Comparative Study of Waste to Energy (WtE) Technology in Municipal Solid Waste Management (MSWM) in Yogyakarta

Wildan Elsha [1*] and Rachmawan Budiarto [2]

[1] Department of System Engineering, Faculty of Engineering, Gadjah Mada University, Jalan Grafika No. 2, Yogyakarta, Indonesia, 55281
PT Enthalphy Environergy Consulting, Yogyakarta
[2] Department of Nuclear Engineering and Engineering Physics, Faculty of Engineering, Gadjah Mada University, Jalan Grafika No. 2, Yogyakarta, Indonesia, 55281

ABSTRACT

With a population of 268 million, Indonesia is faced with an increase in energy demand by 3.9% every year. Currently, around 62.0% of its electrical energy production comes from coal plants. Meanwhile, Indonesia has renewable energy potential equivalent to 442 GW which has not been utilized optimally, where municipal solid waste has a portion of 2 GW. This study aims to determine the most optimal waste to energy (WtE) technology option to process waste into energy at the Piyungan Landfill in Yogyakarta. The study was conducted using the analytical hierarchy process (AHP) method to analyse 4 criteria, 11 sub-criteria, and 5 alternatives where technical, environmental, economic, and social aspects are the basis for consideration. The WtE technologies analysed are incineration, gasification, pyrolysis, anaerobic digester, and landfill gas recovery technologies. The results showed that technical factors were the most influential factor in the selection of WtE technology with a weight of 0.455, followed by economic factors (0.442), and environmental factors (0.103). The most optimal WtE technology to be applied to the Piyungan landfill is gasification technology with a preference value of 0.699, followed by Pyrolysis (0.623), Incineration (0.519), Landfill Gas Recovery (0.326), and the last is Anaerobic Digester technology (0.318).

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***Correspondence**

Wildan Elsha
wildanelsha@gmail.com

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1. Introduction

Indonesia as a country with an area of about 1.9 million km^2 and a population of 268 million people (Badan Pusat Statistik, 2020), is faced with a tendency to increase energy demand and consumption every year. The rate of increase in energy demand and consumption is expected to increase to reach 3.9% per year. Meanwhile, Indonesia's energy production in 2020 is 443.1 million ton The ton of oil equivalent (TOE), most of which (94.9%) comes from fossil energy which includes coal, gas and oil. Meanwhile, renewable energy production is only about 5.1% of national energy production (Dewan Energi Nasional, 2021). The use of fossil energy in Indonesia is exacerbated by data in the electricity sector which produces electricity in 2020 reaching 292.0 TWh, but around 62.0% of electricity production comes from coal powerplant (Dewan Energi Nasional, 2020) and only 18.2% comes from new renewable energy sources.

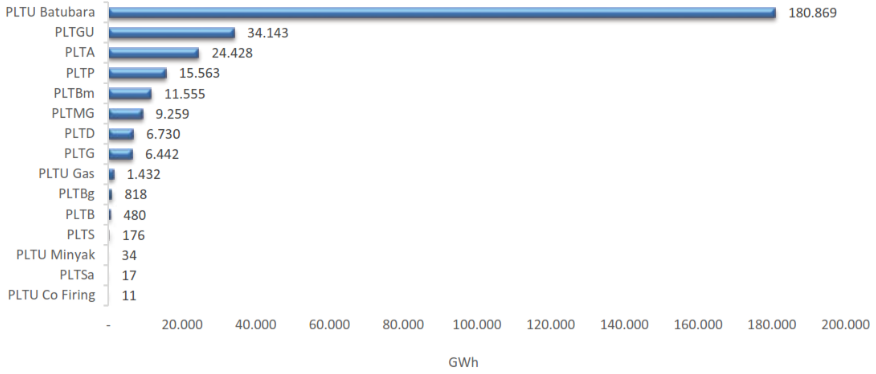

Figure 1. Electricity Production by Type of Generator (Dewan Energi Nasional, 2021)

This condition is inversely proportional to Indonesia's efforts to meet sustainable energy access and supply as regulated in Presidential Regulation (PP) Number 79 of 2014 concerning Kebijakan Energi Nasional (KEN). Gradually, KEN targets the energy mix with the NRE portion to be 23% in 2025 and 31% in 2050 (Dewan Energi Nasional, 2020). On the other hand, Indonesia has a large potential for renewable energy. The total renewable energy potential is equivalent to 442 GW (Dewan Energi Nasional, 2019). Bioenergy reaches 32.6 GW. Meanwhile, municipal solid waste (MSW) has a potential of 2 GW of the total bioenergy potential in Indonesia.

Apart from being a potential source of renewable energy, MSW also has the potential to cause disturbance to the environment. The latest Greenhouse Gases (GHG) inventory shows that Indonesia's waste sector was responsible for 25% (743 kgCO2e/capita) of the country's GHG emissions in 2005 (Carbon Trust, 2014). Currently, only 60.63% of the national waste can be managed (59.08% transportation and 1.55% reduction), so there is still a gap of around 39.37% towards 100% managed waste (Dewan Energi Nasional, 2020). Therefore, it is necessary to take appropriate management actions to take advantage of the potential and overcome the problems related to the MSW. Waste-to-energy (WtE) technology is one solution in waste management and utilization that offers a good opportunity in terms of reducing waste that goes to landfills by using waste as raw material to produce electrical energy.

This study aims to determine the most optimal waste-to-energy (WtE) technology option to be applied to the Piyuangan Landfill in the Special Region of Yogyakarta by analysing the priority order of criteria including technical factors, environmental factors, economic factors, and social factors using the analytical hierarchy process (AHP) method. AHP analysis was used to decide among five WTE alternatives, which treat the whole stream of municipal solid waste or some of its components. A four-level hierarchy model was developed and used by combining primary data from experts who participated in the pairwise comparison process based on a specially designed questionnaire and secondary data were gathered from journal articles, proceedings, ministries/government reports, news, and other references.

2. Literature Review

Researchers have conducted several studies on several studies that have been conducted before to starting research activities with the title Comparative Study of Waste to Energy (WtE) Technology in Municipal Solid Waste Management (MSWM) in Yogyakarta. This initial study was conducted to add insight and knowledge to researchers in developing and compiling the research to be carried out. The literature review that forms the basis of this research comes from various sources of study, both from within the country and from abroad. The themes and topics also vary, ranging from research related to energy planning, feasibility studies, potential studies, to analytical studies related to the use of waste to energy technology.

Table 1. Literature Review

No	Author	Title	Year	Research Object	Analysis Method
1	Carlos Robles Algarín, Aura Polo Llanos, Adalberto Ospino Castro	An Analytic Hierarchy Process Based Approach for Evaluating Renewable Energy Sources	2017	This paper uses the analytic hierarchy process (AHP) to prioritize a set of criteria, sub criteria and alternatives as a support for decision-making in the process of energy planning with renewable energies for rural areas in the Caribbean region of Colombia.	Using the AHP. Based on the participation of experts, 5 criteria, 20 sub criteria and 4 alternatives were defined
2	Anna Kurbatova and Hani Ahmed Abu-Qdais	Using Multi-Criteria Decision Analysis to Select Waste to Energy Technology for a Mega City: The Case of Moscow	2020	In this study, various Waste to Energy (WTE) options were evaluated using analytical hierarchy process (AHP) to select the most appropriate technology for the Moscow region. Assessed four WTE technologies, namely landfill biogas, anaerobic digestion, incineration, and refuse derived fuel (RDF).	Using AHP. model consists of 4 levels, which assessed four WTE technologies, using four criteria and nine sub criteria. Determined using Expert Choice Software
3	Afshin Khosh and, Hamidreza K amalan, Hamidreza R ezaei	Application of analytical hierarchy process (AHP) to assess options of energy recovery from municipal solid waste: a case study in Tehran, Iran	2018	In the current study, a model was established to assess different alternatives for energy recovery from the waste in Tehran. The selected criteria include water quality, soil quality, air quality, habitat depletion, occupational health and safety, aesthetic, noise, technical feasibility, and economic issues.	AHP method for assessment. To establish a database for an assessment in this case study, a questionnaire survey for lay person and institutional experts in central Tehran municipality was carried out
4	Carlos, Aura, and Adalberto	An Analytic Hierarchy Process Based Approach for Evaluating Renewable Energy Sources	2018	Conducted a study regarding the planning of renewable energy systems in the Colombian Caribbean region using multi-criteria decision analysis in the analysis process. Several factors such as factors from social, technological to economic are used as indicators for evaluating the planning of the renewable energy system.	Researchers used the Analytic Hierarchy Process (AHP) method to prioritize a set of criteria, sub-criteria, and alternatives in making decisions. The data in this study were obtained from the participation of experts (through a questionnaire) to prioritize all aspects by filling in/assessing 5 criteria, 20 sub-criteria and 4 predetermined alternatives
5	Wajeeha A Qazi, Mohammed FM Abushammal and Mohammed-Hasham Azam	Multi-criteria decision analysis of waste to-energy technologies for municipal solid waste management in Sultanate of Oman	2018	This study is an initiative to improve the waste managing system in Oman by proposing optimum waste-to-energy technology using an analytical hierarchy process. parameters were considered in an analytical hierarchy process model to rank the waste-to-energy technology alternatives	Analytical hierarchy process manually and through expect choice software as well

This study concluded that the most suitable waste to energy technology for Oman, based on the identified criteria, is anaerobic digestion followed by fermentation and incineration. Anaerobic digestion technology will help reduce the amount of waste, greenhouse gas emissions, as well as develop and maintain the amount of costs that must be incurred by landfills.

3. Methodology

The study was conducted using the analytical hierarchy process (AHP) method. The AHP is a decision-making tool used to solve problems with multiple criteria with qualitative and quantitative analysis based on the knowledge or experience of many experts and actual parameter, respectively (Saaty, 2008), and can help to select appropriate alternatives in decision-making process when the environment is complex and more factors need to be considered (Kim *et al.*, 2013). The data in this study were obtained through combining primary data from experts who participated in the pairwise comparison process based on a specially designed questionnaire and secondary data were gathered from journal articles, proceedings, ministries/government reports, news, and other references. Primary data in this study were obtained from experts who filled out research questionnaires that had been prepared previously. The number of respondents selected was 8 people with each respondent coming from expertise in the fields of energy, environment, and solid waste. Respondents in this study were chosen because they are experts who have experience in developing power plants from renewable energy sources and has a background such as Chair of the Indonesia Solid Waste Association (InSWA), System and Waste Management consultant, PLN Engineering Expert, Retired Centre for Electricity Research and Development, and others.

AHP analysis was used to decide among five WTE alternatives, which treat the whole stream of municipal solid waste or some of its components. A four-level hierarchy model was developed and used by combining primary data from experts who participated in the pairwise comparison process based on a specially designed questionnaire and secondary data were gathered from journal articles, proceedings, ministries/government reports, news, and other references (Saaty & Vargas, 2012). There is a structured process of successfully applying AHP in decision-making, which can be summarized in the following steps:

3.1 Defining the Hierarchical Structure of The Problem

Problems are decomposed into a hierarchical tree that shows the relationship between problems, criteria, and alternative solutions. The hierarchical tree is illustrated in Figure 2 (Saaty, 2008).

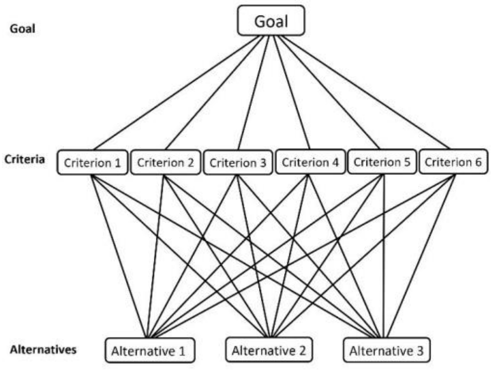

Figure 2. Hierarchical Tree (Saaty, 2008)

3.2 Establishing Criteria, Sub-criteria, and Alternatives

In determining the criteria and sub-criteria, the researcher uses several literatures as a reference source. there are six sources of reference related to the selection of criteria and sub-criteria in this study. The six references are used because they both conduct studies related to power generation from renewable energy, which includes discussing waste to energy. Table 2 is a summary of the criteria and sub-criteria options from the various reference sources.

Based on these data, then technical, economic, environmental, and social factors were selected to be used as criteria in this study. In more detail, the Technical Factors criteria have three sub-criteria, namely (1) Potential energy that can be generated by WtE Technology, (2) Energy required by WtE technology to operate, and (3) Percentage of waste that can be processed by WtE technology. In the Environmental Factors criteria there are three sub-criteria, namely (1) The impact of WtE technology on GHG Emissions, (2) B3 waste generated from the WtE technology process, and (3) Amount of reduced waste from landfills. In the Environmental Factors criteria, there are three sub-criteria, namely (1) the amount of CapEx costs for WtE technology, (2) the amount of OpEx costs for WtE technology, and (3) the amount of revenue for WtE technology. In terms of social factors, there are two sub-criteria, namely (1) acceptance of WtE technology and (2) potential for open employment opportunities.

Table 2. Reference Selection Criteria

	(Algarin *et al.*, 2017)	**(Kurbatova & Abu-Odais, 2020)**	**(Qazi *et al.*, 2018)**	**(Nixon *et al.*, 2013)**	**(Yap & Nixon, 2013)**	**(Yin *et al.*, 2016)**
Technical	x	x	x	x	x	x
Economic/Cost	x	x	x	x	x	x
Social	x	x	x			x
Enviromental	x	x	x	x		x
Health		x				
Risk	x			x	x	
Policy					x	

3.3 Weighting The Criteria at Each Level of The Hierarchy

Criteria and alternatives are carried out by pairwise comparisons. According to Saaty (2008), for various problems, the Saaty weighting standard with a scale ranging from 1 to 9 and vice versa is the best scale for expressing opinions. Information about the scale can be seen in Table 3 below.

Table 3. Pairwise Comparison (Saaty, 2008)

Numerical rating	**Definition**
1	*i* is equally important to *j*
3	*i* is slightly more important than *j*
5	*i* is strongly more important than *j*
7	*i* is very strongly more important than *j*
9	*i* is extremely more important than *j*
2,4,6,8	Intermediate
Reciprocals	If activity *i* has one of the above numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*

Based on the values of these criteria, a pairwise comparison matrix A can be compiled as follows

$$A = \left| \begin{array}{ccccccc} a_{1,1} & a_{1,2} & a_{1,3} & \dots & \dots & \dots & a_{i.j} \\ a_{2,1} & a_{2,2} & a_{2,3} & \dots & \dots & \dots & a_{2,j} \\ a_{3,1} & a_{3,2} & a_{3,3} & \dots & \dots & \dots & a_{3,j} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ a_{i,1} & a_{i,2} & a_{i,3} & \dots & \dots & \dots & a_{i,j} \end{array} \right|$$

a_{ij}, represents the elements of the matrix A th row i column j

3.4 Calculating The Weighting and Consistency Check of The Criteria and Sub-criteria

This stage calculates the weighting priority by finding the eigenvector value of the matrix A. After matrix A established and calculated, the next step is consistency checking. The assessment between one criterion and another cannot be completely consistent. This inconsistency can be caused by errors in entering judgments into the system, lack of information, lack of concentration, the real world is not always consistent, or the hierarchical structure model is not suitable. This step ensures that the pairwise comparison judgements are sufficiently consistent by computing the consistency ratio (*CR*):

3.4.1 First, calculate the principal eigenvalue (λ_{max}) for each matrix using equation (1):

$$A.\,W = \lambda.W \tag{1}$$

where A is the comparison matrix, λ_{max} is the principal eigenvalue and w is the normalised right eigenvector (priority vector)

3.4.2 Second, estimate the consistency index (*CI*) for each matrix with the dimension 'n' using equation (2):

$$CI = \frac{\lambda_{\text{maks}} - n}{n - 1} \tag{2}$$

3.4.3 Then finally calculate the CR using equation (3):

$$CI = \frac{CI}{CR} \tag{3}$$

The AHP method allows the occurrence of inconsistencies in the assessment of criteria, but the inconsistency of the assessment must not exceed the consistency ratio value of 10%. where *RI* is the random index. The value of *RI* is selected depending on the dimension of comparison matrix (*n*). Table 4 illustrates the different *RI* values for matrices having order n from 1 to 10 (Saaty, 2008).

Table 4. Random Index (RI) Value

Matrix size (n)	1	2	3	4	5	6	7	8	9	10
Random index	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

3.5 Calculating Alternative Weighting

At this stage, the alternative weighting for each criterion in the pairwise comparison matrix is carried out. The process for weighting these alternatives is the same as the process for calculating the weighting of the criteria.

3.6 Displays The Order of Alternatives Considered and Selects Alternatives

This stage calculates the eigenvector values obtained by weighting the alternatives for each criterion with the eigenvector values obtained by weighting the criteria. This is done to determine the choice of the available alternatives. The largest number of values is the best choice.

4. Results

This study aims to determine the most optimal waste-to-energy (WtE) technology option to be applied to the Piyungan Landfill in the Special Region of Yogyakarta. Primary data in this study were obtained from experts who filled out research questionnaires. Secondary data related to WtE technology used in this work were gathered from journal articles, proceedings, ministries/government reports, news, and other references.

Table 5. Waste Composition of Piyungan Landfill

	Waste Composition in Piyungan Landfill										
	Unit	**Food**	**Wood**	**Paper**	**Plastic**	**Metal**	**Fabrics**	**Leather**	**Glass**	**Others**	**Total**
Quantity [SIPSN]											
D.I	%	54,63%	8,48%	6,19%	9,34%	5,74%	0,81%	0,25%	7,64%	6,23%	**99,31%**
Yogyakarta	ton	110,94	17,21	12,56	18,97	11,67	1,65	0,50	15,52	12,65	**201,68**
Specification [a] [b] [c]											
Water Content	%wt	84,84	40,15	38,93	17,89	n.a	41,72	8,43	n.a	n.a	**63,07**
Total Solid	%wt	15,17	59,85	61,07	82,11	n.a	58,28	91,57	n.a	n.a	**29,69**
Volatile Matter	%wt	64,64	67,74	44,94	88,09	n.a	82,84	55,88	n.a	n.a	**61,54**
Ash	%db	28,49	8,12	35,80	7,84	n.a	4,83	42,90	n.a	n.a	**22,51**
Fixed Carbon	%db	6,89	24,15	19,26	4,07	n.a	12,34	1,23	n.a	n.a	**8,71**
Volatile Solid	%db	10,19	0,00	0,00	0,00	n.a	0,00	0,00	n.a	n.a	**6,48**
C-Biogenic	%db	40,42	44,53	32,53	0,00	n.a	0,00	32,26	n.a	n.a	**32,52**
C-Fossil	%db	0,00	0,00	0,81	61,44	n.a	23,51	2,29	n.a	n.a	**6,97**
C	%db	40,42	44,53	33,34	61,44	n.a	58,78	46,32	n.a	51,27 [c]	**43,58**
H	%wt	5,80	5,08	5,81	10,98	n.a	4,46	1,30	n.a	5,74 [c]	**6,26**
O	%wt	41,06	39,00	42,24	10,60	n.a	36,54	0,00 [b]	n.a	40,58 [c]	**37,43**
N	%db	3,45 [b]	0,90	1,98	0,00	n.a	1,84	3,81	n.a	1,95 [c]	**2,59**
S	%db	0,43	0,12	0,32	0,00	n.a	0,13	0,13	n.a	0,44 [c]	**0,34**
Heating Value	GJ/ton	2,26	2,24	12,40	30,70	n.a	130,34	25,45	n.a	n.a	**7,19**

Source: [a] Made Gunamantha, Sarto (2012); [b] Hanifrahmawan Sudibyo, et al (2017); [c] Zongao Zhen et al (2019)

4.1 Validating Criteria, Sub-criteria, and Alternatives

After a thorough literature review, a consultation process was carried out with 8 experts from diverse background. Based on the results of the interview, the criteria for social factors were abolished in this study. This is because the location where the WtE facility will be built is not included in this study, while social factors in WtE facilities are highly dynamic towards the location where the WtE facility will be constructed. In addition, the social factor criteria require a special questionnaire, while in this study the questionnaire was made in general. Thus, social factors were eliminated in this study, so that the results obtained that the criteria and sub-criteria that represent the topic of this research are as follows:

Table 6. Selected Criteria and Sub-Criteria

No	Criteria	Sub-criteria	Unit
1	Technical Factors (Tech)	Energy potential that can be generated (T1)	kWh/ton waste processed
		Energy required to operate (T2)	kWh/ton waste processed
		Percentage of waste that can be processed (T3)	Percent (%)
2	Economic Factors (Eco)	Amount of Capital Expenditure Fee (CapEx) (E1)	Rupiah/ton
		Amount of Operational Expenditure (OpEx) (E2)	Rupiah/ton
		Amount of Revenue (E3)	Rupiah/ton
3	Environmental Factors (Envi)	Amount of GHG Emissions (L1)	kg CO2 eq/ton waste processed
		Hazardous Waste and Emissions Produced (L2)	ton/ton waste processed
		Waste reduction in Landfill (L3)	ton

Table 7. Description of waste to energy alternatives used in AHP analysis.

Waste to Energy Alternative	**Description**
Anaerobic digestion (AD)	Anaerobic digestion (AD) is a decomposition process of easily biodegradable organic substances in the absence of oxygen. The AD process is applied to assist the decomposition of organic matter in an airtight reactor/tank, commonly called a digester, to produce biogas.
Incineration (Inc)	Incineration is waste processing technologies through direct combustion using sufficient air and at high temperatures. With high temperature combustion, waste undergoes oxidation and changes from a solid or liquid phase to a gas. The hot gases used as energy for generating electricity.
Gasification (Gas)	Gasification is the process of burning waste with limited oxygen conditions so that (oxidation process occurs. The result of the combustion is in the form of residual solids and also flue gas which is called synthetic. The gas obtained is then used as fuel in the electricity generation process
Pyrolysis (Pyro)	Pyrolysis is defined as the process of thermal degradation of materials under inert conditions (in the absence of oxygen). This process will cause devolatilization of the hydrocarbon materia, causing changes in the properties of the material from solid to liquid and gaseous form and a small amount of solid residue. Liquid products (biofuel) as the main product for generating electricity.
Landfill Gas Recovery (LFG)	Utilization of biogas from landfill waste is often known as landfill gas recovery. the waste is piled up in layers and every certain period it is covered with topsoil, the landfill is turned into an anaerobic landfill. In this anaerobic condition, biogas will be formed.

Based on these data, then technical, economic, environmental, and social factors were selected to be used as criteria in this study. In more detail, the Technical Factors criteria have three sub-criteria, namely (1) Potential energy that can be generated by WtE Technology, (2) Energy required by WtE technology to operate, and (3) Percentage of waste that can be processed by WtE technology. In the Environmental Factors criteria there are three sub-criteria, namely (1) The impact of WtE technology on GHG Emissions, (2) B3 waste generated from the WtE technology.

4.2 AHP Hierarchical Structure Model

The AHP model in this study consists of four levels. The first level represents the objective of the study problem, to determine the most optimal WtE technology option to be applied to the Piyungan Landfill. The second level is the selection criteria of the waste to energy option which consists of three main criteria, namely technical, environmental, and economic factor. The third level of the hierarchy is devoted to the sub-criteria, where each of the three main criteria involves three sub-criteria. Table 6 shows the criteria and sub-criteria that were used in the development of the AHP model. The fourth level is alternatives, which include incineration, gasification, pyrolysis, anaerobic digester, and landfill gas recovery technologies. Table 7 presents a description of the five wastes to energy alternatives considered by the study, while Figure 3 shows the structure of the AHP model.

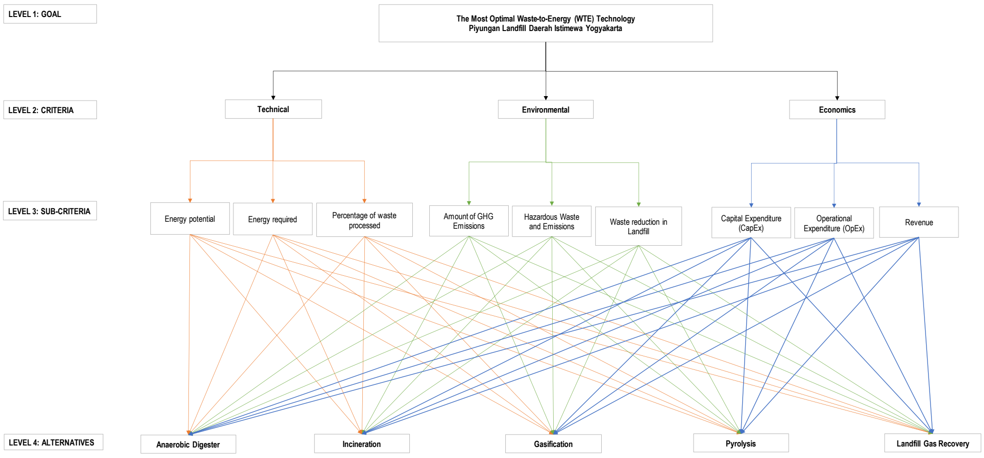

Figure 3. Analytical Hierarchy Model for The Selection of WtE Technology

4.3 Weighting and Prioritization Criteria and Sub-criteria

In the process of Weighting and prioritization uses the same experts as validation. For the case of prioritization of the criteria and sub-criteria, a questionnaire was developed following the methodology proposed for the AHP, which was answered by 8 experts. Each expert was assigned the same weight, so a process of aggregation of all the judgments was performed using the geometric mean. For the case of prioritization of the criteria and sub-criteria, after the aggregation process performed with the answers of the 8 experts, the comparison matrix from Table 8-11 was obtained.

Table 8. Pairwise Comparison Matrix, Local Priorities, and CR of Criteria

Criteria	Tech	Envi	Eco	Geometric Mean	Normalized Weight	Lamda	CI	RI	CR
Tech	1,000	1,236	3,672	1,656	0,455	3,033	0,017	0,580	0,029
Envi	0,809	1,000	5,125	1,607	0,442	3,033			
Eco	0,272	0,195	1,000	0,376	0,103	3,033			
				3,638	1,000	3,033			

Table 9. Pairwise Comparison Matrix, Local Priorities, and CR of Sub-criteria Technical

Sub-Criteria Technical	T1	T2	T3	Geometric Mean	Normalized Weight	Lamda	CI	RI	CR
T1	1,000	4,896	1,412	1,905	0,518	3,001	0,001	0,580	0,001
T2	0,204	1,000	0,260	0,376	0,102	3,001			
T3	0,708	3,848	1,000	1,397	0,380	3,001			
				3,678	1,000	3,001			

Table 10. Pairwise Comparison Matrix, Local Priorities, and CR of Sub-criteria Environmental

Sub-Criteria Environmental	L1	L2	L3	Geometric Mean	Normalized Weight	Lamda	CI	RI	CR
L1	1,000	3,289	3,307	2,216	0,616	3,056	0,028	0,580	0,048
L2	0,304	1,000	2,036	0,852	0,237	3,056			
L3	0,302	0,491	1,000	0,530	0,147	3,056			
				3,597	1,000	3,056			

Table 11. Pairwise Comparison Matrix, Local Priorities, and CR of Sub-criteria Economic

Sub-Criteria Economic	E1	E2	E3	Geometric Mean	Normalized Weight	Lamda	CI	RI	CR
E1	1,000	2,703	3,432	2,101	0,586	3,072	0,036	0,580	0,062
E2	0,370	1,000	2,829	1,015	0,283	3,072			
E3	0,291	0,353	1,000	0,469	0,131	3,072			
				3,585	1,000	3,072			

Based on Table 8-11, data obtained that the CR for the criteria is 0.029, The CR for the technical factor sub-criteria is 0.001, The CR for the environmental factor sub-criteria is 0.048, and the CR for the sub-criteria for economic factors is 0.062. If CR < 0.1 then the pairwise comparison value in the matrix is consistent. If CR > 0.1 then the pairwise comparison value in the matrix is inconsistent. If it is not consistent, then the pairwise comparison matrix must be repeated (the questionnaire is repeated). The calculation of the CR value in Table 8-11 shows that the data used is consistent so that it can be accepted.

After all the weights of each criterion and sub-criteria are obtained, then the global weight calculation is carried out which is the product of the weight of the criteria and the weight of the sub-criteria. The weight results from this AHP will be used in subsequent calculations. The weights for each sub-criteria can be seen in the following Table 12.

Table 12. Local priorities criteria

Criteria		Sub-Criteria		Global Weight
	Local Weight		Local Weight	
Tech	0,455	T1	0,518	0,236
		T2	0,102	0,047
		T3	0,380	0,173
Envi	0,442	L1	0,616	0,272
		L2	0,237	0,105
		L3	0,147	0,065
Eco	0,103	E1	0,586	0,061
		E2	0,283	0,029
		E3	0,131	0,014

Based on Table 12, the technical factor criteria have the highest weight with a value of 0.455, economic factor criteria with a weight of 0.442, and environmental factor criteria with a weight of 0.103. The sub-criteria that has the highest weight is the sub-criteria for Impact on GHG Emissions with a value of 0.272. Meanwhile, the sub-criteria with the lowest weight is Revenue from WtE Technology with a value of 0.014.

4.4 Weighting and Prioritization Alternatives

After obtaining the weights of each criterion and sub-criteria, the next step is to determine the weights for each alternative WtE technology. The weight of each alternative will be used to determine the preference value of each alternative WtE technology. Data related to WtE technology used in this work were gathered from journal articles, proceedings, ministries/government reports, news, and other references. The literature sources used are in accordance with the waste specifications at the Piyungan landfill (Table 5). Table 13 shows the data obtained regarding WtE technology from several literatures used.

Table 13. Specifications of WTE technologies

	Technical Factor			Environmental Factor			Economical Factor		
	T1	T2	T3	L1	L2	L3	E1	E2	E3
	kWh*	kWh*	%	kg CO2*	Kg*	Kilo ton	Million Rp*	Million Rp*	Million Rp*
Inc	448,55	99,35	86,52	340,47	383,28	135,96	1.566,51	0,32	0,98
Gas	739,94	227,02	79,18	226,53	408,29	119,73	2.336,00	1,00	1,43
Pyro	599,79	139,74	72,95	304,44	408,36	111,85	2.059,19	0,56	1,16
AD	195,50	94,53	55,01	292,79	168,81	59,35	706,65	0,23	0,38
LFG	62,47	10,07	100,00	314,24	248,94	55,47	84,61	0,01	0,12

**Each ton waste processed*

Once the alternative WtE technical data are obtained, the next step is weighting the normalized decision matrix. The weighting of the normalized decision matrix is done by multiplying the global weight of each criterion with the value of each attribute.

Table 14. Weighted Normalized Decision Matrix

	T1	T2	T3	L1	L2	L3	E1	E2	E3
Inc	0,099	0,031	0,083	0,133	0,052	0,039	0,034	0,022	0,006
Gas	0,163	0,011	0,076	0,180	0,048	0,034	0,021	0,005	0,009
Pyro	0,132	0,025	0,070	0,148	0,048	0,032	0,026	0,016	0,007
AD	0,043	0,032	0,053	0,153	0,081	0,017	0,049	0,024	0,002
LFG	0,014	0,045	0,096	0,144	0,070	0,016	0,059	0,029	0,001

4.5 Weighting and Prioritization Alternatives

The final step in the AHP analysis is to determine the global priorities of WtE alternatives. This can be achieved by synthesizing the local priorities of all criteria, sub-criteria, and alternatives to obtain the global weight for each alternative. To determine, the local priorities across all matrices of criteria are synthesized by multiplying the local priority vector of alternatives by local priority vector of each criterion and aggregated to get the final priority vector (global weight for each alternative) through additives aggregation with normalization of the local criteria priorities to unity as follows. Figure 4 shows the global (overall) priorities of the WtE technologies for Piyungan landfill.

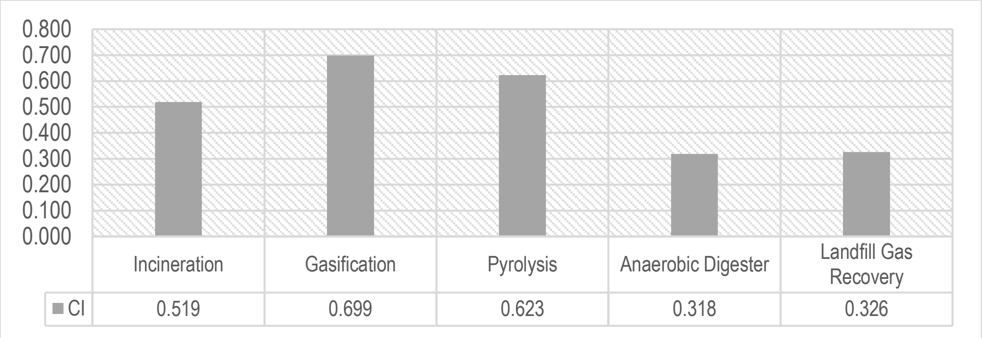

Figure 4. Global Priorities of the Waste to Energy Alternatives for Piyungan Landfill

Based on Figure 4, it can be observed that gasification is the best alternative of waste to energy with a global weight of 0.699. The results in this study are also linear with the existing conditions of WtE facilities that have been or are being built in Indonesia, such as the gasification technology in Benowo TPA, Surabaya city, and gasification technology which is also applied in Putri Cempo TPA, Solo city. The order of technology alternatives that have the largest to the smallest values are (1) Gasification with a preference value of 0.699; (2) Pyrolysis with a preference value of 0.623; (3) Incineration with a preference value of 0.519; (4) Landfill Gas Recovery with a preference value of 0.326; and (5) Anaerobic Digester with a preference value of 0.318. The alternative WtE technology that has the greatest value is Gasification, and the alternative WtE technology that has the lowest value is the Anaerobic Digester. These results indicate that gasification technology is the most ideal WtE technology for use in processing MSW waste at the Piyungan TPA

5. Discussions

Before starting this research activity, the researcher has conducted several studies on a number of studies that have been conducted before. This initial study was conducted to add insight and knowledge to researchers in developing and compiling the research to be carried out. The literature review that forms the basis of this research comes from various sources of study, both from within the country and from abroad. The themes and topics also vary, ranging from research related to energy planning, feasibility studies, potential studies, to analytical studies related to the use of waste-to-energy technology.

The results of this study can be implemented for other WtE technologies without having to change the model. However, to implement it in different locations or conditions, there are several things that must be observed, especially related to the characterization of the waste to be processed. In this study, the WtE technology studied is used to process municipal solid waste (MSW), so that if the results of this study are to be applied to a different location, it is necessary to ensure that the designation is to process MSW with identical specifications to MSW conditions. at the Piyungan Landfill, Special Region of Yogyakarta. In addition, social factors need to be added to further research because they have the potential to become one of the influential factors in selecting waste to energy technologies in Indonesia. In this study, only three factors were analyzed, namely technical, environmental, and economic.

In this study, the basis for calculating WtE technology revenue is based on PERPRES No. 35 of 2018 concerning the Acceleration of the Development of Installations for Processing Waste into Electrical Energy Based on Environmentally Friendly Technology which stipulates that the national electricity tariff (feed in tariff) for waste power plants (PLTSa) is 13.35 cents USD or equivalent to Rp. 1,935.75 for every kilowatt hour (kWh) of electricity produced. Meanwhile, the main cost of generation (BPP) on the island of Java, especially in Central Java which includes the Special Region of Yogyakarta, is 6.23 cents USD or the equivalent of IDR 907.77 for every kilowatt hour (kWh) of electricity produced in 2021. The difference between the feed in the tariff (FIT) for PLTSa which is IDR 1,935.75/kWh and the Central Java BPP which is IDR 907.77/kWh need special attention in future studies. The importance of analysis related to the difference in tariffs is due to the potential for this to be one of the factors that affect the sustainability of the operation of waste to energy facilities.

The results of this study show that gasification technology is the most ideal WtE technology for use in processing MSW waste at the Piyungan landfill, it is based on three main aspects, namely technical factors, economic factors, and environmental factors. Thus, if in subsequent studies social factors and policy factors are included as one of the other aspects of the assessment, gasification technology may become irrelevant for application in the Piyungan TPA. In addition, the gap between the PLTSa feed in tariff (FIT) which is IDR 1,935.75/kWh and the Central Java BPP which is IDR 907.77/kWh has not yet been analyzed in this study. If the analysis is included as one of the sub-criteria for economic factors, it is possible that there will be a change in priority (weighting) at the criterion level in this study. Likewise with problems related to the condition of waste that goes to the TPA. Mixing all types of waste into a single unit upstream is a very complex problem for any WtE technology to process it. The mechanical pre-treatment process (homogenization and shorting) in this study was felt to be able to be further improved to obtain more actual results. The more comprehensive the variables analyzed, the more factual the results obtained from research regarding the selection of waste to energy technology.

6. Conclusion

This study aims to determine the most optimal waste-to-energy (WtE) technology option to be applied to the Piyuangan Landfill in the Special Region of Yogyakarta by analyzing the priority order of criteria including technical factors, environmental factors, economic factors, and social factors using the analytical hierarchy process (AHP) method. AHP analysis was used to decide among five WTE alternatives, which treat the whole stream of municipal solid waste or some of its components. A four-level hierarchy model was developed and used by combining primary data from experts who participated in the pairwise comparison process based on a specially designed questionnaire and secondary data were gathered from journal articles, proceedings, ministries/government reports, news, and other references.

The technical factor criteria have the highest weight with a value of 0.455; economic factor criteria with a weight of 0.442; and environmental factor criteria with a weight of 0.103. Thus, technical factors, environmental factors, and economic factors are in the first, second, and third place respectively. Meanwhile, the criteria for social factors were omitted in this study. This is because the location where the WtE facility will be built is not included in this study, while the acceptability of the WtE facility is very dynamic towards the location where the WtE facility will be constructed. the sub-criteria that have the highest weight is the sub-criteria for Impact on GHG Emissions with a value of 0.272. Meanwhile, the sub-criterion with the lowest weight is Revenue from WtE Technology with a value of 0.014.

The order of technology alternatives that have the largest to the smallest values are (1) Gasification with a preference value of 0.699; (2) Pyrolysis with a preference value of 0.623; (3) Incineration with a preference value of 0.519; (4) Landfill Gas Recovery with a preference value of 0.326; and (5) Anaerobic Digester with a preference value of 0.318. The alternative WtE technology that has the greatest value is Gasification, and the alternative WtE technology that has the lowest value is the Anaerobic Digester).

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