, the following three measuring methods can be considered as ways to measure CO_2 emissions per unit monetary value:

(i) Measuring based on damage costs
(ii) Measuring based on countermeasure costs
(iii) Measuring based on emission trading prices

This study adopts the first of the above, i.e., measuring based on damage costs, determined from literature[11)] searches because the cumulative existing studies provide positive results. However, uncertainties are still present regarding conversion of environmental loads into monetary values in all of the above-mentioned methods. Therefore, attention needs to be paid when environmental loads are converted into monetary values. Moreover, there is also uncertainty regarding damage caused by on-going global warming which obviously is different for different regions, depending on which country or area is being considered. For this reason, damage costs must be set up for each country or area, and the respective values must be different.

For the emission factor of CO_2 in Thailand[12)], a value calculated from the inter-industry table found from the literature[11), 12)] searches should be used. The differences in emission factors between Japan and Thailand are shown in Table 2.

4. ENVIRONMENTAL EVALUATION OF WASTE TREATMENT IN BANGKOK, THAILAND

(1) Current situation of waste treatment system and basic information setting

In order to apply the evaluation models properly to the conditions in Bangkok, Thailand, each input value needs to be appropriate for the situation in that city. In order to achieve this, the current section summarizes the treatment system and basic information provided by Muttamara et al.[4] and UNEP[13] on the current situation regarding the waste treatment system in Bangkok. For the data which cannot be obtained from Muttamara et al.[4] and UNEP[13], data from Japan[9), 10] has been used. Figure 2 shows the waste treatment flow in Bangkok. The information for this figure was derived from literature[4), 13] searches. The information related to waste disposal is as follows:

(i) In Bangkok, waste is collected at 6 p.m. or later to avoid traffic jams. The collection rate is approximately 100% in the centre of the city, which is different than in other developing countries. However, the collection efficiency is low because there are many dead-end alleys in Bangkok. Also, another reason for the low collection efficiency centres upon the work habits of collection workers. Many of the collection workers collect recyclable items which can be traded as valuable resources during their work hours to gain additional income. Therefore, their work efficiency is very low. According to the literature[4), 13], within work hours at one site, collecting recyclable items took up half or more of the total work hours.

(ii) The collected waste is gathered at the relay stations at On-Nut, Nongkhaem, and Tharaeng. Then, recyclable waste is collected by waste pickers. Intermediate treatments at the relay stations have been considered; however, nothing has been implemented yet due to financial reasons and objections by local residents.

(iii) The waste collected at the On-Nut relay station is transferred to Phanomsarakam. The waste collected at Nongkhaem and Tharaeng is transferred to Kamphaengsaen. Subsequently, private companies approved by the BMA (Bangkok Metropolitan Administration) landfill all the waste at the final disposal sites. Since 1994, the BMA has been subcontracting work to approved private companies through bidding, because it has been difficult for the government to secure a new landfill site because of a sharp increase in land prices and objections by local residents.

(iv) The BMA is in charge of Bangkok public services. Previously the DPC (Department of Public Cleansing) of the BMA was collecting urban waste; however, recently, the work has been delegated to the cleaning sections of each area. Therefore, currently, the cleaning sections of each area collect waste, and the DPC formulates a cleaning-related policy and manages the budgets. On the other hand, under the present situation, fees collected from residents by the BMA are very small, and they can only cover a few waste management operating costs.

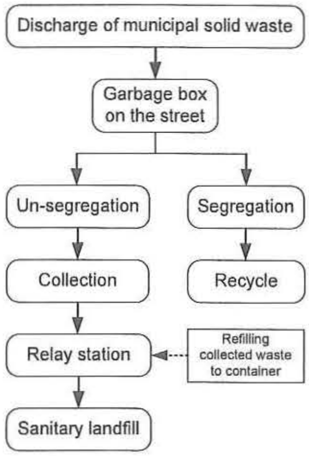

Fig. 2 Waste treatment flow in Bangkok, Thailand

(v) Since the data gained from literature[4), 13] searches is limited, other necessary information for the area should be input, on the basis of the assumptions made.

(vi) The basic information regarding the waste treatment system in Bangkok is shown in Table 3[4), 13].

(2) Baseline scenario setting

On the basis of the characteristics of the waste treatment system in Bangkok, the baseline scenario should be set as follows. The target area is the central area of the BMA. The BMA is divided into three areas with base facilities[3]. In each area, the respective processes of collection and transport, intermediate treatment, and final disposal are studied. Also, the collection and transport should be managed, intermediate treatment should not be executed, and the final disposal site should be a sanitary landfill. As a matter of convenience, the baseline scenario should be indicated as (none + sanitary landfill).

Based on the baseline set in the above conditions, a countermeasure scenario is set. The intermediate treatment (six patterns) and final disposal (three patterns), considered to be countermeasures, are set according to Muttamara et al.[14]. For the intermediate treatment, the following six patterns are used:

Table 3 Basic information regarding the waste treatment system in Bangkok, Thailand

(a) Required information for collection and transportation of municipal solid waste

	On-Nut	Nongkhaem	Tharaeng
Population	1,917,773	2,583,824	1,151,902
Distance from collection point to relay station (km)	16.79	18.26	11.42
Distance from relay station to landfill site (km)	92.70	80.10	97.5
Discharge of municipal solid waste (ton/year)	985,500	1,314,000	985,500
Collection frequency (per week)	6	6	6

(b) Composition of municipal solid waste

Composition	Ratio to total amount of waste discharge
Food scraps	35.9 %
Paper	13.6 %
Cloth	4.6 %
Plastic and foam	20.8 %
Leather and rubber	2.2 %
Wood and leaves	6.6 %
Unclassifiable	8.6 %
Metal	2.2 %
Glass	5.1 %
Stones and ceramics	0.6 %

resource sorting, composting, incineration, a combination of resource sorting and composting, and a combination of resource sorting and incineration. For the final disposal, the following three patterns are used: sanitary landfill, semiaerobic landfill, and anaerobic landfill. The number of countermeasure scenarios should be equal to the number of intermediate treatment and final disposal combinations. Therefore, eighteen patterns should be set (6 × 3 = 18).

(3) Environmental evaluation based on scenario setting differences

a) Treatment costs

Figure 3 shows the treatment cost for each scenario. The breakdown of treatment costs in the baseline scenario is around 53% for the collection process, around 37% for the transport process, and around 10% for the final disposal process. This is about the same level of waste collection cost as in the current waste treatment process.

In the scenario where composting or incineration is selected as the intermediate treatment method, facility construction costs were high. As a result, the overall treatment cost of this scenario becomes high (*see* Fig. 3). The basic values selected in this study for the intermediate treatment are based on literature[9), 10)] regarding treatment facilities in Japan. Thus, if an intermediate treatment facility is actually built in Bangkok, there is a high possibility that its cost will be different. Also, the costs for building an

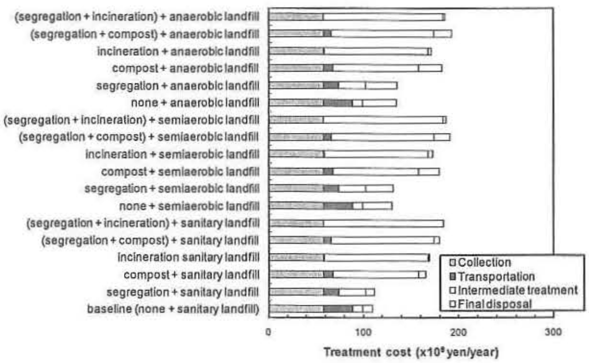

Fig. 3 Treatment costs in each scenario

intermediate treatment facility can be managed in many ways, e.g., by support from other countries such as Japan, or by improvements resulting from adoption of certain technologies. Therefore, to evaluate a waste treatment system in practice, it is also possible to incorporate changes in the unit price of construction which take into account adoption of certain technologies or funding from other countries to cover the cost of intermediate treatment facilities.

It is presumed that the reason for the values being quite different for the final disposal process is that the tenure of use differs vastly depending on treatment amounts, which in turn depend on the size selected for a landfill. Thus, it is also assumed that this has an impact on the final disposal costs.

b) Environmental loads

With the selection of substances that are a load on the environment in terms of the amount of greenhouse gases (CO_2, CH_4, and N_2O) and of waste, environmental loads for each scenario are compared and evaluated. Figure 4 shows the environmental load for each scenario. In the graph the final disposal amount of greenhouse gases and the waste itself are shown on the corresponding axes. The effects of a countermeasure scenario in decreasing the environmental load can be clearly seen. The decrease in environmental loading caused by the selection of final disposal is not very clear, but the decrease caused by intermediate treatment can be clearly seen. The scenario that applies incineration as an intermediate treatment has a great impact on the reduction of both greenhouse gases and waste; therefore, it can be concluded that its environmental load is smaller than that of the baseline scenario.

(4) Environmental evaluation by selecting intermediate treatment

a) Treatment costs

Sorting is an intermediate treatment which is assumed to be relatively inexpensive; however, we cannot fully compare its cost with that of other methods because it is assumed to be a paid service. The transport cost is high because the reduction caused by it is lower than for the others. In addition, the results show that the cost of running a facility to sort resources is not much different than the cost of incineration (*see* Fig. 3).

As for composting, the electricity consumption is larger because special equipment has to be used. This is reflected in the running cost of a composting facility. However, because organic matters are reduced, environmental load reduction can be enhanced if facility operations are replaced by something else for composting (*see* Fig. 3).

In the case of incineration, construction costs of an incineration facility are quite high. We assume that electricity at a site can be covered by energy collection. As with other intermediate treatments, the result shows that the cost of incineration can be lowered, along with transport costs, by reducing the waste amount. If the construction costs can be reduced by adopting efficient technology, incineration will be the best available intermediate treatment (*see* Fig. 3).

For the combination of resource sorting and composting, and the combination of resource sorting and incineration, their treatment costs are relatively high because they require two facilities. The results indicates that although the cost of each facility is low due to the small amount treated, the overall treatment cost of running two facilities becomes high (*see* Fig. 3).

b) Environmental loads

Compared with other intermediate treatments, resource sorting does not emit much CO_2 in a facility operation. However, it results in the amount of CH_4 in a landfill not being different from the case of no treatment, because virtually no organic matter is wasted (*see* Fig. 4).

For composting, electricity consumption for facility operation is high as is the case for treatment costs. The results shows that the amount of CO_2 emissions is more than for other intermediate treatments, and in general, this leads to higher amounts of greenhouse gas emissions than for other intermediate treatments (*see* Fig. 4). However, CH_4 emissions in the landfill are reduced because organic matter is treated.

Incineration is satisfactory for reducing the amount of waste itself compared with the other intermediate treatments. It is the same for the amount of CH_4 emissions. However, the CO_2 emitted by waste combustions is still high (*see* Fig. 4). Therefore, it can be assumed that the amount can be greatly reduced if a countermeasure is implemented, e.g., sorting out plastics in advance before transportation to a facility.

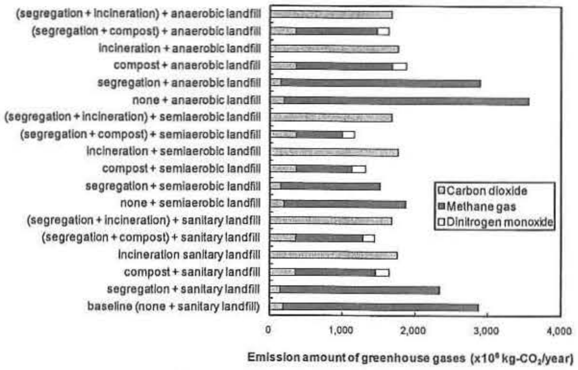

Fig. 4 Environmental loads in each scenario

(5) Environmental evaluation by selecting final disposal

a) Treatment costs

The construction costs of a sanitary landfill and a semiaerobic landfill are not much different. However, the results indicate that the treatment costs for the leachate from a semiaerobic landfill are greater than those for sanitary or anaerobic landfills. On the other hand, the results shows that for the scenario of an anaerobic landfill, the landfill construction costs are greater than for sanitary landfills or semiaerobic landfills (*see* Fig. 3).

b) Environmental loads

A semiaerobic landfill emits more CO_2 than other types of landfill because of the electricity consumed for the leachate. However, the results indicate that, as in the case of a landfill, the contribution to greenhouse gas emissions of CH_4 is very high and that the produced amount of CH_4 varies depending on disposal selections. In the case of the anaerobic landfill, there could be a considerable reduction in the amount of greenhouse gas emission, including CH_4, and a reduction in costs can be anticipated because of the possibility of using CH_4 (*see* Fig. 4).

(6) Converting environmental loads into monetary value

In order to compare the environmental loads with their treatment cost, the environmental loads are converted into monetary values. In this study, greenhouse gases are selected as the substances responsible for environmental loads and the associated final disposal amounts are determined. Monetary conversion values for greenhouse gases used in this study, based on the costs of damage caused by global warming, are as follows: 3.04

yen/kg-CO_2, 63.63 yen/kg-CH_4, and 939.3 yen/kg-N_2O[11]. A countermeasure cost for soil decontamination of 3,000 yen/m^3, based on the data by Ministry of Environment, Japan, is used for the final disposal amount.

a) Total costs

The total cost, which is the sum of the treatment cost and the monetary value converted from environmental loads, is used to evaluate each scenario. Using the total cost for an evaluation ensures that the evaluation of each scenario is based not only on the treatment costs but also on environmental loads. Figure 5 illustrates the total cost of each scenario.

In comparison with the baseline, almost all the countermeasure scenarios show smaller values in their respective total costs. The scenario in which resource sorting or incineration is selected as the intermediate treatment, presents a particularly smaller value of the total cost (*see* Fig. 5). It is well-known that there is a significant cost associated with any countermeasure that is taken to solve a waste problem. The results that include environmental loads provide a better indication of the real cost of a countermeasure. As is obvious, it costs a significant amount to include an intermediate treatment facility in the waste treatment system, and the results do not provide suggestions on how to reduce these costs. However, the load on the environment and the total cost, including treatment cost, will be reduced if a countermeasure is taken.

The scenario of selecting a semiaerobic landfill shows a particularly lower value for the final disposal (*see* Fig. 5). For intermediate treatment, a good countermeasure scenario as regards total cost is the scenario that includes resource sorting or incineration. There is an assumption that the total cost of waste management may become lower when the waste is managed at a landfill. However, more importantly, there is another assumption according to which, such low cost waste management might increase the environmental load.

In the case of selecting incineration as the intermediate treatment, the construction cost of an incineration facility impacts greatly on the initial cost (*see* Fig. 5). However, results indicate that when compared with the effects of reducing the environmental load, the construction cost is worthwhile.

When the total cost of each scenario is evaluated, it is found that the environmental load is higher when no countermeasures are taken, like in the baseline scenario which reflects the current situation. Therefore, it is obvious from the results that waste should be treated even when there is an associated treatment cost, as shown in the countermeasure scenarios.

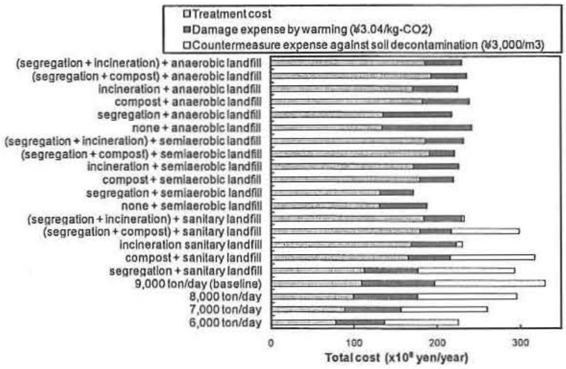

Fig. 5 Total costs of each scenario

b) Comparison with master plan

The case in which the amount of emissions per person per day is suppressed and in which the total cost of each scenario is considered, is also shown in Fig. 5. The condition is the case where the amount of emissions per person per day is set to 1.0 kg according to the master plan for Thailand, i.e., the emission rate for Bangkok, population six million, is 6,000 ton/day. The results show that the total cost of each countermeasure scenario that includes some treatment is smaller than the total cost of the case with reduced emissions. In the case where waste production is suppressed, the treatment cost of the waste is certainly lower than in the current base plan. However, as regards the environmental load, countermeasures provide better overall results.

If only the treatment cost in the waste treatment system is to be evaluated, then obviously suppressing the production of waste will achieve a better result. However, the impact of untreated waste on the environment is vast, as shown in the estimated results. Therefore, it is important to reduce environmental loads by treatment in the waste treatment system. The costs of the intermediate treatment and final disposal are more than the costs of the current situation. Also, the current situation is far from being profitable. Private companies would already have been involved if there was any profit associated with the treatment. The government needs to reconfirm the significance of waste treatment, and if necessary, implement appropriate waste treatment. To solve the problem of covering treatment costs and execute the necessary treatment, one should examine executable countermeasures such as collection of taxes from residents after explaining the situation to them and getting their assent, or receiving funds from other countries through emission credits because global warming is a universal problem. As matters now stand, because waste treatment is not properly handled, waste is continuing to load the environment which is resulting in the creation of an environment that is becoming unfit for habitation. If the waste treatment system is evaluated from the view of treatment cost and environmental load, costs will be a precondition for any treatment. Therefore, costs should be covered. It is necessary to reduce the environmental load by treatment such as incineration. Because incineration is the most effective countermeasure to reduce the environmental load among all the countermeasures including final disposal, discussion is required on treatment costs and how to cover them.

5. CONCLUSIONS

The following findings are obtained from this study:

(1) The evaluation models provided estimates of the treatment costs and environmental loads for the current waste treatment system in Bangkok, Thailand.

(2) The study showed that the CO_2 and CH_4 contributions to greenhouse gases from the current waste treatment system in Bangkok are very large.

(3) The study provided a quantitative estimate of the reduction in the environmental load resulting from applying countermeasure scenarios; the baseline scenario was used as the standard.

(4) The study converted the environmental loads into monetary values by a basic unit of monetary conversion and was able to obtain the treatment cost of each scenario.

(5) Each scenario was compared on the basis of the costs, and the environmental efficiency of each countermeasure scenario was presented. Furthermore, the master plan and each scenario were compared on the basis of the costs, and the environmental efficiency of each countermeasure scenario was presented.

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