SUITABLE MULTI CRITERIA DECISION ANALYSIS TOOL FOR SELECTING MUNICIPAL SOLID WASTE TREATMENT IN THE CITY OF BANDUNG

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Abstract

Municipal solid waste (MSW) generated by the dwellers of the City of Bandung which amounted to 7500 m^3 per day is big deal of a problem for the Government of the City since MSW treatment and management is carried out by the Government business branch (PD Kebersihan). The Government has decided to implement waste to energy (WTE) incineration for MSW treatment three years ago. The realization, however, was nowhere to be seen. One of the reasons that the realization is halted is due to the objection by residents in the neighbourhood of the planned WTE plant site. This paper aims to systematically and objectively assist and support the decision makers in the Government in selecting the most appropriate MSW treatment technology and management for the City via implementation of sound multi criteria decision analysis (MCDA) tools available. Herein, the MSW treatment technology and management regarded as alternatives are open dumping landfill, sanitary landfill, power generation from biogas via anaerobic digestion, power generation via gasification, composting, and waste to energy (WTE) incineration. Moreover, aspects of technology, social, economy, and environment are considered as criteria for selecting the most suitable MSW treatment technology and management. Several well established MCDA tools such as AHP, ELECTRE II, PROMETHEE II, and TOPSIS are applied. Each of the MCDA tool has its own merits and drawbacks which will be investigated in this paper. In addition, sensitivity analyses were carried out in order to investigate the robustness of the methods. Among all MCDA tools mentioned, TOPSIS is the simplest to be used for it does not need much intervention from the decision maker, and yet yields comparable results with others.

Keywords: *multi criteria decision analysis, municipal solid waste treatment technology and management, AHP, ELECTRE II, PROMETHEE II, TOPSIS*

1. Introduction

Municipal solid waste (MSW) generated by some 2.5 millions dwellers in the City of Bandung which is amounted to 7,500 m^3 per day is big deal of a problem for the Government of the City since MSW management is carried out by the Government business branch (PD Kebersihan) [1, 2]. At present, the Government of the City is still practicing open dumping landfill MSW treatment. As the availability of open spaces for open dumping landfill MSW treatment is declining, the Government has decided to implement waste to energy (WTE) incinerator for MSW treatment three years ago. The realization to the policy, however, was nowhere to be seen. One of the reasons that the realization is halted is due to the objection by residents in the neighbourhood of the planned WTE plant site. To make matter worse, the Government has not been keen to reveal the reasoning behind and the methodology used to come up with such decision to the citizen of the City.

This paper aims, therefore, to systematically and objectively assist and support the decision makers in the Government in selecting the most appropriate and agreed upon MSW treatment technology and management for the City through application of suitable multi criteria decision analysis (MCDA) tools. Herein, the MCDA tools considered in accomplishing this task are AHP

(Analytic Hierarchy Process), ELECTRE II (Elimination et Choix Traduisant la Réalité – Elimination and Choice which Translate Reality II), PROMETHEE II (Preference Ranking Organization Method for Enrichment Evaluation II), and TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) [3-5].

Moreover, the MSW treatment technology and management regarded as alternatives are open dumping landfill, sanitary landfill, power generation from biogas via anaerobic digestion, power generation via gasification, composting, and WTE incineration. In addition, aspects of technology, social, economy, and environment are considered as criteria for selecting the most suitable MSW treatment technology and management.

2. Method

Two types of MSW management schemes are proposed to the City of Bandung, i.e., 1) 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 the likelihood of near-plant-site community objection and economic of size. The other three MSW treatment technology alternatives, namely, composting, biogas via anaerobic digestion, and gasification are implemented in a distributed management scheme in order to reduce transportation expenses as to offset higher capital cost in erecting these MSW treatment plants. The sizing of each MSW treatment technology and management alternative that has been carried out by the authors [6, 7] will be used without any alteration. The evaluation matrix of alternatives and criteria is presented in Tab. 1.

Tab. 1. Evaluation matrix of alternatives and criteria

Criteria	Sub-Criteria	Unit	Open Dumping	Sanitary Landfill	Wte Incin'n	Biogas	Gasifi'n	Compost
Technology	Local Content	Percent	90	80	40	60	60	80
	Development Time	Months	3	9	54	15	15	12
	Vol Reduction	Percent	20	20	92	55	60	50
	Maturity	Relative	2	2	2	1	1	2
Economics	LCC - 15 Years	Billion Rp	1108	1885	5019	3231	4209	1896
	Revenue	Billion Rp	0	0	3161	2887	2170	4
Environment	Plant Area	Hectares	119	160	14	28	22	23
	Ghg Emission	Million Ton	30	7	16	2	14	2
	Leachate	Relative	4	2	1	1	1	1
	Landslide Potential	Relative	2	1	0	0	0	0
	Water Supply	Relative	0	0	2	1	0	1
Social	Job Creation	Persons	10	14	80	60	60	75
	Commn'ty Approval	Relative	1	2	4	6	3	5

Furthermore, in order to elaborate each criterion, the aforementioned criteria are broken down into sub-criteria. Aspect of technology is broken down into 4 (four) sub-criteria, i.e., volume reduction, development time required from planning to commissioning to erect MSW treatment plant, maturity of MSW treatment technology, and local content of parts and equipment in MSW treatment technology. Next, aspect of economy is broken down into 2 (two) sub-criteria, i.e., life cycle cost of MSW treatment plant per 15-year period, and revenue generated by the MSW treatment technology. Moreover, aspect of environment is broken down into 5 (five) sub-criteria, i.e., required plant foot print area, green house gas (GHG) emission, amount of leachate generated, landslide potential, and required water supply. Finally, social aspect is broken down into 2 (two) sub-criteria, i.e., the number of jobs created, and community approval.

The weight assigned to each sub-criterion is based on the survey results in which the respondents of the survey were 2 (two) experts on MSW treatment technology and management, students of Institut Teknologi Bandung (ITB) and community at large. Tab. 2. shows the weight assignment to each criterion and sub-criterion, and also the optimization scheme for each sub-criterion and each criterion.

Tab. 2. Weights assignment and optimization scheme

Criteria	Sub-Criteria	Scheme	Weight	
Technology	Local Content	Maximizing	1	4
	Development Time	Minimizing	2	
	Vol. Reduction	Maximizing	4	
	Maturity	Maximizing	3	
Economics	LCC - 15 Years	Minimizing	2	1
	Revenue	Maximizing	1	
Environment	Plant Area	Minimizing	5	3
	Ghg Emission	Minimizing	4	
	Leachate	Minimizing	2	
	Landslide Potential	Minimizing	3	
	Water Supply	Minimizing	1	
Social	Job Creation	Maximizing	2	2
	Community Approval	Maximizing	1	

The MCDA tools applied in this endeavour are categorized as outranking methods. The basic principle of each MCDA tool applied is piecewise comparison of each alternative to the other for each and every criterion imposed. Each MCDA tool, of course, has different methodology in conducting piecewise comparison. Exhaustive explanation on each MCDA tool, however, will not be presented here. The readers who wish to delve into theoretical derivation on these methods are encouraged to refer to the reference list.

In AHP method, the criteria are normalized in accordance with the Saaty scale of relative importance where the value of each criterion is assigned a value of 1, 3, 5, 7, or 9. Tab. 3. explains the Saaty on scale of importance [8]. Unlike in strictly following Saaty scale where the scale values are integer number, herein the values are allowed to assume real number instead. This technique may also be known as Fuzzy AHP. The comparison of each alternative to the other for each and every criterion is formulated as the ratio of the other alternative to the one to be compared to.

Tab. 3. Saaty scale of relative importance

Intensity of Relative Importance	Definition
1	equal importance
3	weak importance of one over the other
5	strong importance
7	demonstrated importance over the other
9	absolute importance
2, 4, 6, 8	intermediate values between

In applying ELECTRE II method, the role of decision maker is very crucial in determining five threshold values (p^+, p^0, p^-, q^+, and q^-) to signify the order preferences. Herein, those threshold values are set to the maximum for ordering preference of alternatives (p^+, p^0, and p^-) and to the minimum for ordering the outranked (rejected) alternatives (q^+ and q^-). These threshold values are treated as such for there is no decision makers involved in conducting this analysis. Comparison with regard to preference of one alternative to the other is presented in concordance matrix; and with regard to rejection of one alternative to the other is presented in discordance matrix.

In PROMETHEE II method, the relative importance of one alternative to the other is patterned as one of six types of generalized criteria as shown in Fig. 1. Pertaining to this endeavour of selecting MSW treatment technology and management for the City of Bandung, each criterion is patterned to type III: criterion with linear preference. Type III of relative importance was chosen as to eliminate subjectivity of decision makers. Comparison of each alternative to the other for each and every criterion is formulated as the difference between the other alternative and the one to be compared to (Φ^+ for preference and Φ^- for rejection).

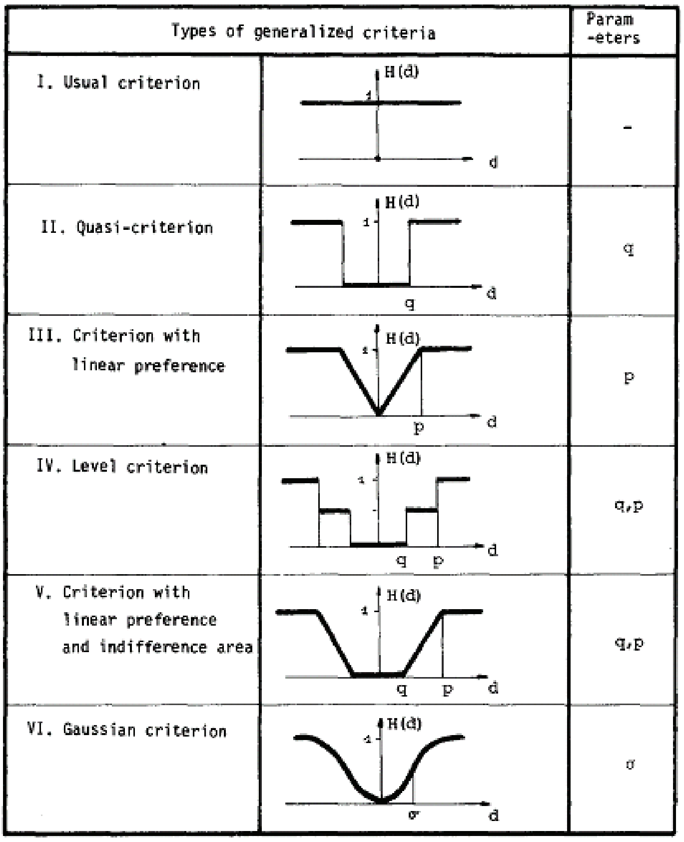

Fig. 1. PROMETHEE six types of generalized criteria [3]

In applying TOPSIS method, the ideal values are set as the maximum or the minimum value which belongs to an alternative for a particular criterion, depending upon the optimization scheme, e.g., maximization or minimization. Comparison of each alternative to the other for each and every criterion is formulated as the difference between the other alternative and the one to be compared to (D^+ and D^-).

3. Result and Discussion

AHP, ELECTRE II, PROMETHEE II, and TOPSIS results are shown in Fig. 2. follows. It must be noted here that the values of preference in each MCDA tool were normalized into values from 0 (zero) to 1 (one). This is done in order to observe the relative importance of one alternative to the other on equal basis. AHP, PROMETHEE II, and TOPSIS results are in agreement; composting of MSW is ranked as the highest preference, and then followed by WTE incineration, biogas anaerobic digestion, gasification, sanitary landfill, and open dumping landfill, respectively. Meanwhile, ELECTRE II resulted in different order of preference; WTE incineration is ranked as the highest preference, and then followed by composting, gasification, biogas anaerobic digestion, sanitary landfill, and open dumping, respectively.

The difference between ELECTRE II and the other three MCDA tools is in the manner it constructs concordance and discordance matrices which are based on Boolean comparison. Whereas in AHP, PROMETHEE II (Φ+ and Φ-), and TOPSIS (D+ and D-) the comparison is based on real numbers. Therefore, in essence, the fuzziness of importance is overlooked in ELECTRE II method.

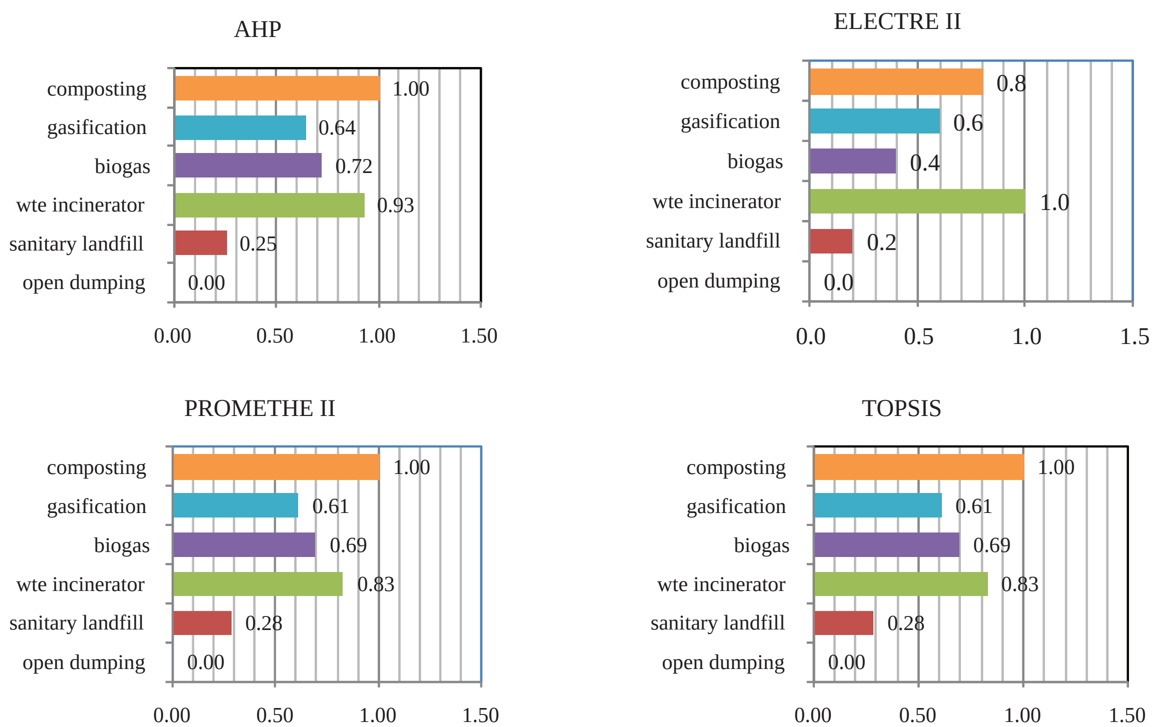

Fig. 2. MSW treatment technology and management order of preference

For the purpose of base lining the order of preference, equal weights for every criterion were imposed, and then the MCDA tools were applied to rank the alternatives. Fig. 3. shows the order of preference resulted from the MCDA tools implementation. Composting as MSW treatment technology and management positioned as the highest rank, and open dumping landfill is in the last position. The second rank of preference falls to biogas anaerobic digestion plant. The third rank of preference revealed by AHP, PROMETHEE II, and TOPSIS is gasification of MSW. ELECTRE II, however, ranks WTE incineration in the third, ahead of gasification. Nevertheless, composting MSW as treatment technology in distributed management is concurred as the highest preference by all MCDA tools applied.

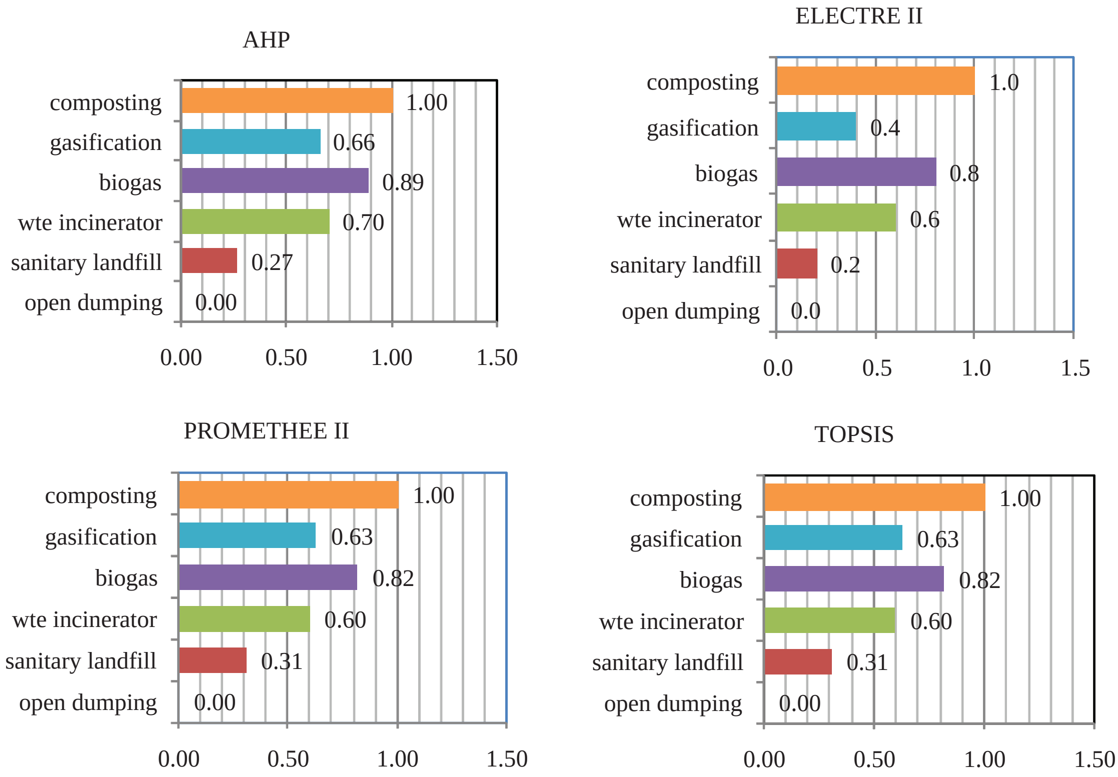

Fig. 3. MSW treatment technology and management order of preference with equal weight assignment

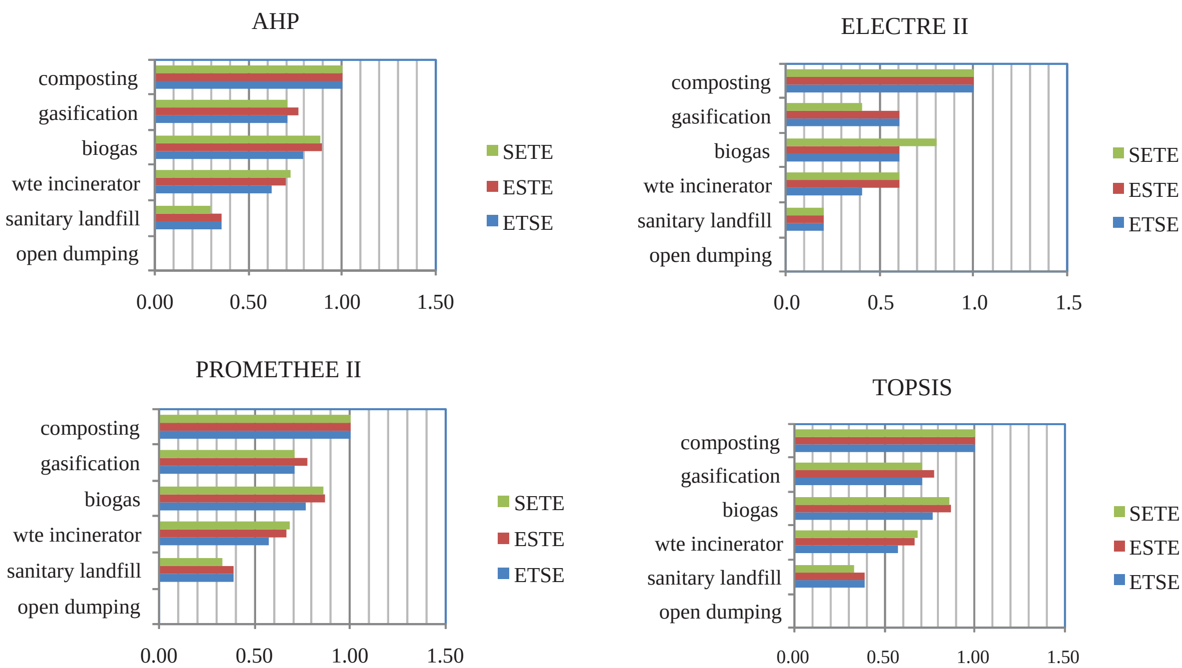

Fig. 4. MSW treatment technology and management order of preference with various criteria weights and equal sub-criteria weights assignment

The next investigations carried out in this analysis are varying the order of importance of criteria. Herein, three order of importance are considered, i.e., 1) social-environment-technology-economy (SETE), 2) environment-social-technology-economy (ESTE), and 3) environment-technology-social-economy (ETSE). The weights for each criterion are set, in decreasing order, to value of 4-3-2-1; whereas the weights for each sub-criterion are set to value of 1. The results are shown in Fig. 4. The figure shows that, in general, composting MSW is positioned in the highest rank of preference independent to MCDA tool applied. AHP, PROMETHEE II, and TOPSIS reveal that biogas generation from anaerobic digestion of MSW ranks second, and then followed by gasification, WTE incineration, sanitary landfill, and open dumping landfill. ELECTRE II, however, ranks differently depending upon variation of order of importance. Nevertheless, once again, composting MSW is seen as the highest rank of preference.

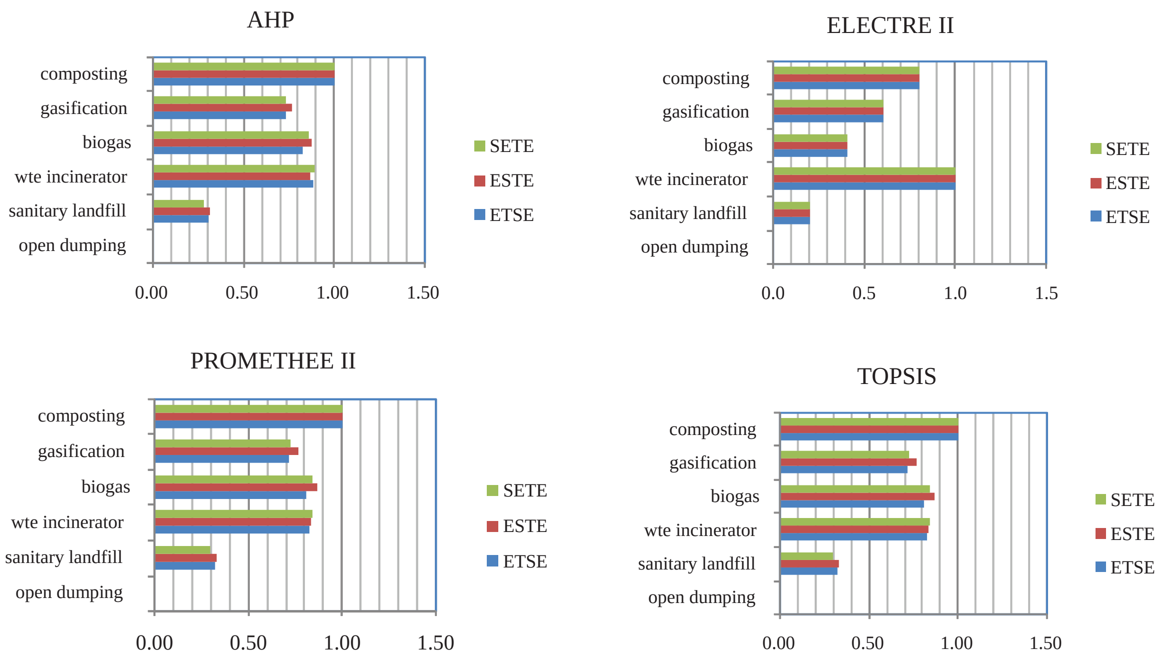

Fig. 5. MSW treatment technology and management order of preference with various criteria and sub-criteria weights assignment

The final investigation in this analysis is varying the sub-criteria weights according to values presented in Tab. 2. in addition to varying criteria weight as aforementioned. The results are shown in Fig. 5. The figure shows that AHP, PROMETHEE II, and TOPSIS yield composting as MSW treatment of highest preference. Meanwhile, ELECTRE II puts WTE incineration of MSW in the highest rank of preference. Next, for all practical purposes, AHP, PROMETHEE II, and TOPSIS resulted in indifferent preference between WTE incineration and biogas generation through anaerobic digestion as the second rank of preference after composting. And then follow gasification, sanitary landfill, and open dumping. ELECTRE II, on the other hand, yields definitive order of preference, i.e., WTE incineration, composting, gasification, biogas from anaerobic digestion, sanitary landfill, and open dumping, irrespective to the weighting schemes.

4. Conclusion

Applying MCDA tools to select a project, especially when the impacts of such project onto stakeholders are enormous as in selecting MSW treatment technology and management, is a prudent policy that must be implemented by any government. Among three MCDA tools applied, AHP, PROMETHEE II, and TOPSIS resulted in the same order of preference independent to weighting schemes used in this analysis. In fact, not only that PROMETHEE II applying type III relative importance pattern and TOPSIS resulted in the same order of preference, but also the same normalized preference value for each alternative. Meanwhile, ELECTRE II method is more sensitive toward weighting schemes applied. Therefore, this method is highly dependent upon subjectivity of decision makers. For sensitive project like this one where decision is influenced by many concerning parties, ELECTRE II method will not likely be suitable for the task.

For equal weighting on all criteria and sub-criteria, composting MSW as treatment technology and distributed management has the highest preference among the other MSW treatment technology and management alternatives. And also, open dumping landfill is in the bottom of preference rank. The same results are also conveyed by AHP, PROMETHEE II, and TOPSIS methods with various weight assignment schemes.

AHP, PROMETHEE II with type III relative importance pattern, and TOPSIS give comparable results; however, TOPSIS is the simplest one to be used. As additional benefit, the acceptability of the result to stakeholders will be more convincing for explaining how TOPSIS method works to layman will not be too difficult.

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