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A Hybrid Fuzzy-AHP and Combined Compromise Solution (CoCoSo) Approach for The Solution of Greenhouse Gas Reduction Project Selection : Study Case in Nickel Mining Company

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Abstract:
This study presents an innovative decision-making approach for the nickel mining industry by combining the hybrid fuzzy-Analytical Hierarchy Process (*fuzzy-AHP*) with the Combined Compromise Solution (*CoCoSo*) method to evaluate and prioritize decarbonization project alternatives. The hybrid approach effectively handles uncertainty in multi-criteria assessments, enabling balanced trade-offs between competing alternatives. Motivated by the global pressure on Indonesia's nickel mining sector to reduce greenhouse gas (GHG) emissions by approximately 29% by 2030, this research focuses on an integrated nickel mining company assessing various projects to meet decarbonization targets. The *fuzzy-AHP* method manages uncertainty in weighting criteria, while the *CoCoSo* method ranks projects based on environmental, technical, financial, and supply-related criteria. A sensitivity analysis tests the robustness of results against changes in decision criteria weightings. The findings reveal that GHG emission reduction (30.4%), system impact (26.8%), and technology feasibility (16.1%) are the most influential criteria. The "Biomass for Kiln" project emerges as the top priority, though it is sensitive to changes in the emission reduction and CAPEX weightings, while the "Hydrotreated Vegetable Oil (HVO)" project consistently ranks lowest. These insights guide company decision-makers in selecting the most strategic projects for achieving sustainability goals.
Keywords: Greenhouse gas emissions, Fuzzy-AHP, CoCoSo, Green Sustainable Mining

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INTRODUCTION

As part of its global commitment to reducing greenhouse gas emissions, the Indonesian government has set a target in its Nationally Determined Contribution (NDC) document to reduce CO_2 emissions by 29% independently by 2030, or 834 million tons of CO_2eq across all sectors (ESDM RI, 2020). This target requires contributions from various industrial sectors, including the nickel mining sector, which has a significant impact on the national carbon footprint.

PT. X is a multinational company engaged in the mining sector, specifically nickel mining and processing. In line with the company's vision and mission regarding *Environment, Social, and Governance* (ESG), PT. X is committed to reducing greenhouse gas emissions generated from mining and nickel metal processing activities. The company has conducted an inventory of greenhouse gas emission sources, including mobile sources, stationary sources, fugitive emissions, process emissions, and land-clearing emissions (Kasinathan & Kanchan, 2025; Pashaei Farahani, 2020; からの排出インベントリのモデリング, 2020).

In response, PT. X has developed a long-term internal decarbonization plan as part of its sustainable business strategy. PT. X is committed to supporting the Indonesian government's program to reduce greenhouse gas emissions by 30% from absolute values, or 605 thousand tons of CO_2eq, through efficiency and optimization programs and investments in capital projects.

To carry out its production activities, PT. X uses 71.2% of its energy from non-renewable fossil fuels. Therefore, strategic projects to reduce greenhouse gas emissions will focus on reducing energy consumption, utilizing alternative energy sources, or replacing fossil fuels with renewable fuels.

Currently, PT. X has received 12 strategic project proposals aimed at reducing GHG emissions directly and indirectly. These projects vary in terms of technology, cost, emission reduction potential, and impact on the current production system. To determine which projects to prioritize, the company needs a selection process that considers various aspects in a structured manner. In this study, the selection process considered six main criteria that are interrelated and potentially conflicting: emission reduction, capital costs, operational costs, technological feasibility, effects on the current system, and raw material supply. The assessment of these criteria was conducted by experts from various divisions with different backgrounds and expertise. These differences in perception and preference can lead to subjective and inconsistent assessments, thus requiring a decision-making method capable of handling uncertainty and supporting compromise between criteria (Kampalasiri et al., 2025; Pelissari et al., 2021; Sharaf et al., 2024; Tomelleri et al., 2025).

Various multi-criteria decision-making (MCDM) methods have been developed and used in the literature to address similar problems. For example, the Analytic Hierarchy Process (AHP) method was used in the evaluation of restaurant service quality by Ulkhaq et al. (2016) and in manufacturing optimization by Sivam & Rajendran (2025). However, classic AHP cannot handle the uncertainty and linguistic assessments commonly used in expert-based evaluations.

The TOPSIS and VIKOR methods were used in studies on post-mining planning (Arratia-Solar et al., 2022) and livestock waste management (Coimbra et al., 2023). However, these methods are susceptible to rank reversal and highly sensitive to normalization techniques and changes in criterion weights. The MOORA and MOLP methods, used by Wang & Li (2025) and Permata & Singgih (2024), are effective for numerical data and optimization but not designed to handle linguistic or fuzzy data.

Weighting methods such as BWM and FUCOM, adopted by Albayrak et al. (2023) and Demircan et al. (2022), provide efficiency in determining weights but do not support hierarchical structures or fuzzy data, making them less ideal for expert perception-based decision-making. A study by Sabaei et al. (2015) confirms that various MCDM methods, such as AHP, MAUT, PROMETHEE, ELECTRE, and SAW, have limitations in hierarchical frameworks, data handling, and sensitivity to criterion structures and decision-makers' preferences.

As the need for sustainability-based decision-making grows, fuzzy approaches address uncertainty and subjectivity in expert assessments. The Fuzzy-AHP method has become popular because it represents expert preferences as triangular fuzzy numbers and synthesizes criterion weights mathematically through the extent analysis method (Chang, 1996). A study by Ulkhaq (2022) shows that fuzzy approaches improve the validity of restaurant service rankings with multidimensional criteria, while Wang (2023) applied Fuzzy-AHP in evaluating sustainable maritime transport strategies. However, Fuzzy-AHP only produces criterion weights without evaluating alternatives, so it is insufficient for comprehensively selecting greenhouse gas emission reduction projects. Additionally, the weight results are sensitive to consistency ratios and variations in expert opinions (Permata et al., 2023; Naghadehi, 2012).

The Combined Compromise Solution (CoCoSo) method is a modern approach developed by Yazdani et al. (2018) to provide compromise between additive and multiplicative aggregation in alternative ranking. It combines three aggregation strategies (*K^{i_a}*, *K^{i_b}*, and *K^{i_c}*) and uses the *Kⁱ* composite index to produce stable rankings adaptive to weight changes. In Saputra's (2022) study, CoCoSo was used for modem selection with a cost-benefit criteria structure, while Sivam (2023) applied it to rank forming parameters validated by FEM tests and experiments. Although CoCoSo excels in alternative evaluation, it lacks an internal mechanism for criterion weighting, remaining dependent on other methods.

This study proposes a hybrid approach. Fuzzy-AHP accommodates subjective and linguistic assessments through fuzzy number representation and produces realistic criterion weights based on diverse expert perceptions. Meanwhile, CoCoSo generates the final ranking of project alternatives via compromise between summation and multiplication of weights. CoCoSo demonstrates high stability against criterion weight changes and greater flexibility than TOPSIS, VIKOR, or SAW.

This research contributes to enriching MCDM approaches, particularly by integrating uncertainty-based (fuzzy) and compromise methods. It also offers adaptable solutions for sustainable project decision-making in other sectors with similar complex characteristics.

RESEARCH METHOD

Research Flowchart

The following is a flowchart of the research process.

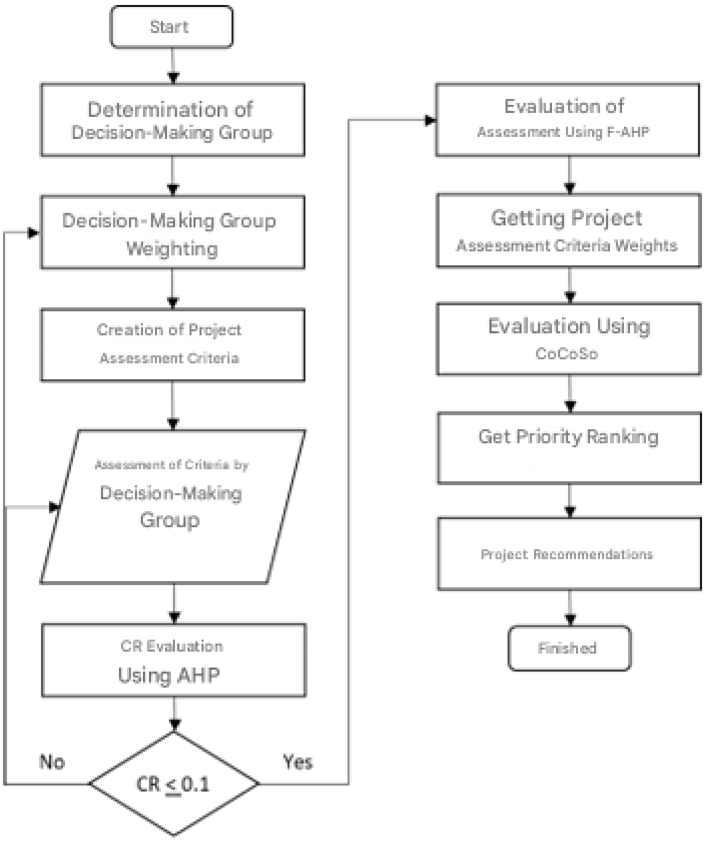

Figure 1. Research flow chart

Explanation of the Research Flowchart

This subchapter contains an explanation of each stage of the flowchart in the research after identifying the problem and conducting a literature study. The following is an explanation of each stage of the research flowchart.

Step 1: Establishing criteria for decision-making groups

To avoid bias, decision-making criteria based on background information must be weighted. The decision-making group consists of experts currently working at PT. X. Decision-making criteria are based on work experience, background, and position.

Table 1. Respondent Data

Initials	Position	Work Experience	Educational Background
ZA	*Head of Department*	22	S2
AL	*Head of Department*	18	S2
FS	*Head of Department*	14	S2
UK	*Senior Manager*	20	S2
AA	*Senior Manager*	26	S1
FR	*Manager*	18	S1
HD	*Engineer*	4	S1

Step 2: Weighting of decision-making groups
Weighting is based on work experience, background, and position in accordance with Table 3.2.

Table 2. Weighting of Respondents or Experts

Position	Weight	Work Experience	Weight	Educational	Weight
Head of Department	7	>15 Year	7	S3	7
Sr. Manager	5	10-15 Year	5	S2	5
Manager	3	5-10 Year	3	S1	3
Engineer	1	<5 Year	1	SMA	1

Step 3: Development of project assessment criteria. The list of project assessment criteria was obtained from a literature review and the results of discussions among the decision-making group, resulting in criteria that may have a significant influence on the decision-making process for alternative projects to reduce greenhouse gas emissions.

Step 4: Assessment of Criteria by the Decision-Making Group. Data collection is carried out using a questionnaire that will be given to the experts. The experts will then assess the paired comparisons for each criterion of the decision-making group and project assessment criteria. In general, the scoring technique used in this research questionnaire is the Saaty scale technique, as shown in Table 3. Paired comparisons for criteria assessment.

Table 3. Pairwise comparison for criteria assessment

Criteria	Assessment																	Criteria
A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	B
B	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	C
C	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	A

where the values are:
1: Equally important
3: Slightly more important
5: Important
7: Much more important
9: Very important
2,4,6,8: Values between two adjacent considerations

In Table 3, each criterion will be compared in pairs with the variables that will later be selected by the experts.

Step 5: Evaluate using the AHP method to obtain the Consistency Ratio (CR).

Step 6: Evaluate the Consistency Ratio (CR) value <0.1. The weight of each criterion that has been calculated is then evaluated to ensure that the comparisons made by each respondent are consistent by calculating the CR value. The CR value is obtained by dividing the Consistency Index (CI) by the Random Index (RI).

$$CR = \frac{CI}{RI} = \frac{\frac{\lambda_{max}-\eta}{\eta-1}}{RI} \quad (3.1)$$

Where, λ_{max} = Maximum eigenvalue

If the CR value is less than 0.1, it indicates that the results are consistent and the calculation can proceed.

Step 7: Processing of data on the weights of the decision-making group criteria and project assessment criteria using the F-AHP method. Each expert provides an assessment of the comparison between criteria using the Saaty scale, which is translated into fuzzy triangular numbers (TFN) in accordance with Chang's (1996) calculations.

Table 4. ***Triangular Fuzzy Number*** **(TFN)**

Rating Scale	**Linguistics**	***Triangular Fuzzy Number* (TFN)**	***Reciprocal***
1	Equal	(1,1,1)	(1,1,1)
2	Intermediate	(1/2,1,3/2)	(2/3,1,2)
3	One element is moderately more important than the other	(1,3/2,2)	(1/2,2/3,1)
4	Intermediate	(3/2,2,5/2)	(2/5,1/2,2/3)
5	One element is strongly more important than the other	(2,5/2,3)	(1/3,2/5,1/2)
6	Intermediate	(5/2,3,7/2)	(2/7,1/3,2/5)
7	One element is very strongly more important than the other	(3,7/2,4)	(1/4,2/7,1/3)
8	Intermediate	(7/2,4,9/2)	(2/9,1/4,2/7)
9	One element is extremely more important than the other	(4,9/2,9/2)	(2/9,2/9,1/4)

(Ulkhaq, et al, 2016)

After converting the assessment to TFN, a fuzzy comparison matrix was then created for each respondent. For each fuzzy matrix, we calculated the geometric mean for each row and performed defuzzification to obtain the weight of each criterion for the decision-making group and project assessment criteria.

Step 8: Combine the respondent weights with the criterion weights to obtain the assessment criteria that will later be used in the CoCoSo method.

Step 9: Process the best investment alternatives using the CoCoSo (Combined Compromise Solution) method with the following steps

- Normalization of Decision Matrices
- Calculating the Values of S_i and P_i
- Calculating K_{ia}, K_{ib}, and K_{ic} Values
- Calculating the Total Ki Value

Step 10: Ranking Alternatives, sorting the project alternatives obtained from the previous calculations.

Step 11: Recommendations for the best project from all available alternatives. The results of this study can provide recommendations, evaluations, and suggestions regarding the best project to reduce greenhouse gas emissions to be carried out by PT. X.

Data Analysis Techniques

The technique used in data analysis in this study is Fuzzy-AHP (Analytical Hierarchy Process). This method is used to determine the criteria and weights of respondents, each indicator of project success obtained from the questionnaire results. The F-AHP method is considered suitable for providing input related to the best project success criteria in reducing greenhouse gas emissions by providing a measurement scale and method for obtaining priorities, where the solution to the problem in this study requires ranking the most important successes to be carried out by PT. X, as well as considering the relative priorities of factors in the system so that people are able to choose the best alternative based on the objectives. F-AHP considers logical consistency in the assessment used to determine priorities, where the consistency ratio value must be less than 0.1, and if it exceeds this value, the comparison between indicators needs to be reviewed to produce more consistent output.

The CoCoSO method was then selected to complement the previously selected F-AHP method. This method combines the principle of compromise to produce the best solution using various assessment and comparison factors that provide more stable and accurate results. CoCoSo provides a balance between various criteria and produces a better compromise solution in conditions of conflict between criteria. The scores used in this study are Larger is Better or characteristics for quality that include measurements where the higher the value, the better the result.

Sensitivity Analysis

Sensitivity analysis was conducted using the scenario analysis method to evaluate the extent to which small changes in inputs (criteria weights) affect the final results (Ki scores). The assumption used in the scenario was to change the weight of one criterion while the other criteria were weighted proportionally (Muanley et al. 2022). According to Saltelli et al. (2004), a change in criterion weight of up to +10% is robust enough to see how sensitive a criterion is to the final result. In this study, sensitivity analysis will be performed by changing the weight values into several scenarios.

- Scenario 1: Changes to greenhouse gas emission reduction criteria In this scenario, greenhouse gas emission reduction criteria are increased by 10%.
- Scenario 2: Changes to CAPEX cost criteria In this scenario, CAPEX cost criteria are increased by 10%.
- Scenario 3: Changes to system impact criteria In this scenario, the system impact criteria will be increased by 10%.
- Scenario 4: Changes to OPEX cost criteria In this scenario, the OPEX cost criteria will be increased by 10%.
- Scenario 5: Changes to technology feasibility criteria In this scenario, the technology feasibility criteria will be increased by 10%.
- Scenario 6: Changes to raw material supply criteria In this scenario, the raw material supply criteria will be increased by 10%.

RESULT AND DISCUSSION

Decision-Making Group

This study involved seven respondents who were referred to as the decision-making group in this study. They had different positions, work experiences, and educational backgrounds, so weighting was necessary to ensure that the assessment was not biased.

The following are the steps and calculations for obtaining the weighting of the decision-making group criteria:

- Determining the TFN (Triangular Fuzzy Number) scale

  This scale will be used in the fuzzification process, which consists of three functions, namely the lowest value (l), the middle value (m), and the highest value (u).

Table 5. TFN (Triangular Fuzzy Number) Scale

Rating Scale	Linguistics	*Triangular Fuzzy Number (TFN)*	*Reciprocal*
1	Equal	(1,1,1)	(1,1,1)
2	Intermediate	(1/2,1,3/2)	(2/3,1,2)
3	One element is moderately more important than the other	(1,3/2,2)	(1/2,2/3,1)
4	Intermediate	(3/2,2,5/2)	(2/5,1/2,2/3)
5	One element is strongly more important than the other	(2,5/2,3)	(1/3,2/5,1/2)
6	Intermediate	(5/2,3,7/2)	(2/7,1/3,2/5)
7	One element is very strongly more important than the other	(3,7/2,4)	(1/4,2/7,1/3)
8	Intermediate	(7/2,4,9/2)	(2/9,1/4,2/7)
9	One element is extremely more important than the other	(4,9/2,9/2)	(2/9,2/9,1/4)

- Determining the priority comparison between criteria using the TFN scale

Table 6. Comparison of priorities between criteria using the TFN scale

	Position			Experience			Education		
	L	M	U	L	M	U	L	M	U
Position (C1)	1.00	1.00	1.00	1.00	1.50	2.00	3.00	3.50	4.00
Experience (C2)	0.50	0.67	1.00	1.00	1.00	1.00	2.00	2.50	3.00
Education (C3)	0.25	0.29	0.33	0.33	0.40	0.50	1.00	1.00	1.00

- Determining fuzzy synthesis values

$$Si = \sum_j^m M_i^j x\left[\sum_{i=l}^n \sum_{j=l}^m M_{gi}^i\right]^{-1} \quad (4.1)$$

$$\sum_j^m M_i^j = \sum_{j=1}^m lj \,, \sum_{j=1}^m mj \,, \sum_{j=1}^m uj \quad (4.2)$$

$$\left[\sum_{i=l}^n \sum_{j=l}^m M_{gi}^i\right]^{-1} = \frac{i}{\sum_{j=1}^n uj, \sum_{j=1}^n mj, \sum_{j=1}^n lj} \quad (4.3)$$

Where,
Si = Fuzzy synthesis value
M = TFN
i = Row index
j = Column index
$\sum_j^m M_i^j$ = Total column value, starting from column 1

Table 7. Fuzzy synthesis values

	Number of Fuzzy in each row M			**Fuzzy Synthesis Value (Si)**		
	L	M	U	L	M	U
Position (C1)	3.50	4.50	5.50	0.29	0.46	0.70
Experience (C2)	2.50	3.17	4.00	0.21	0.32	0.51
Education (C3)	1.90	2.17	2.67	0.16	0.22	0.34
Total	**7.90**	**9.83**	**12.17**			

- Determining the degree of probability and the value of defuzzification ordinates

$$V(M2 \geq M1) = sup_{y \geq x}[\min(\alpha_{M1}(x), (\alpha_{M2}(y)] \quad (4.4)$$

Where x and y are values on the membership function axis of each criterion, or can be written as below

$$V(M_2 \geq M_1) = \begin{cases} 1 & jika, m_2 \geq m_1 \\ 0 & jika, l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & lain - nya \end{cases} \quad (4.5)$$

The defuzzification ordinate value is obtained from the minimum degree of possibility value.

$$d(A_i) = \min V\ (S_i \geq S_k) \quad (4.6)$$

Where, k = 1,2,3,…,n

Table 8. Degree of possibility and defuzzification ordinate values

	Degree of Probability Mi>Mj			**Degree of Probability (Mi)**
	C1	C2	C3	
Position (C1)	1.00	1.00	1.00	1.00
Experience (C2)	0.62	1.00	1.00	0.62
Education (C3)	0.17	0.56	1.00	0.17
		Total		1.79

- Normalization of fuzzy vector weight values (W)

$$W' = \left(d'(A_1), d'(A_2), \dots, d'(A_n)\right)^T \quad (4.7)$$

Where (Ai = 1,2,3,…,n) is the nth element.

Table 9. Results of weighting criteria for decision-making groups

Normalization			
Position (C1)	0. 56	0. 56	Weight of each criterion
Experience (C2)	0. 34	0. 34	
Education (C3)	0. 10	0. 10	
Total	**1.00**		

- Calculating the Consistency Index value (CI)

$$CI = \frac{\lambda_{maks} - n}{n - 1} \quad (4.8)$$

Based on calculations, the value λ_{maks}=3.07 dan n=3, so that it is obtained CI= 0.037.

- Calculating the Consistency Ratio value (CR)

$$CR = \frac{CI}{RI} \quad (4.9)$$

Where, the RI value for matrix n=3 is 0.58, so that $CR = \frac{0.037}{0.58} = 0.063$. Because of the value CR < 0.1, then the questionnaire for comparing respondents is declared valid and consistent.

- Calculate the vector value for each respondent

The results of the weighting of the decision-making group criteria can be seen in Table 4.6, where the job criteria (55.8%) have the highest weight compared to other criteria in the decision-making process for selecting projects to reduce greenhouse gas emissions. Meanwhile, the results of the weighting of the decision-making group can be seen in Table 11, where ZA (19%) and AL (19%) have the highest weights.

Project Assessment Criteria

In evaluating greenhouse gas (GHG) emission reduction projects, experts agreed to select six main criteria for evaluation, namely GHG emission reduction, investment costs (CAPEX), effects on the system, operational costs (OPEX), technological feasibility, and raw material supply. Several parameters were eliminated because they did not meet the Company's requirements for determining a project, so the criteria to be analyzed are as follows:

- GHG emission reduction: GHG emission reduction criteria are key parameters because they directly indicate a project's contribution to climate change mitigation efforts. Only projects that can significantly reduce emissions are considered feasible for implementation.
- CAPEX costs: Initial investment costs (CAPEX) are a crucial consideration because projects requiring large amounts of funding are difficult to implement, making budget efficiency one of the indicators of feasibility.
- System impact: parameters considered appropriate for determining whether there is a significant impact on existing systems, where the impact is expected to be minimal
- OPEX costs: parameters considered appropriate for determining whether there is an increase or decrease in operational costs, where projects requiring high operational costs have the potential to burden the sustainability of their implementation
- Technological feasibility: parameters used to determine whether the selected project is proven/mature or has never been undertaken by anyone before
- Raw material supply: raw material supply is an equally important criterion because projects that depend on unstable raw materials are at risk of operational disruption.

CAPEX and OPEX costs are separated in accordance with expert recommendations, as it is believed that this project may not be profitable at all. Therefore, it is recommended that CAPEX and OPEX cost parameters be separated so that their effects can be seen more clearly.

In practice, these six criteria often reveal conflicts or trade-offs that need to be carefully managed. For example, projects with high potential for GHG emission reduction often require large investments (CAPEX) or advanced technologies that are not yet compatible with existing systems. On the other hand, projects with low operating costs may depend on unsustainable raw materials. Such conflicts indicate that no single project excels in all aspects, requiring a multi-criteria evaluation approach such as Fuzzy-AHP and CoCoSo to systematically address the complexity and conflicts between criteria. Through this approach, each project alternative can be assessed proportionally, taking into account the weight of preferences derived from expert decisions and the performance value of each project against each criterion, resulting in priorities that are more rational and adaptive to the context.

The questionnaire provided (Appendix 1) was used to compare each criterion with other criteria, where respondents selected answers based on their level of importance. The results of this data collection were used to weight the criteria using the Fuzzy-AHP method.

Criteria Weighting Results (Fuzzy-AHP)

The questionnaire data from each respondent was then processed by converting the assessment scale to the TFN (triangular fuzzy number) scale, calculating the fuzzy synthesis value, determining the degree of possibility and fuzzification value, and finally producing the weight of each criterion.

The results of the questionnaire completed by respondents were then checked for consistency using the AHP method, whereby if the consistency ratio value was <0.1 or 10%, the data filled in by the respondents was considered consistent and no need for data collection was required.

The following is the calculation of the assessment criteria using the fuzzy-AHP method

Processing of ZA Respondent Data

- Determining the TFN (Triangular Fuzzy Number) scale

This scale will be used in the fuzzification process, which consists of three functions, namely the lowest value (l), the middle value (m), and the highest value (u).

Table 10. Comparison of priorities between criteria using the TFN scale of respondent ZA

Criteria	GHG Emission Reduction			CAPEX Costs			Effects on the System			OPEX Costs			Technology Feasibility			Raw Material Supply		
	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
GHG Emission Reduction	1.00	1.00	1.00	2.00	2.50	3.00	1.00	1.50	2.00	2.00	2.50	3.00	1.00	1.50	3.00	2.00	2.50	3.00

CAPEX Costs	0.33	0.40	0.50	1.00	1.00	1.00	0.33	0.40	0.50	1.00	1.00	1.00	0.50	0.67	1.00	1.00	1.50	2.00
Effects on the System	0.50	0.67	1.00	2.00	2.50	3.00	1.00	1.00	1.00	2.00	2.50	3.00	1.00	1.50	2.00	1.00	1.50	2.00
OPEX Costs	0.33	0.40	0.50	1.00	1.00	1.00	0.33	0.40	0.50	1.00	1.00	1.00	0.50	0.67	1.00	1.00	1.50	2.00
Technology Feasibility	0.50	0.67	1.00	1.00	1.50	2.00	0.50	0.67	1.00	1.00	1.50	2.00	1.00	1.00	1.00	0.50	1.00	1.50
Raw Material Supply	0.33	0.40	0.50	0.50	0.67	1.00	0.50	0.67	1.00	0.50	0.67	1.00	0.67	1.00	2.00	1.00	1.00	1.00

- Determining fuzzy synthesis values

Table 11. Fuzzy synthesis values of ZA respondents

Criteria	Number of Fuzzy in Each Row			Fuzzy Synthesis Value (Si)		
	L	M	U	L	M	U
GHG Emission Reduction	9.00	11.50	15.00	0.17	0.27	0.46
CAPEX Costs	4.17	4.97	6.00	0.08	0.12	0.18
System Impact	7.50	9.67	12.00	0.14	0.23	0.37
OPEX Costs	4.17	4.97	6.00	0.08	0.12	0.18
Technology Feasibility	4.50	6.33	8.50	0.08	0.15	0.26
Raw Material Supply	3.50	4.40	6.50	0.06	0.11	0.20
Total	32.83	41.83	54.00			

- Determining the degree of possibility, defuzzification ordinate value, normalization value

Table 12. Degree of possibility values, defuzzification ordinate values, ZA respondent normalization values

Criteria	Degree of Probability Mi>Mj						Degree of Probability (Mi)	Normalization
GHG Emission Reduction	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.39
CAPEX Costs	0.09	1.00	0.28	1.00	0.75	1.00	0.09	0.04
System Impact	0.82	1.00	1.00	1.00	1.00	1.00	0.82	0.32
OPEX Costs	0.09	1.00	0.28	1.00	0.75	1.00	0.09	0.04
Technology Feasibility	0.43	1.00	0.60	1.00	1.00	1.00	0.43	0.17
Raw Material Supply	0.16	0.90	0.32	0.90	0.71	1.00	0.16	0.06
							Total	1.00

Consistency Ratio (CR) value = 0.085

Since the CR value is < 0.1, the questionnaire for respondent comparison is declared valid or consistent.

Processing of AL Respondent Data

- Determining the priority comparison between criteria using the TFN scale

Table 13. Comparison of priorities between criteria using the TFN scale of AL respondents

Criteria	GHG Emission Reduction			CAPEX Costs			System Impact			OPEX Costs			Technology Feasibility			Raw Material Supply		
	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
GHG Emission Reduction	1.00	1.00	1.00	1.00	1.50	2.00	0.33	0.40	0.50	1.00	1.50	2.00	0.50	0.67	1.00	1.00	1.50	2.00
CAPEX Costs	0.50	0.67	1.00	1.00	1.00	1.00	0.33	0.40	0.50	1.00	1.00	1.00	0.67	1.00	2.00	1.00	1.50	2.00
System Impact	2.00	2.50	3.00	2.00	2.50	3.00	1.00	1.00	1.00	2.00	2.50	3.00	1.00	1.50	2.00	2.00	2.50	3.00
OPEX Costs	0.50	0.67	1.00	1.00	1.00	1.00	0.33	0.40	0.50	1.00	1.00	1.00	0.67	1.00	2.00	1.00	1.50	2.00

Technology Feasibility	1.00	1.50	2.00	0.50	1.00	1.50	0.50	0.67	1.00	0.50	1.00	1.50	1.00	1.00	1.00	0.50	1.00	1.50
Raw Material Supply	0.50	0.67	1.00	0.50	0.67	1.00	0.33	0.40	0.50	0.50	0.67	1.00	0.67	1.00	2.00	1.00	1.00	1.00

- Determining fuzzy synthesis values

Table 14. Sintesis Fuzzy Responden AL

Criteria	Number of Fuzzy in Each Row			Fuzzy Synthesis Value (Si)		
	L	M	U	L	M	U
GHG Emission Reduction	4.83	6.57	8.50	0.09	0.16	0.27
CAPEX Costs	4.50	5.57	7.50	0.08	0.14	0.24
System Impact	10.00	12.50	15.00	0.19	0.31	0.48
OPEX Costs	4.50	5.57	7.50	0.08	0.14	0.24
Technology Feasibility	4.00	6.17	8.50	0.07	0.15	0.27
Raw Material Supply	3.50	4.40	6.50	0.07	0.11	0.21
Total	31.33	40.77	53.50			

- Determining the degree of probability, defuzzification ordinate value, normalization value

Table 15. Degree of possibility values, defuzzification ordinate values, and respondent normalization values for AL

Criteria	Degree of Probability Mi>Mj						Degree of Probability (Mi)	Normalization
GHG Emission Reduction	1.00	1.00	0.37	1.00	1.00	1.00	0.37	0.16
CAPEX Costs	0.86	1.00	0.24	1.00	0.92	1.00	0.24	0.10
System Impact	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.44
OPEX Costs	0.86	1.00	0.24	1.00	0.92	1.00	0.24	0.10
Technology Feasibility	0.95	1.00	0.35	1.00	1.00	1.00	0.35	0.15
Raw Material Supply	0.69	0.81	0.09	0.81	0.75	1.00	0.09	0.04
							Total	1.00

Consistency Ratio (CR) value = 0.086 Since the CR value is < 0.1, the questionnaire for respondent comparison is declared valid or consistent.

FS Respondent Data Processing

- Determining the priority comparison between criteria using the TFN scale

Table 16. Comparison of priorities between criteria using the TFN scale of FS respondents

Criteria	GHG Emission Reduction			CAPEX Costs			System Impact			OPEX Costs			Technology Feasibility			Raw Material Supply		
	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
GHG Emission Reduction	1.00	1.00	1.00	1.00	1.50	2.00	1.00	1.00	1.00	1.00	1.50	2.00	0.50	1.00	1.50	1.00	1.50	2.00
CAPEX Costs	0.50	0.67	1.00	1.00	1.00	1.00	0.50	0.67	1.00	1.00	1.00	1.00	0.50	0.67	1.00	1.00	1.50	2.00
System Impact	1.00	1.00	1.00	1.00	1.50	2.00	1.00	1.00	1.00	1.00	1.50	2.00	1.00	1.50	2.00	1.00	1.50	2.00
OPEX Costs	0.50	0.67	1.00	1.00	1.00	1.00	0.50	0.67	1.00	1.00	1.00	1.00	1.00	1.50	2.00	1.00	1.50	2.00
Technology Feasibility	0.67	1.00	2.00	1.00	1.50	2.00	0.50	0.67	1.00	0.50	0.67	1.00	1.00	1.00	1.00	1.00	1.50	2.00

Raw Material Supply	0.50	0.67	1.00	0.50	0.67	1.00	0.50	0.67	1.00	0.50	0.67	1.00	0.50	0.67	1.00	1.00	1.00	1.00

- Determining fuzzy synthesis values

Table 17. Fuzzy synthesis values of FS respondents

Criteria	Number of Fuzzy in Each Row			Fuzzy Synthesis Value (Si)		
	L	M	U	L	M	U
GHG Emission Reduction	5.50	7.50	9.50	0.11	0.20	0.33
CAPEX Costs	4.50	5.50	7.00	0.09	0.14	0.24
System Impact	6.00	8.00	10.00	0.12	0.21	0.34
OPEX Costs	5.00	6.33	8.00	0.10	0.17	0.27
Technology Feasibility	4.67	6.33	9.00	0.09	0.17	0.31
Raw Material Supply	3.50	4.33	6.00	0.07	0.11	0.21
Total	29.17	38.00	49.50			

- Determining the degree of possibility, defuzzification ordinate value, normalization value

Table 18. Degree of possibility values, defuzzification ordinate values, respondent normalization values FS

Criteria	Degree of Probability Mi>Mj						Degree of Probability (Mi)	Normalization
GHG Emission Reduction	1.00	1.00	0.94	1.00	1.00	1.00	0.94	0.20
CAPEX Costs	0.71	1.00	0.64	0.86	0.87	1.00	0.64	0.14
System Impact	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.22
OPEX Costs	0.84	1.00	0.78	1.00	1.00	1.00	0.78	0.17
Technology Feasibility	0.87	1.00	0.81	1.00	1.00	1.00	0.81	0.17
Raw Material Supply	0.53	0.79	0.47	0.67	0.68	1.00	0.47	0.10
							Total	1.00

Consistency Ratio (CR) value = 0.092 Since the CR value is < 0.1, the questionnaire for respondent comparison is declared valid or consistent.

UK Respondent Data Processing

- Determining the priority comparison between criteria using the TFN scale

Table 19. Comparison of priorities between criteria using the TFN scale of UK respondents

Criteria	GHG Emission Reduction			CAPEX Costs			System Impact			OPEX Costs			Technology Feasibility			Raw Material Supply		
	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
GHG Emission Reduction	1.00	1.00	1.00	2.00	2.50	3.00	1.50	2.00	2.50	2.00	2.50	3.00	1.50	2.00	2.50	1.00	1.50	2.00
CAPEX Costs	0.33	0.40	0.50	1.00	1.00	1.00	0.50	0.67	1.00	0.50	1.00	1.50	0.50	0.67	1.00	1.00	1.50	2.00
System Impact	0.40	0.50	0.67	1.00	1.50	2.00	1.00	1.00	1.00	1.00	1.50	2.00	1.00	1.50	2.00	1.00	1.50	2.00
OPEX Costs	0.33	0.40	0.50	0.67	1.00	2.00	0.50	0.67	1.00	1.00	1.00	1.00	0.50	0.67	1.00	0.50	1.00	1.50
Technology Feasibility	0.40	0.50	0.67	1.00	1.50	2.00	0.50	0.67	1.00	1.00	1.50	2.00	1.00	1.00	1.00	1.00	1.50	2.00
Raw Material Supply	0.50	0.67	1.00	0.50	0.67	1.00	0.50	0.67	1.00	0.67	1.00	2.00	0.50	0.67	1.00	1.00	1.00	1.00

- Determining fuzzy synthesis values

Table 20. Fuzzy synthesis values of UK respondents

Criteria	Number of Fuzzy in Each Row			Fuzzy Synthesis Value (Si)		
	L	M	U	L	M	U
GHG Emission Reduction	9.00	11.50	14.00	0.17	0.29	0.46
CAPEX Costs	3.83	5.23	7.00	0.07	0.13	0.23
System Impact	5.40	7.50	9.67	0.10	0.19	0.32
OPEX Costs	3.50	4.73	7.00	0.07	0.12	0.23
Technology Feasibility	4.90	6.67	8.67	0.09	0.17	0.29
Raw Material Supply	3.67	4.67	7.00	0.07	0.12	0.23
Total	30.30	40.30	53.33			

- Determining the degree of probability, defuzzification ordinate value, normalization value

Table 21. Degree of possibility values, defuzzification ordinate values, UK respondent normalization values

Criteria	Degree of Probability Mi>Mj						Degree of Probability (Mi)	Normalization
GHG Emission Reduction	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.34
CAPEX Costs	0.29	1.00	0.70	1.00	0.80	1.00	0.29	0.10
System Impact	0.60	1.00	1.00	1.00	1.00	1.00	0.60	0.21
OPEX Costs	0.27	0.93	0.65	1.00	0.74	1.00	0.27	0.09
Technology Feasibility	0.49	1.00	0.90	1.00	1.00	1.00	0.49	0.17
Raw Material Supply	0.27	0.92	0.65	1.00	0.74	1.00	0.27	0.09
							Total	1.00

Consistency Ratio (CR) value = 0.098 Since the CR value is < 0.1, the questionnaire for respondent comparison is declared valid or consistent.

Processing of AA Respondent Data

- Determining the priority comparison between criteria using the TFN scale
- Determining fuzzy synthesis values

Table 22. Fuzzy synthesis values of AA respondents

Criteria	Number of Fuzzy in Each Row			Fuzzy Synthesis Value (Si)		
	L	M	U	L	M	U
GHG Emission Reduction	11.00	13.50	16.00	0.20	0.32	0.51
CAPEX Costs	3.83	5.23	7.00	0.07	0.13	0.22
System Impact	4.83	6.90	9.00	0.09	0.17	0.28
OPEX Costs	3.50	4.73	7.00	0.06	0.11	0.22
Technology Feasibility	4.83	6.57	8.50	0.09	0.16	0.27
Raw Material Supply	3.67	4.73	7.50	0.07	0.11	0.24
Total	31.67	41.67	55.00			

- Determining the degree of probability, defuzzification ordinate value, normalization value

Table 23. Degree of possibility values, defuzzification ordinate values, AA respondent normalization values

Criteria	Degree of Probability Mi>Mj						Degree of Probability (Mi)	Normalization
GHG Emission Reduction	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.51
CAPEX Costs	0.10	1.00	0.77	1.00	0.81	1.00	0.10	0.05
System Impact	0.35	1.00	1.00	1.00	1.00	1.00	0.35	0.18
OPEX Costs	0.09	0.93	0.72	1.00	0.75	1.00	0.09	0.05
Technology Feasibility	0.29	1.00	0.96	1.00	1.00	1.00	0.29	0.15
Raw Material Supply	0.15	0.93	0.74	1.00	0.77	1.00	0.15	0.08
							Total	1.00

Consistency Ratio (CR) value = 0.098

Since the CR value is < 0.1, the questionnaire for respondent comparison is declared valid or consistent.

Processing of FR Respondent Data

- Determining the priority comparison between criteria using the TFN scale

Table 24. Comparison of priorities between criteria using the TFN scale of FR respondents

Criteria	GHG Emission Reduction			CAPEX Costs			System Impact			OPEX Costs			Technology Feasibility			Raw Material Supply		
	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
GHG Emission Reduction	1.00	1.00	1.00	2.00	2.50	3.00	1.00	1.50	2.00	1.00	1.50	2.00	1.00	1.50	2.00	1.00	1.50	2.00
CAPEX Costs	0.33	0.40	0.50	1.00	1.00	1.00	0.50	0.67	1.00	1.00	1.00	1.00	0.50	0.67	1.00	0.50	0.67	1.00
System Impact	0.50	0.67	1.00	1.00	1.50	2.00	1.00	1.00	1.00	1.00	1.50	2.00	1.00	1.50	2.00	1.00	1.50	2.00
OPEX Costs	0.50	0.67	1.00	1.00	1.00	1.00	0.50	0.67	1.00	1.00	1.00	1.00	1.00	1.50	2.00	0.50	1.00	1.50
Technology Feasibility	0.50	0.67	1.00	1.00	1.50	2.00	0.50	0.67	1.00	0.50	0.67	1.00	1.00	1.00	1.00	0.67	1.00	2.00
Raw Material Supply	0.50	0.67	1.00	1.00	1.50	2.00	0.50	0.67	1.00	0.67	1.00	2.00	0.50	1.00	1.50	1.00	1.00	1.00

- Determining fuzzy synthesis values

Table 25. Fuzzy synthesis values of FR respondents

Criteria	Number of Fuzzy in Each Row			Fuzzy Synthesis Value (Si)		
	L	M	U	L	M	U
GHG Emission Reduction	7.00	9.50	12.00	0.14	0.25	0.41
CAPEX Costs	3.83	4.40	5.50	0.07	0.11	0.19
System Impact	5.50	7.67	10.00	0.11	0.20	0.34
OPEX Costs	4.50	5.83	7.50	0.09	0.15	0.26
Technology Feasibility	4.17	5.50	8.00	0.08	0.14	0.27
Raw Material Supply	4.17	5.83	8.50	0.08	0.15	0.29
Total	29.17	38.73	51.50			

- Determining the degree of possibility, defuzzification ordinate value, normalization value

Table 26. Degree of possibility values, defuzzification ordinate values, and respondent normalization values for FR

Criteria	Degree of Probability Mi>Mj						Degree of Probability (Mi)	Normalization
GHG Emission Reduction	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.26
CAPEX Costs	0.29	1.00	0.49	0.73	0.79	0.74	0.29	0.07
System Impact	0.81	1.00	1.00	1.00	1.00	1.00	0.81	0.21
OPEX Costs	0.56	1.00	0.76	1.00	1.00	1.00	0.56	0.15
Technology Feasibility	0.57	1.00	0.75	0.96	1.00	0.96	0.57	0.15
Raw Material Supply	0.62	1.00	0.80	1.00	1.00	1.00	0.62	0.16
							Total	1.00

Consistency Ratio (CR) value = 0.096

Since the CR value is < 0.1, the questionnaire for respondent comparison is declared valid or consistent.

Processing of HD Respondent Data

- Determining the priority comparison between criteria using the TFN scale

Table 27. Comparison of priorities between criteria using the TFN scale of HD respondents

Criteria	GHG Emission Reduction			CAPEX Costs			System Impact			OPEX Costs			Technology Feasibility			Raw Material Supply		
	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
GHG Emission Reduction	1.00	1.00	1.00	1.00	1.50	2.00	1.00	1.00	1.00	0.50	1.00	1.50	0.50	1.00	1.50	1.00	1.50	2.00
CAPEX Costs	0.50	0.67	1.00	1.00	1.00	1.00	0.50	0.67	1.00	1.00	1.00	1.00	0.50	0.67	1.00	1.00	1.50	2.00
System Impact	1.00	1.00	1.00	1.00	1.50	2.00	1.00	1.00	1.00	1.00	1.50	2.00	1.00	1.50	2.00	1.00	1.50	2.00
OPEX Costs	0.67	1.00	2.00	1.00	1.00	1.00	0.50	0.67	1.00	1.00	1.00	1.00	1.00	1.50	2.00	1.00	1.50	2.00
Technology Feasibility	0.67	1.00	2.00	1.00	1.50	2.00	0.50	0.67	1.00	0.50	0.67	1.00	1.00	1.00	1.00	1.00	1.50	2.00
Raw Material Supply	0.50	0.67	1.00	0.50	0.67	1.00	0.50	0.67	1.00	0.50	0.67	1.00	0.50	0.67	1.00	1.00	1.00	1.00

- Determining fuzzy synthesis values

Table 28. Fuzzy synthesis values of HD respondents

Criteria	Number of Fuzzy in Each Row			Fuzzy Synthesis Value (Si)		
	L	M	U	L	M	U
GHG Emission Reduction	5.00	7.00	9.00	0.10	0.19	0.31
CAPEX Costs	4.50	5.50	7.00	0.09	0.15	0.24
System Impact	6.00	8.00	10.00	0.12	0.21	0.35
OPEX Costs	5.17	6.67	9.00	0.10	0.18	0.31
Technology Feasibility	4.67	6.33	9.00	0.09	0.17	0.31
Raw Material Supply	3.50	4.33	6.00	0.07	0.11	0.21
Total	28.83	37.83	50.00			

- Determining the degree of possibility, defuzzification ordinate value, normalization value

Table 29. Degree of possibility value, defuzzification ordinate value, normalization value of HD respondents

Criteria	Degree of Probability Mi>Mj						Degree of Probability (Mi)	Normalization
GHG Emission Reduction	1.00	1.00	0.88	1.00	1.00	1.00	1.00	0.21
CAPEX Costs	0.78	1.00	0.65	0.82	0.87	1.00	0.65	0.14
System Impact	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.21
OPEX Costs	0.96	1.00	0.85	1.00	1.00	1.00	0.85	0.18
Technology Feasibility	0.92	1.00	0.81	0.96	1.00	1.00	0.81	0.17
Raw Material Supply	0.61	0.79	0.48	0.63	0.68	1.00	0.48	0.10
							Total	1.00

Consistency Ratio (CR) value = 0.085

Since the CR value is < 0.1, the questionnaire for respondent comparison is declared valid or consistent. The final results for each criterion are as follows.

Table 30. Final results of the weighting for each criterion

Responden	GHG Emission Reduction	CAPEX costs	Effects on the System	OPEX costs	Technology Feasibility	Raw Material Supply
ZA	0.072	0.007	0.059	0.007	0.031	0.011
AL	0.030	0.019	0.082	0.019	0.029	0.008
FS	0.034	0.023	0.036	0.028	0.029	0.017
UK	0.053	0.015	0.032	0.014	0.026	0.014
AA	0.076	0.007	0.026	0.007	0.022	0.011
FR	0.031	0.009	0.025	0.017	0.018	0.019
HD	0.007	0.004	0.007	0.006	0.006	0.003
Normalization	0.304	0.085	0.268	0.099	0.161	0.084
Rank	**1**	**5**	**2**	**4**	**3**	**6**

Based on the assessment, the greatest weight is given to the criteria of GHG emission reduction (30.4%), effects on the system (26.8%), technological feasibility (16.1%), OPEX costs (9.9%), CAPEX costs (8.5%), and raw material supply (8.4%).

The above assessment results show that experts prioritize projects that can have a direct impact on reducing greenhouse gas emissions and do not have a significant impact on the current system compared to the costs incurred. In general, cost is a fairly important factor or constraint in the selection of a project, but this study shows that this factor is not considered particularly important.

- Determining the degree of possibility, defuzzification ordinate value, normalization value

Table 31. Degree of possibility value, defuzzification ordinate value, normalization value of HD respondents

Criteria	Degree of Probability Mi>Mj						Degree of Probability (Mi)	Normalization
GHG Emission Reduction	1.00	1.00	0.88	1.00	1.00	1.00	1.00	0.21
CAPEX Costs	0.78	1.00	0.65	0.82	0.87	1.00	0.65	0.14
System Impact	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.21

OPEX Costs	0.96	1.00	0.85	1.00	1.00	1.00	0.85	0.18
Technology Feasibility	0.92	1.00	0.81	0.96	1.00	1.00	0.81	0.17
Raw Material Supply	0.61	0.79	0.48	0.63	0.68	1.00	0.48	0.10
							Total	1.00

Consistency Ratio (CR) value = 0.085
Since the CR value is < 0.1, the questionnaire for respondent comparison is declared valid or consistent The final results for each criterion are as follows

Table 32. Final results of the weighting for each criterion

Respondent	Greenhouse Gas Emission Reduction	CAPEX costs	Effects on the System	OPEX costs	Technology Feasibility	Raw Material Supply
ZA	0.072	0.007	0.059	0.007	0.031	0.011
AL	0.030	0.019	0.082	0.019	0.029	0.008
FS	0.034	0.023	0.036	0.028	0.029	0.017
UK	0.053	0.015	0.032	0.014	0.026	0.014
AA	0.076	0.007	0.026	0.007	0.022	0.011
FR	0.031	0.009	0.025	0.017	0.018	0.019
HD	0.007	0.004	0.007	0.006	0.006	0.003
Normalization	0.304	0.085	0.268	0.099	0.161	0.084
Rank	**1**	**5**	**2**	**4**	**3**	**6**

Based on the assessment, the greatest weight is given to the criteria of GHG emission reduction (30.4%), effects on the system (26.8%), technological feasibility (16.1%), OPEX costs (9.9%), CAPEX costs (8.5%), and raw material supply (8.4%).

The above assessment results show that experts prioritize projects that can have a direct impact on reducing greenhouse gas emissions and do not have a significant impact on the current system compared to the costs incurred. In general, cost is a fairly important factor or constraint in the selection of a project, but this study shows that this factor is not considered particularly important. Based on the assessment, the first priority project for reducing greenhouse gas emissions is the Biomass for Kiln – A9 project, while the lowest priority is the Hydrotreated Vegetable Oil (HVO) - A12 project.

The K_{ia} value can indicate the total contribution of all criteria, where the higher the K_{ia} value, the greater the total contribution of the alternative. Then K_{ib} can show that the alternative is not only superior in one criterion but also stable in other criteria, where the higher the K_{ib} value, the more consistent and stronger it is across all criteria. Meanwhile, the K_{ic} value shows how close the alternative is to the ideal solution, where the higher the K_{ic} value, the closer it is to the ideal solution. Based on the data for projects A9, A10, A1, and A7, they have relatively close values, so they can be considered for implementation, while projects A6 and A12 have values far below average, so they need to be evaluated further before they can be implemented.

The above results are also in line with the evaluation results of the consultant selected by the Company to evaluate project priorities, whereby the consultant recommended implementing the Biomass project to reduce greenhouse gas emissions.

Sensitivity Analysis Results

Sensitivity analysis was conducted to evaluate the extent of the impact of small changes in the weight of criteria according to the scenarios described in subsection 3.4 on the final K_i score. The results of the sensitivity analysis for all scenarios are as follows

- Scenario 1

Table 34 shows that the Biomass for Kiln project received the highest priority, while the Hydrotreated Vegetable Oil (HVO) project received the lowest priority. A 10% change in the weighting of the greenhouse gas emission reduction criterion had a significant impact on the priority ranking of the Biomass for Kiln project.

- Scenario 2

  Table 34 shows that the Biomass for Dryer project is given the highest priority, while the Hydrotreated Vegetable Oil (HVO) project is given the lowest priority. On the other hand, the Biomass for Kiln project is given the fourth priority. Based on the assessment, the Biomass for Kiln project has a fairly large CAPEX cost, resulting in different outcomes compared to the baseline and Scenario 1. This scenario sufficiently illustrates that CAPEX costs are a fairly sensitive factor for the Biomass for Kiln project
- Scenario 3

  Table 34 shows that the Biomass for Kiln project received the highest priority, while the Heat Recovery from Slag Granulation project received the lowest priority. A 10% change in the weighting of the criteria for the effect on the system had a significant impact on the priority ranking of the Biomass for Kiln project.
- Scenario 4

  Table 34 shows that the Biomass for Dryer project has the highest priority, while the Hydrotreated Vegetable Oil (HVO) project has the lowest priority. On the other hand, the Biomass for Kiln project has the second highest priority. Based on the assessment, the Biomass for Kiln project has considerable OPEX costs, but this does not have a significant impact on the change in project priority in this scenario.
- Scenario 5

  Table 34 shows that the Biomass for Kiln project received the highest priority, while the Heat Recovery from Slag Granulation project received the lowest priority. A 10% change in the weighting of the technological feasibility criterion had a significant impact on the priority ranking of the Biomass for Kiln project.
- Scenario 6

  Table 34 shows that the Electric Air Heater for Converter project has the highest priority, while the Hydrotreated Vegetable Oil (HVO) project has the lowest priority. On the other hand, the Biomass for Kiln project has the third highest priority. Based on the assessment, the Biomass for Kiln project has a raw material supply that is quite far from the location. The Biomass for Kiln project is quite sensitive to changes in raw material supply criteria, but not too significantly.

The sensitivity analysis results for all scenarios indicate that the Biomass for Kiln project is quite robust in facing most scenarios. The CAPEX cost criterion has a significant impact if there is a 10% increase in weight. As for the OPEX cost and raw material supply criteria, although the priority of the Biomass for Kiln project decreases, it does not have a significant impact.

Table 34. Sensitivity analysis results for all scenarios

Project Alternative	***Code***	***Baseline***	**Scenario**					
			1	2	3	4	5	6
Biomass for Kiln	A9	1	1	4	1	2	1	3
Biomass for Dryer	A10	2	2	1	2	1	2	5
Electric Air Heater for Converter	A1	3	3	2	3	3	3	1
Electric Boilers	A7	4	4	3	4	4	4	2
Conveyor WOS	A2	5	5	5	5	5	5	4
Ore Dewatering	A5	6	7	6	6	6	6	6
Heat Recovery from Kiln	A3	7	6	7	7	7	7	7
Electric Vehicle	A8	8	8	8	8	8	8	8
Biomass for Reductant	A11	9	9	9	9	9	9	9
Heat Recovery from Electric Furnace	A4	10	10	10	10	10	10	10
Heat Recovery from Slag Granulation	A6	11	11	11	12	11	12	11
Hydrotreated Vegetable Oil (HVO)	A12	12	12	12	11	12	11	12

CONCLUSION

Expert assessments via fuzzy-AHP ranked project criteria by priority as greenhouse gas emission reduction (30.4%), system impact (26.8%), technological feasibility (16.1%), OPEX costs (9.9%), CAPEX costs (8.5%), and raw material supply (8.4%), revealing that experts prioritize direct emission reductions and minimal system disruption over costs—indicating the company's strong commitment to decarbonization despite cost constraints typically being significant. The hybrid fuzzy-AHP and CoCoSo analysis identified the Biomass for Kiln project as top priority and Hydrotreated Vegetable Oil (HVO) as lowest, aligning with independent consultant recommendations, while sensitivity analysis confirmed the Biomass project's robustness across scenarios (except a notable CAPEX weight increase). For future research, incorporating stakeholder-imposed constraints (e.g., budgets) and comparing the method against alternatives would enhance realism, optimize resource allocation, and better reflect field conditions in MCDM applications for sustainable project selection.

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