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AHP TOPSIS Analysis in Selecting Waste Processing Technology Based on Energy Justice

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ABSTRACT — The amount of waste in Bantul Regency increased by 4.96% from 2020 to 2021, indicating that the capacity of final disposal sites (FDS) in Piyungan District, Bantul Regency, was decreasing. The peak occurred from 23 July 2023 to 5 September 2023, during which the Piyungan FDS could not provide waste disposal services. The high poverty rate in Bantul Regency forces the government to process waste into energy as a sustainable waste management effort. However, numerous criteria make it difficult to determine which technology is most suitable for this purpose. Energy justice criteria need to be considered when choosing technology and efforts to improve the welfare of Bantul Regency's residents. This research aimed to present an assessment of each alternative technology for processing waste into energy and decide one suitable alternative for sustainable waste management in Bantul Regency using a combination of AHP and TOPSIS methods based on energy justice. AHP was used to assess the level of importance of each criterion, while TOPSIS was used to determine the optimal alternative based on the criteria by considering costs and benefits. The findings showed that the preference value for three alternatives was 0.579, 0.414, and 0.341 for incineration, pyrolysis, and gasification, respectively. According to these preference value, incineration was identified as the foremost viable alternative technology for implementation in Bantul Regency. Gasification and pyrolysis ranked as the subsequent and third alternatives, respectively.

KEYWORDS — Sustainable Waste Management, Waste to Energy, Energy Justice, AHP, TOPSIS.

I. INTRODUCTION

City waste, which results from the life development in urban areas, is increasing and starting to cause many problems. In 2021, the Bantul Regency Environmental Service said that the amount of waste reached 123,272.79 tons per year, an increase of 4.96% from 2020. The rapid growth of waste due to urbanization raises economic, environmental, and social concerns. Waste in Bantul Regency was only disposed of directly at the landfill in Piyungan District, which had an area of 12 hectares [1]. However, in August 2023, the capacity of the Piyungan landfill could no longer accommodate additional waste, resulting in the closure of the waste disposal service. In implementing sustainable waste management and efforts to reduce poverty, the regional government intends to convert waste into energy. However, the regional government experiences difficulties in determining appropriate technologies due to the numerous criteria and the interests of stakeholders in realizing energy justice for the Bantul Regency's residents.

The notion of energy justice has recently emerged as a significant topic widely employed across diverse research domains. Energy justice is carried out by integrating moral and social principles when making decisions that are not biased towards one party in energy production, distribution, and consumption. It aims to ensure a fair sharing of the costs and benefits of the energy system [2]. Arguments regarding the energy justice framework center on the eight criteria: intragenerational equity, good governance, intergenerational equity, availability, responsibility, sustainability, affordability, and legal process [3].

According to the book issued by the Ministry of Energy and Mineral Resources of the Republic of Indonesia (MEMRRI), there are three waste-to-energy technologies: incineration (INC), gasification (GAS), and pyrolysis (PYR) [4]. Considering the number of technologies and technology selection criteria, selecting waste-to-energy processing technology requires appropriate decision-making. Policymakers need to pay attention to selection factors, criteria weighting methods, and decision-making methods that exist in previous research.

Factors for choosing waste-to-energy technology have been widely used in previous research. Literature studies in the SCOPUS bibliography from 2019 to 2023 obtained 15 papers, namely [2], [5]–[18]. These papers were then analyzed to determine the selection criteria, which could be divided into seven categories: environmental, social, economic, technical, health, employment, and energy justice. The energy justice factor aligns with policymakers' interests in efforts to reduce poverty. Prior research was conducted on using the energy justice factor, but only five criteria were used in the energy justice factor [2]. The energy justice criteria conceptually consist of eight criteria [3], so to realize regional policy priorities in meeting the energy needs of the community to reduce poverty rates in Bantul Regency, it is necessary to apply the energy justice criteria in their entirety.

The weighting methods used in previous research were the analytic hierarchy process (AHP) method [7]–[9], integrated determination of objective CRIteria weights (IDOCRIW)-weighted [5]; cross-entropy measure-based weight (CEMBW) [10]; interval-valued fuzzy decision making trial and evaluation laboratory (DEMATEL) [11]; multi-criteria hesitant fuzzy linguistic term set (MC-HFLTS) [12]; entropy weight [13], [14]; cumulative prospect theory (CPT) [15]; the best–worst method (BWM) [6], [16]; fuzzy DEMATEL[2]; and two studies without weighting methods [17], [18]. However, each method has disadvantages, such as the calculation process taking a long time and being complex, as well as dependence on the availability of extensive data in the CEMBW method

[10]. Limitations in comparison between criteria and priority scales are determined by the subjectivity of the decision-maker, which is a deficiency in the BWM method [6], [16]. IDOCRIW-weighted method [5] also has the limitation of being inconsistent in pair comparisons. he AHP method is most widely used because it has the advantages of a clear hierarchical structure, consistent pairwise comparisons, and sensitivity analysis. The AHP weighting method is deemed the most suitable for determining waste processing technology that produces energy in consideration of the priorities of regional policy stakeholders' interests.

In previous research, the risk-multi objective optimization by ratio analysis and linear programming (R-MULTIMOOSRAL) method, Mult-attributive ideal-real comparative analysis (MAIRCA)- multi-attributive border approximation area comparison (MABAC), stratified BWM (SBWM), technique for order of preference by similarity to ideal solution (TOPSIS), fuzzy simple additive weighting (SAW), sustainability assessment of technologies (SAT), preference ranking organization method for enrichment evaluations (PROMETHEE)-interval 2-tuple linguistic integrated cloud (ITLIC), interval-valued fuzzy TOPSIS, and generalized orthopair fuzzy information- evaluation based on distance from average solution (GOFI-EDAS) were used in decision-making, with the most widely used method being the TOPSIS method. Despite its disadvantages in subjectivity when determining alternative values, the TOPSIS method has advantages in categorizing criteria as costs or benefits in decision-making and intuitive concepts, namely the concept of comparison with the ideal solution for evaluating alternatives, determining the best alternative by measuring the distance between technological alternatives and the ideal solution and providing a clear and structured ranking of the alternatives evaluated. It facilitates policymakers to understand and compare alternatives in accordance with the provided rankings.

Based on previous explanations, the energy justice factor that has not been used in determining the waste processing technology that produces energy is this research gap. In addition, previous research has not determined the level of importance of each criterion in the energy justice factor. Among the eight criteria, the criteria categories according to cost and benefit have not yet determined.

This research aimed to fully inform the concept of energy justice [3] in selecting technology for processing waste into energy to reduce the level of poverty in Bantul Regency by determining the level of importance of criteria using the AHP method, subsequently employing the TOPSIS approach to ascertain the optimal alternative based on criteria considering costs and benefits. The contribution of this research is to provide information about the level of importance of each energy justice criterion and determine the best alternative based on each criterion's cost and benefit categories. In this paper, the author will describe the results in four chapters: Introduction, Methodology, Results and Discussion, and Conclusions.

II. METHODOLOGY

A. METHOD OF COLLECTING DATA

At the data collection stage, a preliminary study was conducted to determine initial information about the problems and phenomena that occurred through interviews. Data collection was then carried out by distributing questionnaires given to experts at regional apparatus organizations of the Bantul Regency government, namely at the Environmental Service of Bantul Regency and the Regional Technical Implementation Unit for Cleanliness, Waste, and Parks of Bantul Regency. The determination of these experts was based on the suitability of their expertise and duties related to waste management. At the time the research was conducted, there were three experts responsible for waste management in Bantul Regency was three people.

The questions in the questionnaire referred to the criteria contained in the concept of energy justice [3]. The questionnaire was divided into three according to the required data: criteria comparison data, alternative comparison data, and alternative assessment data. The evaluation of questionnaires for criteria comparison data and alternative comparison data was based on the AHP method assessment [19]. Meanwhile, the questionnaire for alternative assessment data used a Likert scale from 1–5 [20] and category assessment for each criterion based on costs and benefits. The final data collection used documentary methods from available records and documentary sources.

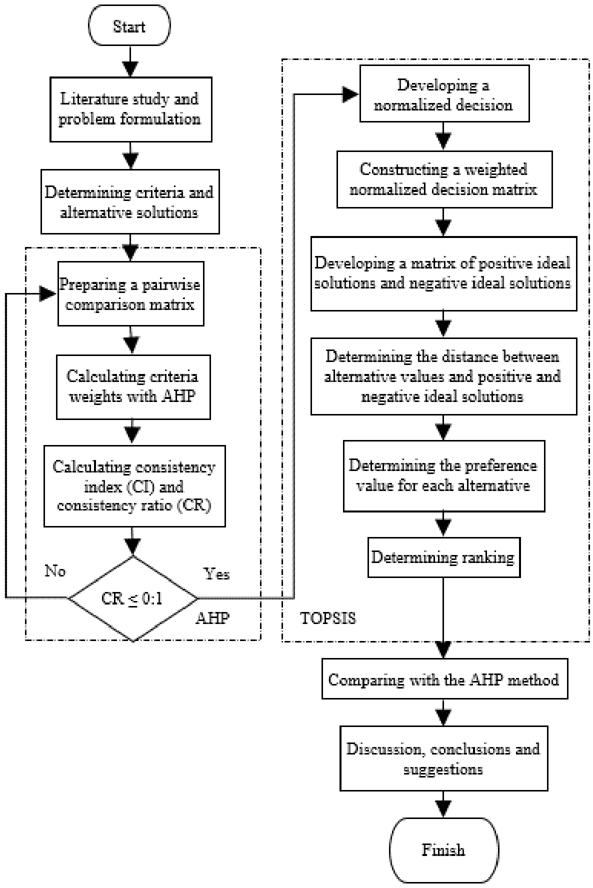

Figure 1. Research flow.

B. RESEARCH FLOW

This research followed a structured research path to analyze energy justice factors in determining waste processing technology that produced energy using a combination of the AHP and TOPSIS methods. Figure 1 presents the research flow carried out.

1) LITERATURE STUDY AND PROBLEM FORMULATION

A literature study was carried out to collect data regarding waste processing technology that produced energy, sustainable waste management, and decision-making models with numerous criteria. The results of this search became the background for the research and was used as a basis for formulating the problem.

2) DETERMINATION OF CRITERIA AND ALTERNATIVE SOLUTION

The criteria in this research were determined based on energy justice factors [3]. The alternative solutions were determined to consist of three alternatives according to the guidebook for processing waste into energy published by the MEMRRI [4].

3) CONSTRUCTION OF A PAIRED COMPARISON MATRIX

At this stage, respondents assessed the criteria by comparing the level of importance of the criteria based on a scale from the AHP method, with 1 indicating both criteria had equal superiority, scale 3 indicating one criterion had a slight advantage over other criteria, scale 5 indicating one criterion had a higher level of superiority compared to other criteria, scale 7 indicating one criterion had very high importance compared to other criteria, Scale 9 indicating one criterion was superior or absolute compared to other criteria. Meanwhile, scale 2, 4, 6, 8 showed a value between two consideration values that were almost the same; scale 1/(1-9) showed the opposite value, where if criterion *i* had a value above criterion *j* when compared, then criterion *j* had a value of 1 divided by the value of criterion *i*.

Geometric mean calculations, such as (1), were used to find the median value since the research had an extensive number of respondents [21]. The results of these calculations were then used to construct a pairwise comparison matrix.

$$GM = \sqrt[n]{x_{1,}x_2, x_{3,} \dots x_n} \quad (1)$$

where *GM* is the geometric mean, *n* is the number of respondents, x_1 is the 1st respondent, and x_n is the *n*th respondent.

4) CALCULATION OF CRITERIA WEIGHT

The calculation of weights involved amalgamating values from individual columns within the pairwise comparison matrix. Next, each value in a column was divided by the overall value of the corresponding column, so that a normalized matrix was obtained. Next, values were added to each row, then the sum results were divided by the number of criteria to obtain the median value, or weight.

5) CALCULATION OF CONSISTENCY OF INDEXES AND RATIO

The next step was to calculate the consistency index (CI) using (2) based on the eigenvalue obtained in the previous calculation. Subsequently, it was necessary to determine the consistency ratio (CR) using (3) to ensure that the weight used was consistent; the conditions for consistent pairwise comparisons are CR ≤ 0.1. The random index (RI) value can be seen in Table I [19].

$$CI = \frac{(\lambda max - n)}{(n-1)} \quad (2)$$

where CI indicates consistency index, λmax indicates eigen value, and n indicates the number of elements being compared.

$$CR = \frac{CI}{RI} \quad (3)$$

where CR is the consistency ratio and RI is the random index.

TABLE I
RANDOM INDEX VALUES

Number of *n*	1	2	3	4	5	6	7	8
RI Value	0.0	0.0	0.58	0.90	1.12	1.24	1.32	1.41

6) DEVELOPMENT OF NORMALIZED DECISION MATRIX

This stage is a step in the TOPSIS method [22]. It was done by creating a normalized decision matrix using (4).

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (4)$$

where r_{ij} is the result of normalizing the decision matrix r with i = 1,2,…...*m*; and *j* = 1,2,…..*n*. Meanwhile, x_{ij} denotes value of an alternative (*i*) against criterion (*j*), with *i* = 1,2,….m; and *j* = 1,2,…..*n*.

7) CONSTRUCTION OF WEIGHTED NORMALIZED DECISION MATRIX

The weight used was that of the criteria calculated using the AHP method, so the calculation was carried out using (5).

$$y_{ij} = w_j r_{ij} \quad (5)$$

where y_{ij} denotes elements of the weighted normalized decision matrix, w_j denotes weight of the *j*th criterion, and r_{ij} denotes elements of the normalized decision matrix.

8) CREATION OF A MATRIX OF POSITIVE AND NEGATIVE IDEAL SOLUTIONS

The positive ideal solution matrix is a matrix containing the maximum value for each criterion using (6). On the other hand, the negative ideal solution matrix is the matrix containing the minimum value for each criterion using (7).

$$A^+ = (y_1^+, y_2^+, \dots, y_n^+) \quad (6)$$

where A^+ is the positive ideal solution and y_i^+ is the highest value of the weighted normalized decision matrix.

$$A^- = (y_1^-, y_2^-, \dots, y_n^-) \quad (7)$$

where A^- is the negative ideal solution and y_i^- is the lowest value of the weighted normalized decision matrix.

9) DETERMINATION OF SEPARATION OF ALTERNATIVE VALUES AND POSITIVE AND NEGATIVE IDEAL SOLUTIONS

This step was conducted to compare each alternative with the two ideal solutions to determine the extent to which each alternative approached the positive ideal solution (using (8)) and the extent to which each alternative moved away from the negative ideal solution (using (9)).

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (y_{ij} - y_i^+)^2 \, ; i = 1,2, \dots, m} \quad (8)$$

where S_i^+ denotes the distance between alternative *i* and the positive ideal solution at criterion *j*.

$$S_i^- = \sqrt{\sum_{j=1}^{n} (y_{ij} - y_i^-)^2} \, ; i = 1,2, \dots, m \quad (9)$$

where S_i^- denotes the distance between alternative *i* and the negative ideal solution at criterion *j*.

10) SELECTION OF A PREFERENCE FOR EACH ALTERNATIVE

These preference values were used to rank alternatives according to the degree to which they matched the positive ideal solution. These values were calculated using (10).

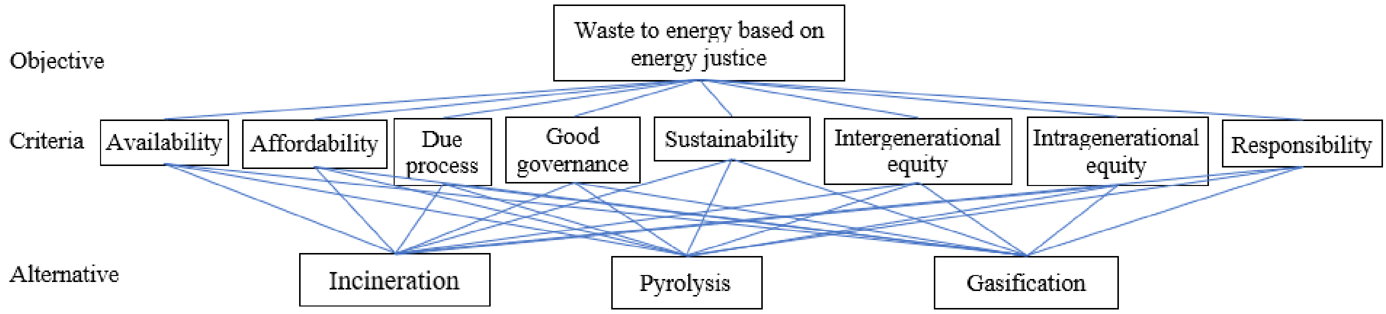

Figure 2. Hierarchy chart for selection of waste to energy processing technology.

$$C_i = \frac{S_i^-}{S_i^- + S_i^+} \quad (10)$$

where C_i is the preference value.

11) DETERMINATION OF THE RANKING

The alternative with the highest index value was recognized as the top priority solution, the greater the index value, the better the performance of the alternative.

C. A COMPARISON OF CALCULATION RESULTS FROM A COMBINATION OF AHP AND THE TOPSIS METHOD WITH THE AHP METHOD

This research compared the results of the AHP and TOPSIS method calculations with the AHP method calculations. By comparing and analyzing the use of different methods, researchers could gain a deeper understanding of reliability and improve calculations in determining results according to the context of this research.

III. RESULTS AND DISCUSSION

A. DETERMINATION OF CRITERIA AND ALTERNATIVES

The energy justice criteria used were availability (K1), affordability (K2), legal process (K3), good governance (K4), sustainability (K5), intergenerational equity (K6), intragenerational equity (K7), and responsibility (K8) [3]. At the same time, the alternative included incineration (P1), pyrolysis (P2), and gasification (P3) [4]. Figure 2 depicts the relationship between objectives, criteria, and alternatives in the form of a chart based on a functional hierarchy.

B. DATA COLLECTION

The data used for the analysis and calculation process were acquired by distributing questionnaires to experts working at regional agencies in Bantul Regency who specialize in environmental matters. The experts in question were: 1) the Head of the Waste Management and Environmental Capacity Building Division, 2) the Head of the Regional Technical Implementation Unit for Cleanliness, Waste, and Parks, and 3) the Subcoordinator for Waste Management. The data obtained were divided into three categories: criteria comparison data, alternative comparison data, and alternative assessment data.

In the alternative assessment data, respondent A gave categories for the criteria K1 as benefit, K2 as cost, K3 as cost, K4 as cost, K5 as benefit, K6 as benefit, K7 as benefit, K8 as cost. Respondent B gave categories for the criteria K1 as benefit, K2 as benefit, K3 as cost, K4 as cost, K5 as benefit, K6 as benefit, K7 as benefit, K8 as cost. Respondent C gave categories for the criteria K1 as benefit, K2 as cost, K3 as benefit, K4 as benefit, K5 as benefit, K6 as benefit, K7 as benefit, K8 as cost.

TABLE II
PAIRED COMPARISON VALUE AND CRITERIA WEIGHTING

Criteria	K1	K2	K3	K4	K5	K6	K7	K8	Weight
K1	1.00	1.74	0.33	0.58	0.58	2.08	2.08	0.87	0.12
K2	0.58	1.00	0.87	0.69	1.00	2.08	2.08	0.48	0.12
K3	3.00	1.14	1.00	1.44	2.47	1.19	1.19	1.00	0.18
K4	1.71	1.44	0.69	1.00	1.00	2.08	2.62	1.00	0.15
K5	1.71	1.00	0.41	1.00	1.00	1.44	1.82	2.29	0.14
K6	0.48	0.48	0.84	0.48	0.69	1.00	0.91	1.00	0.08
K7	0.48	0.48	0.84	0.38	0.55	1.10	1.00	1.44	0.09
K8	1.14	2.08	1.00	1.00	0.44	1.00	0.69	1.00	0.12

TABLE III
CI AND CR VALUES

Energy Justice Factor	λmax	CI	CR
	8.6419171	0.0917024	0.0650372

C. DATA ANALYSIS USING THE AHP METHOD

The data obtained from the questionnaires filled out by experts were analyzed according to the research flow.

1) PAIRED COMPARISON VALUE AND CRITERIA WEIGHTING

Pairwise comparisons for criteria were calculated based on the geometric mean of three respondents' values taken from the criteria comparison data. Table II presents the results of calculating the pairwise comparison matrix with the weights of each criterion. The legal process criterion had the highest weight with a value of 0.18, while the intergenerational equality criterion had the lowest weight with a value of 0.08. The criterion for good governance was in second place with a value of 0.15; the criterion for sustainability was in third place with a value of 0.14; the criteria for availability, affordability, and responsibility were in fourth place with the same value weight, namely 0.12; and the criterion for fairness in intrageneration ranked fifth with a value of 0.09.

The factor influencing the weight of the legal process criterion, which had the greatest weight, was the superiority of this criterion in four comparisons with other criteria, namely superior to the criteria of good governance, sustainability, intergenerational equality, and intragenerational justice. Meanwhile, the factor influencing the weight of the criteria for intergenerational equity to have the lowest weight was that it was surpassed by five other criteria: availability, affordability, legal process, good governance, and sustainability. Furthermore, the weight of this criterion value was used to calculate alternative determination using the TOPSIS method. Subsequently, this weight value was calculated for the consistency value by calculating CI and CR.

TABLE IV
NORMALIZED DECISION MATRIX

Criteria	Respondent								
	A			*B*			*C*		
	P1	*P2*	*P3*	*P1*	*P2*	*P3*	*P1*	*P2*	*P3*
K1	0.685	0.514	0.514	0.639	0.426	0.639	0.727	0.485	0.485
K2	0.577	0.577	0.577	0.742	0.371	0.557	0.577	0.577	0.577
K3	0.624	0.468	0.624	0.468	0.624	0.624	0.685	0.514	0.514
K4	0.624	0.624	0.468	0.742	0.371	0.557	0.577	0.577	0.577
K5	0.685	0.514	0.514	0.624	0.624	0.468	0.685	0.514	0.514
K6	0.685	0.514	0.514	0.577	0.577	0.577	0.742	0.557	0.371
K7	0.577	0.577	0.577	0.624	0.624	0.468	0.577	0.577	0.577
K8	0.577	0.577	0.577	0.514	0.514	0.685	0.685	0.514	0.514

TABLE V
WEIGHTED NORMALIZED DECISION MATRIX

Criteria	Respondent								
	A			*B*			*C*		
	P1	*P2*	*P3*	*P1*	*P2*	*P3*	*P1*	*P2*	*P3*
K1	0.080	0.060	0.060	0.075	0.050	0.075	0.085	0.057	0.057
K2	0.067	0.067	0.067	0.087	0.043	0.065	0.067	0.067	0.067
K3	0.111	0.083	0.111	0.083	0.111	0.111	0.122	0.091	0.091
K4	0.094	0.094	0.071	0.112	0.056	0.084	0.087	0.087	0.087
K5	0.098	0.073	0.073	0.089	0.089	0.067	0.098	0.073	0.073
K6	0.057	0.043	0.043	0.048	0.048	0.048	0.062	0.046	0.031
K7	0.050	0.050	0.050	0.054	0.054	0.041	0.050	0.050	0.050
K8	0.069	0.069	0.069	0.061	0.061	0.082	0.082	0.061	0.061

TABLE VI
POSITIVE IDEAL SOLUTIONS AND NEGATIVE IDEAL SOLUTIONS

Criteria	Respondent					
	A		*B*		*C*	
	y_j^+	y_j^-	y_j^+	y_j^-	y_j^+	y_j^-
K1	0.080	0.060	0.075	0.050	0.085	0.057
K2	0.067	0.067	0.087	0.043	0.067	0.067
K3	0.083	0.111	0.083	0.111	0.122	0.091
K4	0.071	0.094	0.056	0.112	0.087	0.087
K5	0.098	0.073	0.089	0.067	0.098	0.073
K6	0.057	0.043	0.048	0.048	0.062	0.031
K7	0.050	0.050	0.054	0.041	0.050	0.050
K8	0.069	0.069	0.061	0.082	0.061	0.082

2) CI AND CR CALCULATION RESULTS

Table III shows the calculation results in determining the CI and CR values. Based on the provisions of CR $\leq$ 0.1, CR 0.0650372 in Table III meets the consistency requirements for the pairwise comparison matrix of criteria, and the criteria weights can be used for calculations.

D. DATA ANALYSIS USING THE TOPSIS METHOD

The next step was to apply the TOPSIS method to determine the best alternative. The alternative comparison data for three respondents could not be used together using the median value as the data to be analyzed since each criterion had cost and benefit categories. The categorization of criteria using costs and benefits affected the calculation of positive and negative ideal solutions. Hence, each respondent's alternative assessment data were calculated individually to acquire a value indicating a preference for each available alternative.

1) NORMALIZED DECISION MATRIX

Table IV shows the normalized decision matrix from the results of analysis and calculation of alternative assessment data. In this research, the computation outcomes were derived from dividing the value of each alternative for every criterion by the overall alternative value that were corresponding to each criterion.

2) WEIGHTED NORMALIZED DECISION MATRIX

Table V shows the results of multiplying the weight of each criterion with the normalized decision value in Table IV. It was done to determine the weighted normalized decision matrix. The legal process criteria weight was the highest with a value of 0.18; it caused the K3 value to have the highest value with a range of 0.083 to 0.122. However, this value did not determine the final preference score for each alternative because cost and benefit categories for each criterion were considered when calculating positive and negative ideal solutions.

3) POSITIVE AND NEGATIVE IDEAL SOLUTIONS

At this stage, each criterion’s cost and benefit categories determined the maximum and minimum values of the weighted normalized decision matrix, which were then used to determine positive and negative ideal solutions. Table VI presents the

TABLE VII
DISTANCE OF ALTERNATIVES TO POSITIVE IDEAL SOLUTIONS AND NEGATIVE IDEAL SOLUTIONS

Alternative	Respondent					
	A		*B*		*C*	
	S_i^+	S_i^-	S_i^+	S_i^-	S_i^+	S_i^-
P1	0.036	0.034	0.056	0.066	0.020	0.057
P2	0.042	0.027	0.057	0.065	0.050	0.025
P3	0.044	0.023	0.056	0.043	0.057	0.020

TABLE VIII
PREFERENCE VALUES BASED ON GEOMETRIC MEAN

Alternative	Respondents' Preference Values			Geometric Mean	Ranking
	A	*B*	*C*		
P1	0.487	0.540	0.736	0.579	1
P2	0.398	0.532	0.335	0.414	2
P3	0.347	0.436	0.263	0.341	3

TABLE IX
ALTERNATIVE WEIGHT FOR EACH CRITERIA AND CR VALUE, PREFERENCE AND RANKING

	Criteria								Preference	Ranking
	K1	*K2*	*K3*	*K4*	*K5*	*K6*	*K7*	*K8*		
P1	0.51	0.35	0.31	0.50	0.48	0.33	0.38	0.30	0.39	1
P2	0.20	0.34	0.30	0.26	0.19	0.37	0.25	0.30	0.27	3
P3	0.29	0.31	0.41	0.23	0.30	0.31	0.33	0.43	0.32	2
CR	0.06	0.09	0.07	0.04	-0.07	0.03	-	0.09		

value of each ideal solution for each criterion resulting from data analysis from respondents.

Table VI shows the alternative assessment data. The benefit category determined y_j^+ or positive ideal solution with the highest score of the y_{ij} score; y_j^- or negative ideal solution was the lowest score of the y_{ij} score. Meanwhile, the cost category determined y_j^+ the lowest score of the y_{ij} score and y_j^- was the highest score of the y_{ij} score.

4) THE SEPARATION OF ALTERNATIVES TO A POSITIVE AND NEGATIVE IDEAL SOLUTION

Table VII presents the results of alternative distance calculations with the ideal solution. The results were obtained from the square root of the sum of each weighted normalized value minus the squared positive and negative ideal solutions. For respondent 1, P1 had the closest distance from S_i^+ with a value of 0.036 and had the furthest distance from S_i^- with a value of 0.034. For respondent 2, P1 and P2 had the same distance from S_i^+ with a value of 0.056, and P1 had the furthest distance from S_i^- with a value of 0.066. For respondent 3, P1 had the closest distance from S_i^+ with a value of 0.020 and the furthest distance from S_i^- with a value of 0.057. The difference in distance above was attributed to the different respondents' perspectives on categorizing criteria, which impacted the distance between alternatives and the ideal solution.

5) PREFERENCE AND RANKING VALUES

Table VIII displays the preference values from the analysis results. The median value of three preference values was calculated using the geometric mean; the values were subsequently sorted in order of rank, from highest to lowest. P1 was in first place with a preference value of 0.579, followed by P2 with a value of 0.414, and P3 with a value of 0.341.

The TOPSIS method has advantages such as the ability to categorize costs and benefits for each criterion; this categorization influences the determination of positive and negative ideal alternatives. However, based on the results of interviews when collecting data using questionnaires, respondents experienced problems giving a value to one alternative, which was slightly superior to other alternatives due to the scale only having a value of 1–5. Respondents gave the same value to alternatives that had different values. Based on information from these respondents, a trial calculation with the same values for three criteria for all alternatives was carried out. Based on the test results, limitations of the TOPSIS method were identified. Specifically, the TOPSIS method gave a value of 0 for the distance of each alternative to the ideal solution. Consequently, the calculation of the preference value was 0, indicating that the TOPSIS method could not determine the best alternative from existing alternatives.

E. A COMPARISON OF CALCULATION RESULTS FROM A COMBINATION OF THE AHP AND THE TOPSIS METHOD WITH THE AHP METHOD

A comparison of calculation results is needed to provide an in-depth explanation of the method chosen in the research. Table IX shows the results of processing alternative comparison data using the AHP method by calculating the weight of each alternative for each criterion. The alternative selection was carried out by multiplying the weight of each alternative for each criterion with the weight of each criterion according to Table II and adding them up to determine the preference value of each alternative. P1 obtained the highest preference with a score of 0.39, followed by P3 with a score of 0.32. Meanwhile, P2 ranked third with a preference score of 0.27 (Table IX).

Calculations using a combination of the AHP and TOPSIS methods revealed that incineration, pyrolysis, and gasification were the best alternative choices. On the other hand, according to the results of calculations using the AHP method, the best alternative choices were incineration, gasification, and pyrolysis. Both methods place incineration as the best technological alternative, but there are differences in the second and third positions.

An advantage of using TOPSIS for alternative selection is that it classifies the categories of each criterion according to the criteria's nature, such as the cost and benefit categories. It results in differences in alternative choices in second and third place when compared with the results of calculations using the AHP method alone. The limitation of the AHP method is that it does not pay attention to the cost and benefit categories for assessing the criteria, so criteria with cost categories that have a high value in this method will give errors. Hence, the results of alternative selection using the AHP method are deemed unsuitable. Utilizing TOPSIS in this research could complement the shortcomings of the AHP in selecting alternatives.

IV. CONCLUSION

This research explained the criteria for selecting waste-to-energy processing technology according to energy justice factors. The use of a combination of the AHP and TOPSIS methods in this research has shown that the results of weighting criteria using the AHP method had a strong assessment with the consistency of the ratio as the validity of the calculation results. Using the TOPSIS method is the appropriate method to complement the shortcomings of the AHP method in providing cost and benefit categories for each criterion. TOPSIS also provides recommendations for the best alternative, namely by recommending the alternative with the closest distance to the positive ideal alternative. The trial calculations utilizing the same alternative scores on three criteria revealed the limitations of the TOPSIS method. These limitations were the respondents' constraints in giving scores to alternatives that had few advantages over other alternatives. The assessment used a rating scale of 1–5, so future research is expected to employ a rating scale with decimal numbers to facilitate the respondents in assessing two alternatives that appear to be the same but have different advantages.

CONFLICTS OF INTEREST

The author declares that there is no conflict of interest.

AUTHORS' CONTRIBUTIONS

Topic, Rudy Hartanto; conceptualization, Miza Zuda Nurlael; methodology, Miza Zuda Nurlael and Irfan Budi Santoso; data analysis, Miza Zuda Nurlael, Rudy Hartanto, and Wing Wahyu Winarno; writing, Miza Zuda Nurlael.

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