M7-022 Application of Life Cycle Cost Analysis and TOPSIS Method for Selecting Municipal Solid Waste Treatment Technology and Management for the City of Bandung

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ABSTRACT

Municipal Solid Waste (MSW) problems in the City of Bandung, as well as other big cities in the country, is in need to be dealt with sooner rather than later. MSW treatment technologies such as open dumping landfill, sanitary landfill, waste to energy (WTE) incineration, composting, biogas anaerobic digestion, and gasification are to be considered as candidates of MSW treatment technology for implementation in the City of Bandung. MSW management scheme proposed are centralized plants for open dumping, sanitary landfill, and WTE incineration; and distributed plants for composting, biogas anaerobic digestion, and gasification. Selecting the most suitable MSW treatment technology and management for the City is accomplished by using Multi Criteria Decision Analysis (MCDA) TOPSIS Method. Criteria that are considered in selecting the MSW treatment technologies cover aspects of technology, economics, social, and environmental. Life cycle cost analysis (LCCA) was applied as a parameter for economic criterion in addition to potential revenue generation. Interview and survey were conducted, in which respondents from experts and college students were involved, in order to determine the weights to MCDA application. The analysis result showed that open dumping MSW treatment is unsuitable for the City. All things considered, it was found out that the most appropriate technology and management for the City is a virtual tie between composting and WTE incineration.

Keywords: municipal solid waste, MSW treatment technology and management, multi criteria decision analysis TOPSIS method, life cycle cost analysis

1. Introduction

Municipal Solid Waste (MSW) problems in the City of Bandung have become harsh issues that need to be solved promptly. The City of 2.2 millions inhabitants roughly generates 7,500 cubic meters of MSW per day [1, 2]. The amount of MSW generated has overwhelmed the City; only sixty percent of the waste produced is able to be hauled to the City's open dumping landfill due to insufficient numbers of garbage truck fleet, the other forty percent is left to the community to deal with [2]. This unfortunate circumstance has awakened up the City's administration to looking for alternatives of MSW treatment technology and management that are capable of reducing the greatest amount of MSW volume. As of today, only two MSW treatment technologies are being considered as alternatives by the City's administration: sanitary landfill and WTE incineration [3].

MSW treatment technologies such as open dumping, sanitary landfill, composting, waste to energy (WTE) incineration, biogas anaerobic digestion, and gasification are considered as candidates of technologies proposed to be implemented in the City. The MSW treatment technologies were preliminarily dimensioned in order to obtain the estimated capital cost, operation and maintenance (O&M) cost, area of landfill required, cost of site acquisition, the amount of pollutant emitted, volume reduction, potential revenues, and potential job creation.

Multi Criteria Decision Analysis (MCDA) TOPSIS (The Technique for Order Preference by Similarity to an Ideal Solution) Method formulated by Hwang and Yoon [4] is to be employed in order to objectively and systematically selecting the most suitable MSW treatment technology for the City. Criteria considered in selecting the MSW treatment technologies cover aspects of technology, economics, environment, and social.

Life cycle cost analysis (LCCA) [5] was applied as one of parameters for economic criteria, in addition to potential revenue generation.

Interview with experts and responds to questionnaire circulated to college students were used as base to determine the weights in the MCDA [6].

The verification to the TOPSIS method applied to the selection of MSW treatment technology and management was undertaken by implementing the MCDA formulation to the experts' preference.

2. Life Cycle Cost Formulation

The economics parameter boundary for LCCA is assumed to include capital cost for erecting the plant and acquiring lot for the plant site, O&M cost to sustain the plant, and transportation cost of hauling the MSW to the plant site. Moreover, the time frame for LCCA is set for 15 years.

It is assumed that the capital cost, which is based on the World Bank pricing [7], is obtained from commercial loan for the period of five years with 10 percent interest rate.

The O&M cost are based on the World Bank estimation cost [7] for the corresponding MSW treatment technology. In addition, a 5-percent per year of O&M cost escalation is imposed on each MSW treatment technology.

The transportation expenses are calculated based on the distance traveled by 10-cubic-meter garbage trucks and by assuming that the fuel economy of each truck is 3 km for each liter of diesel fuel consumed. The fuel price is assumed to increase 2 percent each year based on current diesel fuel price.

MSW technologies that generate revenue such as biogas anaerobic digestion, WTE incineration, gasification, and composting are subject to taxation obliged by the government. It is assumed that 15 percent tax is applicable to the MSW treatment plants.

A discount rate of 5 percent to take inflation rate into account is assumed in order to calculate net present value (NPV) of the life-cycle cost of the MSW treatment plants.

3. Multi Criteria Decision Analysis Formulation

Selecting the best alternative by order of preferences has been studied rigorously during these past four decades. There are two schools of thought for formulating MCDA: by using utility functions and by using preference outranking. TOPSIS, one of the outranking methods, has been widely applied to solve multi criteria decision problems successfully.

Criteria to be imposed on MCDA cover aspects of technology, economics, environment, and social. In addition, each criterion is to be itemized into sub-criteria as such that a deeper analysis can be carried out.

The technological criteria is further divided into 4 sub-criteria: volume reduction that is to be maximized, local content that is to be maximized, time required for planning to commissioning that is to be minimized, and the maturity of the MSW treatment technology that is to be maximized.

The economics criterion is further partitioned into life cycle cost present worth that is to be minimized and revenue generation that is to be maximized

The environmental aspect is divided into plant area, green house gas (GHG) emission, leachate generation, landslide potential, and water supply that are to be minimized.

The social criterion is divided into potential job creation and community approval that both are to be maximized.

4. Sizing of MSW Treatment Technology and Management

Two types of MSW management schemes are proposed to the City: 1) a centralized scheme, where the MSW treatment plant is located at one pertinent site, and 2) a distributed scheme, where three MSW treatment plants are to be located in the West, Central, and East regions of the City.

Open dumping landfill, sanitary landfill, and WTE incinerator technologies are applied in a centralized management scheme due to social rejection and economic of size. The other three MSW treatment technology alternatives, namely composting, biogas digestion, and gasification are implemented in a distributed management scheme in order to reduce transportation expenses as to offset higher capital cost.

The City's MSW generation is assumed to escalate 2 percent per year as to anticipate population and prosperity growths. As of now, 20 to 25 percent MSW is recycled and reused by informal garbage collectors, i.e., "*pemulung*"; the rest of the MSW is managed by the City's business branch (*PD Kebersihan*).

Based on current statistics, the West region generates 38 percent of the City's total MSW generation. The Central and the East regions generate 32 percent and 30 percent of total MSW generation respectively. It is assumed that the MSW generation percentage on each region is particularly constant within 15-year period.

Table 1 on the last page summarizes the sizing calculation. The local content of each MSW treatment technology is estimated as follows: 90 percent of open dumping landfill components are to be supplied locally, and 80, 40, 60, 60, and 80 percent of sanitary landfill, WTE incineration, biogas, gasification, and composting components are locally supplied.

According the World Bank survey [7], the average time required from planning to commissioning on the construction of open dumping landfill, sanitary landfill, WTE incineration, biogas anaerobic digestion, gasification, and composting plants are 3, 9, 54, 15, 15, and 12 months respectively. The same survey mentioned that the average volume reduction achieved by open dumping landfill, sanitary landfill, WTE incineration, biogas anaerobic digestion, gasification, and composting are 20, 20, 92, 55, 60, and 50 percent respectively. Biogas anaerobic digestion and composting do not have great volume reduction characteristics as they are only capable of processing organic matters.

The NPV of LCCA for open dumping landfill, sanitary landfill, WTE incineration, biogas anaerobic digestion, gasification, and composing are calculated resulting in 1108, 1885, 5019, 3231, 4209, and 1896 billion rupiahs of life cycle cost each. In calculating transportation expenses, 70 km trip per day per truck is assumed for open dumping and sanitary landfills, 30 km per day per truck is assumed for WTE, biogas anaerobic digestion, gasification, and composting plants.

Furthermore, the potential revenue generation from selling electricity generated in WTE incineration, biogas anaerobic digestion, and gasification are 3161, 2887, and 2170 billion rupiahs per 15-year period respectively, based on the current electricity selling price of 700 rupiah/kWh and 2 percent price escalation per year. While composting treatment generates revenue of 4 billion rupiahs during its life time of 15 years, based on the current compost selling price of 1000 rupiah/kg and 2 percent price escalation per year.

The site's area required for each MSW treatment plant is calculated based on the volume of MSW disposed during 15-year period, the depth of landfill's quarry of 50 meters, and estimated area for utilities. To offset the scarcity of available open space for landfill, open dumping and sanitary landfills are designed to last for 5 years; hence, three separate landfills are designed to cover 15-year LCCA period. Furthermore, WTE incineration, biogas anaerobic digestion, gasification, and composting plants still need landfill to dispose unprocessed MSW. The plant total area required for open dumping landfill, sanitary landfill, WTE incineration, biogas anaerobic digestion, gasification, and composting are 119, 160, 14, 28, 22, and 23 hectares respectively.

GHG emission is calculated base on the assumption that 1 ton of MSW generates 200 m^3 of methane gas and that methane gas greenhouse effect is 21 times more severe than that of GHG (carbon dioxide) [9]. Following the calculation procedure [10], the GHG emission for open dumping landfill, sanitary landfill, WTE incineration, biogas anaerobic digestion, gasification, and composting are 30, 7, 16, 2, 14, and 2 million tons per 15-year period. Meanwhile, leachate generation, landslide potential, and water supply requirement in MSW treatment technology are not calculated in detail; however, relatives values based on the World Bank surveys are assigned to each criterion.

Potential job creation is estimated as in the World Bank survey results, while community approval score is deducted from polling result of the college student's opinion.

5. TOPSIS Method Formulation

TOPSIS method has been applied for solving various multi criteria (attributes) decision problems in which the method proves to be simple but robust and dependable.

The scheme of the method is to order preference of alternatives that have the closest distance to the ideal solution (D^+) and are the farthest away from the non-ideal solution (D^-). Moreover, a ratio (R) is assigned to each criterion on each alternative. The ratio is calculated as $R = D^- / (D^+ + D^-)$. Then, the sum of scores multiplied by the corresponding weight result in the total score for each alternative. Table 2 shows the weights assigned to each criterion of the alternatives.

Table 2 TOPSIS weights assignment

criteria	sub-criteria	weight	
technology	local content	1	4
	development time	2	
	vol. reduction	8	
	maturity	4	
economics	npv of lcc	2	1
	revenue	1	
environmental	plant area	5	3
	ghg pollutant	4	
	leachate	2	
	landslide potential	3	
	water supply	1	
social	job creation	2	2
	comm'ty approv'l	1	

The rationale behind the weights signing is that the technological aspect is seen as the first priority in MSW treatment plant, especially the volume reduction factor. Environmental aspect is positioned as the second priority, followed by the social and economics aspects. The sub criteria are all weighted in monotonically linear fashion to portray their order of significance, except for those of technological aspect in which the weights are monotonically quadratic in order to underline the significance of volume reduction.

For the problem in hand, the best solution for each criterion is set as the ideal solution (s^+) and the worst solution is set as the non-ideal solution (s^-)

In a nutshell, the TOPSIS algorithm is broken down as follows:

- Obtain performance data for n alternatives over k criteria.
- Convert raw measures x_{ij} into standardized measures s_{ij}.
- Develop a set of importance weights w_k for each criterion.
- Identify the ideal alternative (extreme performance on each criterion) s^+,
- Identify the non-ideal alternative (reverse extreme performance on each criterion) s^-.
- Develop a distance measure over each criterion to both ideal (D^+) and non-ideal (D^-).
- For each alternative, determine a ratio R equal to the distance to the non-ideal divided by the sum of the distance to the non-ideal and the distance to the ideal.

6. Verification on MCDA scheme and TOPSIS Method

Interview with two experts on MSW treatment technology and management was conducted in order to verify the application of MCDA. Both experts claimed that WTE incineration is the most appropriate MSW treatment technology to be implemented to the City of Bandung.

The first expert stated that the criteria he uses for selecting the MSW technology are 1) volume reduction, 2) development time, and 3) potential revenue. His criteria are translated into 1) technology maturity, 2) volume reduction, 3) time from planning to commissioning, and 4) revenue generation. By implementing his criteria into MCDA and by assigning equal weight to each criterion, TOPSIS resulted in an order of preference shown in Figure 1, where it shows that the method is consistent with the expert's preference.

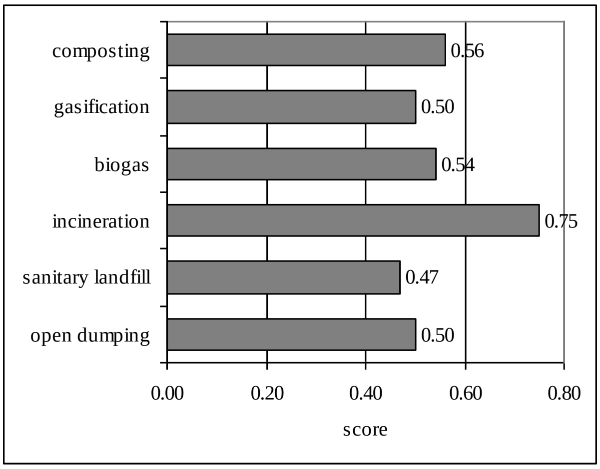

Figure 1 Expert A order of preference

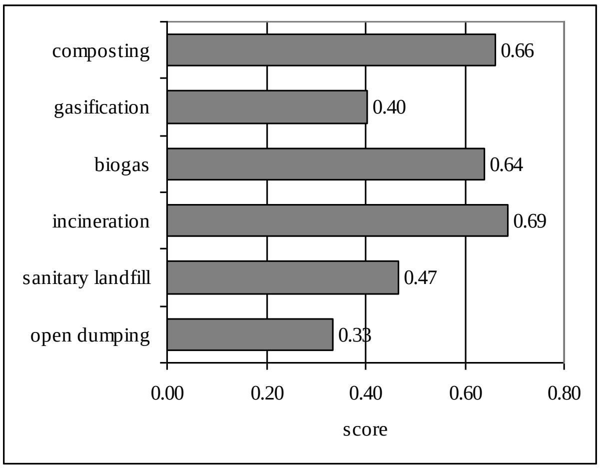

Figure 2 Expert B order of preference

The second expert also selected WTE incineration as the most appropriate MSW treatment technology for the City; however, he has different view regarding criteria imposed to come up with the preference. The criteria he uses are 1) cost, 2) technologically feasible, 3) community approval, and 4) compliance to the local environmental laws. His criteria are translated to 1) NPV of life cycle cost, 2) revenue generation, 3) technology maturity, 4) GHG emission, and 5) community approval. Again, the result of TOPSIS analysis using his criteria, assuming they are having the same weights, is consistent with the expert's preference as illustrated by Figure 2.

7. Result and Discussion

Figure 3 shows the bar chart of MSW treatment alternatives order of preference resulted by TOPSIS analysis. The total score of each alternative is 0.30, 0.39, 0.77, 0.66, 0.59, and 0.77 for open dumping landfill, sanitary landfill, WTE incineration, biogas digestion, gasification, and composting respectively.

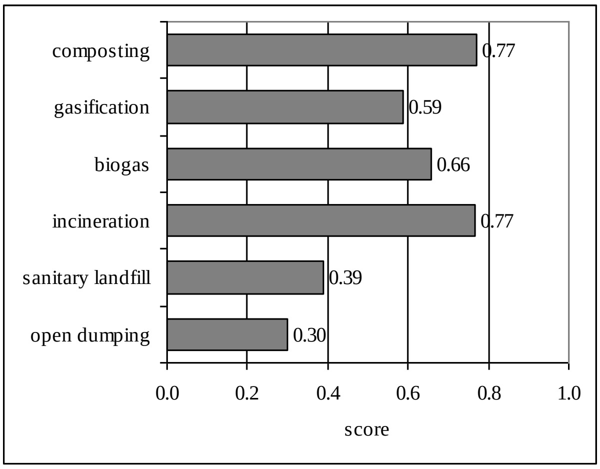

Figure 3 Score and rank of alternatives

The analysis shows that open dumping landfill is attested to be unfitting for MSW treatment technology and management for the City of Bandung.

Sanitary landfill without LFG collection and utilization is costly in all aspects. Collection of LFG and utilization of the gas to fuel a gas engine will improve the applicability of this MSW treatment technology; however, it will add capital and O&M costs.

Despite partial community rejection to WTE incineration for its pollutant emission, it is superior in terms of volume reduction as such that the plant footprint is the smallest compare to the other alternatives.

Biogas anaerobic digestion and gasification as MSW treatment are inferior to those of WTE incineration and composting by virtue of technology immaturity. They are the future MSW treatment for the only drawback is their technology immaturity.

Composting the organic part of MSW is viewed as the prudent process for treating the waste. Community can take part in the process through local organization; however, there is also some concern about the quality of compost that may not be suitable for fertilizing edible plants.

8. Conclusion and Future Development

Composting and/or WTE incineration are two options of MSW treatment technology that answer the City's MSW problems.

Biogas anaerobic digestion and gasification for treating MSW are developing and maturing, hence implementing these technologies this time around are imprudent to solve such urgent problems of MSW in the City of Bandung.

Sanitary landfill is too costly with the only benefit is the significant amount of GHG reduction compare to that of open dumping landfill.

It is the time to abandon open dumping landfill for MSW treatment. Lesson has been learned that this type of MSW treatment has caused more problems rather than resolving them.

MCDA as a tool for selecting preference has been proved to be reliable; however, the data need to be fined tuned by carrying out a more rigorous survey concerning the community opinion on these MSW treatment technologies and management schemes. As of now, a survey is being undertaken to poll the community at large regarding their opinion on these technologies.

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Table 1 Evaluation table for TOPSIS analysis

criteria	sub-criteria	unit	scheme	open dumping	sanitary landfill	wte	biogas	gasific'n	compost
technology	local content	percent	max	90	80	40	60	60	80
	development time	months	min	3	9	54	15	15	12
	vol reduction	percent	max	20	20	92	55	60	50
	maturity	relative	max	2	2	2	1	1	2
economics	lcc - 15 years	billion rp	min	1108	1885	5019	3231	4209	1896
	revenue	billion rp	max	0	0	3161	2887	2170	4
environment	plant area	ha	min	119	160	14	28	22	23
	ghg emission	million ton	min	30	7	16	2	14	2
	leachate	relative	min	4	2	1	1	1	1
	landslide potential	relative	min	2	1	0	0	0	0
	water supply	relative	min	0	0	2	1	0	1
social	job creation	persons	max	10	14	80	60	60	75
	commn'ty approval	relative	max	1	2	4	6	3	5