**SINERGI** Vol. 28, No. 2, June 2024: 305-318
http://publikasi.mercubuana.ac.id/index.php/sinergi
http://doi.org/10.22441/sinergi.2024.2.010

# Civil site selection of the gas engine power plant by value-based decision multicriteria in Kupang, Indonesia

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***Abstract***

*Site selection is one of the main activities in technical system planning to achieve the best design and location of the power plant. Improper site selection methods tend to increase the construction cost, create difficulties in securing primary energy sources, and cause inefficient electricity distribution. The earlier civil site selection process using the scoring method adopted by several utility companies still had some disadvantages that required improvement. This study aimed to propose and test a civil site selection method based on the economic Multi-Criteria Decision-Making (MCDM) that combines Geographical Information System (GIS), Analytical Hierarchy Process (AHP) and Value Based Decision (VBD) simultaneously and based on the collaborative assessment of several engineers. The study investigated Kupang GEPP 40 MW with five alternative locations using the Expert Choice 11 tool to determine the weight of the criteria, alternative locations rating, and the weight of the cost estimate based on GIS data.* The analysis revealed that only alternative 1 and alternative 5 are considered feasible. Alternative 5, Panaf, emerges as the most favorable site for Kupang GEPP *with a value of 7.087. Further research has been suggested to include more detailed data for site selection.*



***Keywords:***
*Analytical Hierarchy Process;*
*Geographical Information System;*
*Multicriteria Decision Making;*
*Site Selection;*
*Value-Based Decision;*

***Article History:***
*Received: August 27, 2023*
*Revised: January 8, 2024*
*Accepted: January 12, 2024*
*Published: June 2, 2024*

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## INTRODUCTION

Site selection is a method with a depth of analysis and uses several criteria to determine the best location [1]. In the Indonesian energy sector context, site selection of power plants aims to get the best location according to the electricity master planning, namely the Indonesian National Electricity Supply Business Plan (*Rencana Umum Penyediaan Tenaga Listrik* or RUPTL). RUPTL was established by Indonesian Electricity State-Owned Company (PT PLN) and authorized by the Indonesian Energy and Mineral Resources Ministry to guide the establishment of electricity infrastructure for the following ten years. RUPTL covers upstream activities such as technology selection, generating capacity, interconnection points, and power plant operation mode (peak load, load follower, or base load).

Technical and operational planning must be conducted before the construction of the power plant project. Technical planning involves a feasibility study that discusses site selection, land availability, technology-related issues, and the financial analysis of the project. Operational planning aims to minimize power plant maintenance costs and maximize reliability and efficiency [2].

Site selection is one of the main activities in technical system planning. Improper site selection tends to increase construction costs, create difficulties in securing primary energy sources, and cause inefficient electricity distribution. Consequently, the appropriate site selection technique is needed to identify the best location for the power plant and to support the decision-maker in making the finest option.

Table 1. PLN Criteria Rating of Site Selection

| Criteria | Rating (%) |
|---|---|
| Topography | 10 |
| Sea Condition/Sea Depth | 10 |
| Cooling System/Water Availability | 10 |
| Reclamation | 15 |
| Road/Bridge Access | 10 |
| River/Road Reroute | 15 |
| Type of Topsoil | 10 |
| Distance of Load Center | 5 |
| Distance of Substation | 5 |
| Site Development | 10 |
| Total | 100 |

PLN has established a site selection guideline by assessing several criteria, as shown in Table 1.

Based on the site selection guideline, all criteria were evaluated and scored based on the actual conditions of each location. Each criterion was given a score of one, five, or ten points, with 10 being the best condition, 5 being the moderate condition, and 1 being the worst. For example, a topographic condition with flat ground earned 10-point mark, while land with height variations less than 20 m received 5 points, and land with height variations more than 20 m got 1-point mark. Site selection had to be conducted in at least five alternative locations.

The current site selection method has a weakness where an assessment of locations with nearly identical land characteristics eventually results in the same points. For example, hilly land conditions with 5 m and 8 m height yielded the same 5-point score. The direct scoring technique also has intrinsic drawbacks that frequently result in a decision-making process that is unacceptable to stakeholders due to the inaccuracy with which considerations like costs, impacts, and benefits are rarely captured [3]. Hence, the current site selection method needs to be improved.

As per the RUPTL, the electricity grid relies on various thermal power plants, including gas-fired ones, which are categorized into gas turbines or gas engine power plants (GEPP). GEPPs are power generation systems whose engine operation uses a gas engine with water as a cooling medium [4].

The site selection process for GEPP involves assessing local primary energy source availability, ease of procurement, proximity to load centers and transmission lines, regional demand, topography, and considerations like technical, environmental, and social constraints. PLN's project agenda includes constructing the Kupang GEPP, designed at a 40 MW capacity, to cater to the electricity demands in East Nusa Tenggara Province's Kupang area, Indonesia.

Table 2. The Site Selection of Previous Research

| No. | Title | Year | Author | Method |
|---|---|---|---|---|
| 1 | GIS-Based Modeling for Selection of Dam Sites in the Kurdistan Region, Iraq [5] | 2020 | Arsalan Ahmed Othman, *et al*. | GIS |
| 2 | AHP-TOPSIS Inspired Shopping Mall Site Selection Problem with Fuzzy Data | 2020 | Neha Ghorui*, et al.* | AHP and TOPSIS |
| 3 | Optimal site selection for solar photovoltaic (PV) power plants using GIS and AHP: A case study of Malatya Province, Turkey [6] | 2020 | H. Ebru Colak, *et al.* | GIS and AHP |
| 4 | Geographical information systems-based analysis of site selection for wind power plants in Kozlu District by multi-criteria decision analysis method [7] | 2020 | Deniz Arca and Hulya Keskin Citiroglu | GIS and MCDA |
| 5 | Dry Port Terminal Location Selection by Applying the Hybrid Grey MCDM Model [8] | 2020 | Snežana Tadic, *et al.* | Delphi, AHP, CODAS |
| 6 | A Multi-Criteria Approach for the Selection of Wave Energy Converter/location | 2020 | Bahareh Kamranzad and Sanaz Hadadpour | MCA |
| 7 | Optimal Location and Size of A Grid-Independent Solar/Hydrogen System for Rural Areas Using an Efficient Heuristic Approach [9] | 2020 | Ge Zhang, *et.al.* | GIS, HIS, LCC |
| 8 | Hospital site selection using fuzzy EDAS method: case study application for districts of İstanbul [10] | 2021 | Melike Yilmaz and Tankut Atan | Fuzzy EDAS |
| 9 | Location Optimization of Wind Plants Using DEA and Fuzzy Multi-Criteria Decision Making: A Case Study in Vietnam [11] | 2021 | Chia-Nan Wang, *et al.* | Fuzzy WASPAS and Fuzzy AHP |
| 10 | A Multicriteria Decision-Making Model for the Selection of Suitable Renewable Energy Sources [12] | 2021 | Chia-Nan Wang, *et al.* | AHP and WASPAS |
| 11 | Comparison of GIS-based AHP and fuzzy AHP methods for hospital site selection: a case study for Prayagraj City, India [13] | 2022 | Tripathi, A.K., *et al.* | GIS Fuzzy AHP and GIS AHP |
| 12 | A decision framework for tidal current power plant site selection based on GIS-MCDM: A case study in China [14] | 2022 | Meng Shao, *et al.* | FGAHP, CRITIC, and VIKOR |
| 13 | Optimal site selection for a solar power plant in Iran via the Analytic Hierarchy Process (AHP) [15] | 2023 | Pedram Ahadi, *et al*. | AHP |

This study proposes and evaluates another site selection alternative method by combining the Analytical Hierarchy Process (AHP) and Value-Based Decision (VBD) using a Geographical Information System (GIS) simultaneously to obtain more optimal site selection results according to the function and cost of each alternative location for the Kupang GEPP project.

## MATERIAL AND METHODS

### Related Works

Several site selection studies have been conducted using various methods, such as the conventional scoring method, GIS, Multiple Criteria Decision Making (MDCM), AHP, and other methods.

MCDM technique consists of Multiple Attributes Decision Making (MADM), including multiple attribute utility theory methods such as TOPSIS, Fuzzy TOPSIS, outranking methods such as ELECTRE, PROMETHEE, and hierarchy methods such as AHP, ANP, Fuzzy AHP, and consists of Multiple Objectives Decision Making (MODM) [16]. The MCDM method helps rank and assess the decision-making process with known limitations [17].

AHP is a decision-making method to produce optimal decisions from several alternatives and criteria [18, 19, 20, 21, 22]. GIS is known for its ability to handle huge geographical information from a wide range of resources [23]. At the same time, VBD multi-criteria is a method used to select options by evaluating and weighing the economic theory that might define variables in making choices [24]. The previous site selection study used either all of the strategies mentioned above individually or in combination to implement each other.

The dam site selection in Iraq was done using GIS analysis [5]. The Istanbul hospital site was chosen using the evaluation based on the Distance from Average Solution (EDAS) approach [10]. The proposed locations of solar power plants in Iran and Turkey were evaluated using AHP [15] and AHP combined with GIS [6]. GIS was combined with [7][25] and combined with PROMETHEE to determine the location of the wind power plant [26].

MCDM with FGAHP, CRITIC, and VIKOR was utilized to assess China's potential sites for tidal current power plants [14]. Combined Fuzzy AHP and Fuzzy WASPAS were used for wind plant location selection in Vietnam [11]. AHP was applied with the Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS) for choosing a shopping mall location [27]. AHP could also be combined with the Weighted Aggregates Sum Product Assessment (WASPAS) method to decide on suitable renewable energy resources in Vietnam [12]. A list of previous studies using MCDM methods is summarized in Table 2. Various criteria were employed to rank site selection methods. For power plant site selection, topographic factors [28] and fuel transportation [29] were considered as civil criteria. Meanwhile, in generator location selection, multiple criteria, such as surface area, altitude, cooling needs, and access, were established [1].

### Methodology

This research aims to merge quantitative methods and qualitative assessments. No method is inherently superior, and its effectiveness depends on the context.

Both approaches can synergize and complement each other effectively [30], utilizing a combined GIS, AHP, and VBD approach. VBD is utilized in this research as a decision-making procedure according to the flowchart model, as indicated in Figure 1. By using the AHP that has three fundamental concepts of decomposition, comparative decision-making, and logical coherence [19], which method is fast, easy, and considered rational [18]. This research conducts a decision-making procedure using the hierarchy structure indicated in Figure 2.

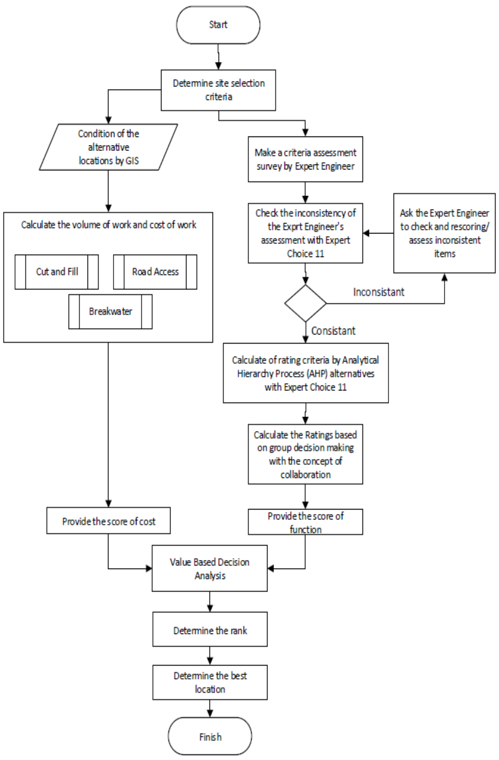
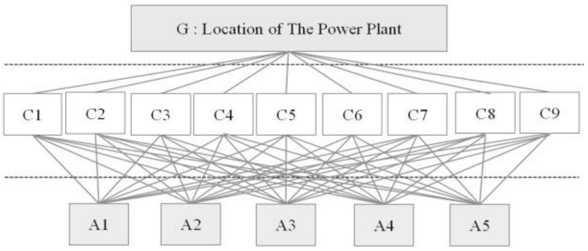



Figure 1. AHP-VBD Multicriteria Flowchart




**Note :**
G is Goal.
C is Criteria.
C1 : Topography, C2 : Sea Condition, C3 : Cooling System, C4 : Reclamation, C5 : Road/Bridge Access, C6 : River/Road Rerouting, C7 : Type of Topsoil, C8 : Distance of Load Center, C9 : Distance of Substation
A is Alternatives.
A1 : Alternative 1 – Teres, A2 : Alternative 2 – Tasikona 1, A3 : Alternative 3 – Tasikona 2, A4 : Alternative 4 – Tasikona 3, and A5 : Alternative 5 – Panaf

Figure 2. Hierarchy of AHP

There are nine criteria for selecting a site based on civil consideration: topography, sea condition, cooling system, reclamation, road/bridge access, river/road rerouting, type of topsoil, the distance of load center, and distance from the substation.

VBD is a method to evaluate system function value with the lowest life cycle cost by comparing function normalization with cost normalization [31][32]. The function normalization is obtained from AHP analysis, while the cost normalization is acquired from cost analysis based on GIS information.

## Case Study Analysis

The GEPP was selected as the adaptable thermal power solution to fulfill Kupang, Indonesia's electricity requirements in alignment with the RUPTL. Estimations based on peak load electricity demand in the Kupang region and Timor Island grid system indicated a need for 40 MW of electricity. The utilization of gas engines aimed to secure a highly efficient power plant, ensuring a relatively sustained electricity capacity output during significant overhauls, given the engine capacity was not as extensive as that of gas turbine types. The site selection process for the GEPP project aimed to determine which sites would be the best for these power plants.

## Alternative Locations

Kupang GEPP had five alternative locations. Alternative 1: Teres Beach (South Amarasi District, Kupang Regency), Alternative 2: Tasikona 1, (Nekamese District, Kupang Regency), Alternative 3: Tasikona 2 (Tasikona, Nekamese District, Kupang Regency), Alternative 4: Tasikona 3 (Tasikona, Nekamese District, Kupang Regency), and Alternative 5: Panaf (West Kupang District, Kupang Regency). The description of five locations is described in Table 3.

Table 3. The Description of Alternatives Location

| Alternatives | Coordinates | Elevation | Material Surface | Sea Access for Gas Supply | Road Access | Distance of Load Center | Distance of Substation |
|---|---|---|---|---|---|---|---|
| A1 : Teres | 10°17'53.43" S and 123°54'49.27" E | Variative 5-11 m | Soil and rock | Hard, influenced by west and east wind season | Required 6.5 km of new pavement road | ±32 km | 20 km to Naibonat Substation, 50 km to Bolok Substation |
| A2 : Tasikona 1 | 10°21'15.77" S and 123°37'58.31" E | Variative 15-44 m | Rock | Hard, influenced by the east wind season | Required 9.6 km of new pavement road | ±19 km | 31 km to Naibonat Substation, 16 km to Maulafa Substation, 20 km to Bolok Substation |
| A3 : Tasikona 2 | 10°22'8.24"S and 123°36'41.49" E | Variative 12-50 m | Soil and rock | Hard, influenced by the east wind season, required a breakwater | Required 7.1 km of new pavement road | ±20 km | 31 km to Naibonat Substation, 16 km to Maulafa Substation, 20 km to Bolok Substation |
| A4 : Tasikona 3 | 10°21'18.18" S and 123°37'38.75" E | Variative 5-41 m | Soil and rock | Hard, influenced by the west wind season, required a breakwater | Required 8.8 km of new pavement road | ±19 km | 31 km to Naibonat Substation, 16 km to Maulafa Substation, 20 km to Bolok Substation |
| A5 : Panaf | 10°21'3.86"S and 123°27'21.79" E | Variative 4-17 m | Soil and rock | Moderate, influenced by east wind season, no need breakwater | Required 3.4 km of new pavement road | ±24 km | 23 km to Maulafa Substation, 16 km to Bolok Substation |

Table 4. The AHP Expert Judgement of Alternatives Location

| No | Pairwise Comparison | Score by Engineers | | | | | | Analysis | | Score of Collaboration |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | π | Std | |
| 1 | C1 to C2 | 1 | 2 | 2 | 1 | 1 | 1 | 1.260 | 0.517 | 1 |
| 2 | C1 to C3 | 2 | 2 | 2 | 1 | 1 | 4 | 1.782 | 1.096 | 2 |
| 3 | C1 to C4 | 1/3 | 2 | 4 | 3 | 1 | 3 | 1.699 | 1.378 | 2 |
| 4 | C1 to C5 | 3 | 1/2 | 1/2 | 2 | 1 | 4 | 1.349 | 1.438 | 1 |
| 5 | C1 to C6 | 3 | 1/2 | 1 | 2 | 1 | 1 | 1.201 | 0.918 | 1 |
| 6 | C1 to C7 | 1 | 1 | 2 | 1 | 1 | 1 | 1.123 | 0.409 | 1 |
| 7 | C1 to C8 | 5 | 3 | 1 | 1 | 1 | 1 | 1.571 | 1.674 | 2 |
| 8 | C1 to C9 | 7 | 3 | 1 | 1 | 1 | 1 | 1.662 | 2.423 | 2 |
| 9 | C2 to C3 | 1 | 1 | 1 | 2 | 1 | 3 | 1.349 | 0.837 | 1 |
| 10 | C2 to C4 | 1/3 | 1 | 3 | 1 | 1 | 3 | 1.201 | 1.149 | 1 |
| 11 | C2 to C5 | 3 | 1/3 | 1 | 2 | 1 | 3 | 1.348 | 1.124 | 1 |
| 12 | C2 to C6 | 3 | 1/3 | 1 | 1 | 1 | ½ | 1.000 | 1.012 | 1 |
| 13 | C2 to C7 | 1 | 1/2 | 1 | 1 | 1 | 1/3 | 0.871 | 0.224 | 1 |
| 14 | C2 to C8 | 5 | 2 | 3 | 1 | 1 | 2 | 1.979 | 1.506 | 2 |
| 15 | C2 to C9 | 7 | 2 | 1 | 1 | 1 | 2 | 1.743 | 2.339 | 2 |
| 16 | C3 to C4 | 1/3 | 1 | 2 | 1 | 1 | 1/3 | 0.779 | 0.612 | 1 |
| 17 | C3 to C5 | 3 | 1/3 | 1 | 1 | 1 | 2 | 1.123 | 0.953 | 1 |
| 18 | C3 to C6 | 3 | 1/3 | 1 | 1 | 1 | 2 | 1.123 | 0.953 | 1 |
| 19 | C3 to C7 | 1 | 1/2 | 1 | 1 | 1 | 1/5 | 0.871 | 0.224 | 1 |
| 20 | C3 to C8 | 5 | 2 | 3 | 1 | 1 | 1/3 | 1.975 | 1.674 | 2 |
| 21 | C3 to C9 | 7 | 2 | 1/3 | 1 | 1 | 1/3 | 1.361 | 2.713 | 1 |
| 22 | C4 to C5 | 3 | 1/3 | 1/3 | 1/3 | 1 | 2 | 0.778 | 1.111 | 1 |
| 23 | C4 to C6 | 6 | 1/3 | 1/2 | 1/3 | 1 | 6 | 1.123 | 2.830 | 1 |
| 24 | C4 to C7 | 1/3 | 1/2 | 1/2 | 1/3 | 1 | ¼ | 0.489 | 0.274 | 1/2 |
| 25 | C4 to C8 | 7 | 2 | 2 | 1/3 | 1 | 1 | 1.563 | 2.632 | 2 |
| 26 | C4 to C9 | 7 | 2 | 1/3 | 1/3 | 1 | 1 | 1.077 | 2.552 | 1 |
| 27 | C5 to C6 | 2 | 1 | 2 | 1 | 1 | ½ | 1.320 | 0.548 | 1 |
| 28 | C5 to C7 | 1/5 | 2 | 1 | 1 | 1 | 1/5 | 0.833 | 0.639 | 1 |
| 29 | C5 to C8 | 7 | 4 | 4 | 1 | 1 | 1/3 | 2.570 | 2.510 | 3 |
| 30 | C5 to C9 | 7 | 4 | 2 | 1 | 1 | 1/3 | 2.237 | 2.550 | 2 |
| 31 | C6 to C7 | 1/5 | 2 | 1 | 1 | 1 | 1/5 | 0.833 | 0.639 | 1 |
| 32 | C6 to C8 | 7 | 4 | 3 | 1 | 1 | 2 | 2.350 | 2.281 | 2 |
| 33 | C6 to C9 | 7 | 4 | 1/2 | 1 | 1 | 2 | 1.743 | 2.499 | 2 |
| 34 | C7 to C8 | 7 | 3 | 3 | 1 | 1 | 2 | 2.240 | 2.229 | 2 |
| 35 | C7 to C9 | 7 | 3 | 1 | 1 | 1 | 3 | 1.995 | 2.339 | 2 |
| 36 | C8 to C9 | 1 | 1 | 1/4 | 1 | 1 | 2 | 0.891 | 0.558 | 1 |
| Consistency Index (CI) | | 0.08 | 0.01 | 0.09 | 0.07 | 0.00 | 0.13 | | | |

Note :
1) Cx and Cy are Criteria
2) n is a score based on a comparison between Criteria;
3) Cx to Cy = n means Cx is n times more important than Cy
4) Cx to Cy = 1/n means Cy is n times more important than Cx
5) Geometric Mean (π) is calculated based on weighting score by Engineers

### Criteria Assessments

Location conditions [1, 33, 34, 35], as well as government policies and regulations, environmental quality, market opportunities, and connections to existing electricity networks [31], represent pivotal site selection criteria extensively utilized in the thermal power plant site selection process. Additional considerations include factors such as conflict with resource availability, spatial content, technology, and growth potential.

Experts carried out criteria assessments by conducting paired assessments of each criterion using an intensity scale from 1 to 9.

Intensity scales are established with markers ranging from 1 to 9. Intensity scales of 1, 3, 5, 7, 9 denote equal, moderately important, strong, extremely strong, and absolute importance, respectively. Furthermore, intermediate values are represented on scales 2, 4, 6, and 8. Meanwhile, the reciprocal for scales $x_i$ and $x_j$ is $r_{ij} = 1/r_{ji}$ [36].

## RESULTS AND DISCUSSIONS

### Multicriteria Scoring using AHP

The pairwise comparison assessment among all alternative locations was carried out by the civil engineers of the Kupang GEPP project because the assessment needed to be carried out by engineers who were familiar with the actual conditions of each alternative location.

The outcome of expert judgment derived from the questionnaire is illustrated in Table 4. Indeed, each engineer had different feedback and perspectives for weighting the criteria assessment.

Table 5. Rating of Alternative Locations by Engineers

| Alternatives | Rating by Engineers | | | | | | Rating Collaboration |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | |
| A1 : Teres | 0.228 | 0.210 | 0.200 | 0.202 | 0.195 | 0.206 | 0.207 |
| A2 : Tasikona 1 | 0.136 | 0.143 | 0.138 | 0.139 | 0.147 | 0.139 | 0.141 |
| A3 : Tasikona 2 | 0.179 | 0.188 | 0.193 | 0.185 | 0.185 | 0.178 | 0.189 |
| A4 : Tasikona 3 | 0.191 | 0.177 | 0.176 | 0.181 | 0.183 | 0.203 | 0.178 |
| A5 : Panaf | 0.266 | 0.282 | 0.293 | 0.294 | 0.291 | 0.274 | 0.285 |
| Total Rating | 1.000 | 1.000 | 1.000 | 1.001 | 1.001 | 1.000 | 1.000 |
| CI | 0.06 | 0.08 | 0.06 | 0.05 | 0.01 | 0.07 | 0.02 |

Table 6. Rating of Criteria by Engineers

| Criteria | Rating by Engineers | | | | | | Rating of Collaboration |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | |
| C1 : Topography | 0.141 | 0.130 | 0.167 | 0.138 | 0.111 | 0.143 | 0.146 |
| C2 : Sea Condition | 0.128 | 0.074 | 0.126 | 0.125 | 0.111 | 0.131 | 0.123 |
| C3 : Cooling System | 0.121 | 0.074 | 0.096 | 0.120 | 0.111 | 0.054 | 0.107 |
| C4 : Reclamation | 0.228 | 0.074 | 0.061 | 0.069 | 0.111 | 0.096 | 0.105 |
| C5 : Road/Bridge Access | 0.069 | 0.216 | 0.130 | 0.103 | 0.111 | 0.035 | 0.130 |
| C6 : River/Road Reroute | 0.056 | 0.216 | 0.117 | 0.109 | 0.111 | 0.104 | 0.134 |
| C7 : Type of Topsoil | 0.218 | 0.130 | 0.115 | 0.133 | 0.111 | 0.254 | 0.117 |
| C8 : Distance of Load Center | 0.020 | 0.043 | 0.038 | 0.084 | 0.111 | 0.100 | 0.065 |
| C9 : Distance of Substation | 0.017 | 0.043 | 0.149 | 0.119 | 0.111 | 0.083 | 0.073 |
| Total Rating | 0.998 | 1.000 | 0.999 | 1.000 | 0.999 | 1.000 | 1.000 |
| CI | 0.09 | 0.06 | 0.08 | 0.07 | 0.00 | 0.10 | 0.02 |

Table 7. Rating of Alternatives Per Criteria

| Alternatives | Rating | | | | | | | | | Fs |
|---|---|---|---|---|---|---|---|---|---|---|
| | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | |
| A1 : Teres | 0.322 | 0.047 | 0.376 | 0.200 | 0.152 | 0.200 | 0.273 | 0.067 | 0.067 | 0.189 |
| A2 : Tasikona 1 | 0.089 | 0.075 | 0.074 | 0.200 | 0.054 | 0.200 | 0.091 | 0.202 | 0.202 | 0.132 |
| A3 : Tasikona 2 | 0.416 | 0.100 | 0.126 | 0.200 | 0.146 | 0.200 | 0.091 | 0.190 | 0.190 | 0.184 |
| A4 : Tasikona 3 | 0.038 | 0.287 | 0.065 | 0.200 | 0.083 | 0.200 | 0.273 | 0.202 | 0.202 | 0.172 |
| A5 : Panaf | 0.135 | 0.490 | 0.358 | 0.200 | 0.565 | 0.200 | 0.273 | 0.339 | 0.339 | 0.322 |
| Total Rating | 1.000 | 1.000 | 0.999 | 1.000 | 1.000 | 1.000 | 1.001 | 1.000 | 1.000 | 1.000 |
| CI | 0.07 | 0.07 | 0.04 | 0.00 | 0.03 | 0.00 | 0.00 | 0.02 | 0.02 | |

Note :
C1 = Topography
C2 = Sea Condition
C3 = Cooling System
C4 = Reclamation
C5 = Road/Bridge Access
C6 = River/Road Reroute
C7= Type of Topsoil
C8 = Distance of Load Center
C9 = Distance of Substation

Considering the evaluation outcome displayed in Table 4, the sixth engineer had a scoring inconsistency with the Consistency Index (CI) = 0.13. It was higher than the required value, for which CI should have a maximum score of 0.1. Therefore, it should be checked by using Expert Choice software. With this method, the first inconsistency was found in the pairwise comparison between C4 and C6, and the second inconsistency was found in the pairwise comparison between C3 and C6.

The sixth engineer reassessed the pairwise comparison between C4 and C6 with a change from score 6 to 3 so that CI < 0.1 was obtained. When decision-making in an organization has significantly different assessment scores among all experts, the AHP literature usually uses the weighted geometric mean method (π) [37][38].

After the reassessment of Table 4 was conducted, the weighted score for each location and criterion was analyzed using Expert Choice software.

The rating of each alternative location and criterion are indicated in Table 5 and Table 6. Using the geometrical mean, the collaboration score was obtained from pairwise comparisons of each rating criteria score.

## Cost Estimation based on GIS

The results of the site selection process are significantly affected by cost considerations [39]. At the initial site selection stage, the estimated cost accuracy is ± 50% of the actual cost [40]. The MCDM technique was able to estimate the lowest construction costs during the early stage of the project in Libya [41].

Cost estimation in this study only estimates the civil project cost. The civil cost estimation in this research was based on a desk study. The civil cost estimation was obtained by calculating the unit price analysis of several items or utilizing historical data of other similar projects.

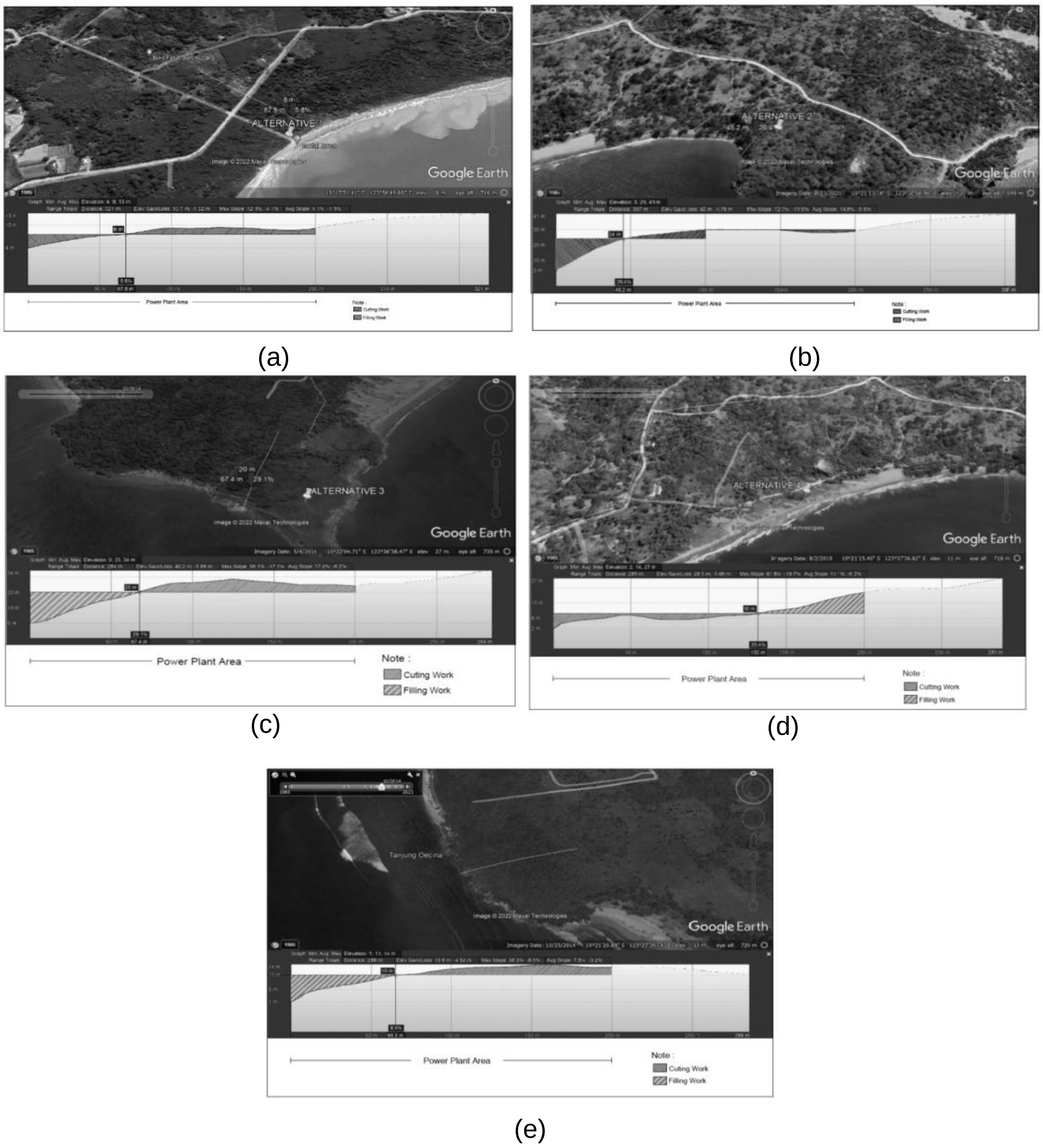



Figure 3. Elevation of (a) Alternative 1 – Teres; (b) Alternative 2 – Tasikona 1; (c) Alternative 3 – Tasikona 2; (d) Alternative 4 – Tasikona 3; (e) Alternative 5 – Panaf

A linear regression technique was used to evaluate historical data from previous projects to determine the relationship between costs and the Construction Cost Index. The Kupang Regency's 2021 Construction Cost Index, with a value of 88.75, was utilized to determine the Kupang GEPP's expected expenses on several items. GIS data, encompassing site conditions like location, surrounding area status, and topography, along with factors such as wave height and substation proximity, were leveraged for computing the civil cost estimate.

The rating assessment score of all alternatives based on each criterion is shown in Table 7, which is obtained from the number of multiplications between the alternative location rating in Table 5 and the criteria rating in Table 6 for each alternative location. From the results of the AHP, as seen in Table 7, it was recognized that different engineers would have different judgments during the site selection assessment. However, the outcome was identical, alternative 5 (Panaf) was the first-rank alternative, and alternative 1 (Teres) came in second place The civil cost estimate analyzed in this study consisted of the cost of land acquisition, power plant structure, cut and fill work, road access, cooling system, and breakwater cost. The cost calculation was conducted through financial modeling supported by a GIS application.

Table 8. Cost of Cut and Fill Work

| Alternatives | Cost (million IDR) | | Total Cost (million IDR) |
|---|---|---|---|
| | Cut | Fill | Cut and Fill |
| A1 : Teres | 22,967 | 4,615 | 27,583 |
| A2 : Tasikona 1 | 8,565 | 9,281 | 17,847 |
| A3 : Tasikona 2 | 35,168 | 12,608 | 47,776 |
| A4 : Tasikona 3 | 20,442 | 7,339 | 27,782 |
| A5 : Panaf | 29,352 | 1,366 | 30,718 |

## Land Acquisitions Cost

Based on the Indonesian Sales Value of Tax Objects or Nilai Jual Objek Pajak (NJOP) for Kupang Regency in 2019, all five potential locations had the same land price, which was around IDR 14,000.00 - 27,000.00 per $m^2$.

Therefore, multiplying the land price by the GEPP area at each location yielded land acquisition costs for Kupang GEPP, ranging roughly between IDR 700 and 1,350 million.

## Power Plant Structures Cost

The construction cost of the upper structure and piling work, assuming that the hard soil on each location was at 10 meters depth, was around IDR 112 billion.

The power plant's structural costs encompassed site preparation, including drainage, fencing, plant roads, paving, and site finishing, alongside main equipment buildings like GEPP foundations, transformer foundations, Balance of Plant (BOP) equipment and buildings, and additional buildings and facilities such as administration building and electrical facilities.

However, due to the site-specific nature of expenses, costs for land acquisition, cut and fill or site development work, access roads from plant roads to existing public roads, the cooling system, and breakwater were separately computed. Despite the similarity in power plant buildings across all locations, the investment cost for the power plant structure among the five alternative sites was assumed to be uniform.

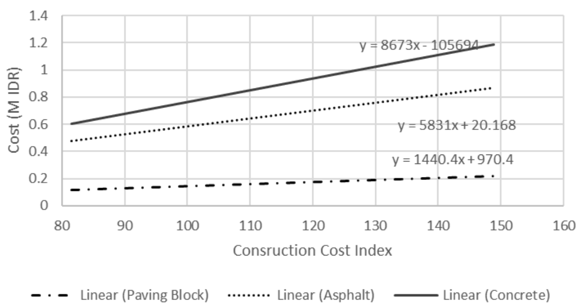



Figure 4. Access Road Work Estimation

Table 9. Access Road Cost

| Alternatives | Length (km) | Cost (million IDR) |
|---|---|---|
| A1 : Teres | 6.5 | 26,442 |
| A2 : Tasikona 1 | 9.6 | 39,053 |
| A3 : Tasikona 2 | 7.1 | 28,883 |
| A4 : Tasikona 3 | 8.8 | 35,799 |
| A5 : Panaf | 3.4 | 13,831 |

## Cut and Fill Works Cost

Based on the topographic condition of each location, as shown in Figure 3, the cut and fill volume could be estimated. Assuming that the required area of each location is 5 hectares, the estimated cut and fill cost for all proposed locations is indicated in Table 8.

## Cooling System Cost

Gas-fired power plants, including gas engines, require a cooling system that can be a once-through, recirculating, or dry cooling system. The cooling system requirements depend on four main parameters: withdrawal rate, consumption rate, internal plant usage, and discharged water [42]. The cooling system cost calculation is determined by comparing technology type and parameters [43].

For a thermal power plant, the estimated capital cost for once through the system was 19 USD per kWh and around 28 USD per kWh if a cooling tower was utilized [44]

A global company in smart technologies and lifecycle solutions for the marine and energy markets indicated that water consumption estimation for the GEPP was around 0.006 $m^3$/MWh, while Gas Engine Combined Cycle (GECC) with a cooling tower required water consumption of around 0.41 $m^3$/MWh, GECC with dry cooling system water requirements was 0.03 $m^3$/MWh, and water consumption for gas turbine combined cycle was around 0.78 $m^3$/MWh. Hence, the water consumption for Kupang GEPP, with 40 MW capacity as a Peaker power plant, was approximately 0.24 $m^3$ per hour.

Given the relatively low water consumption of the Kupang GEPP, the associated costs were presumed to be part of the power plant structure expenses. This included the cooling system costs, which remained consistent across all alternative locations.

## Access Road Cost

By analyzing historical data from previous projects and conducting desk studies, Figure 4 illustrates the estimated costs for three types of access roads: paving blocks, asphalt, and concrete.

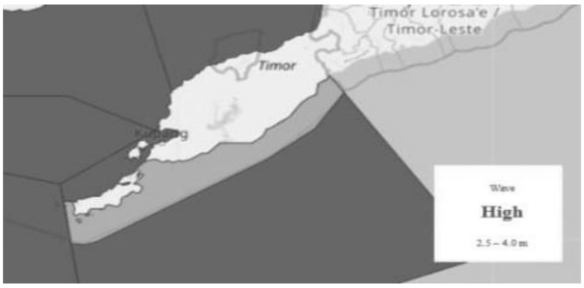



Figure 5. Southern Seas of Kupang Regency

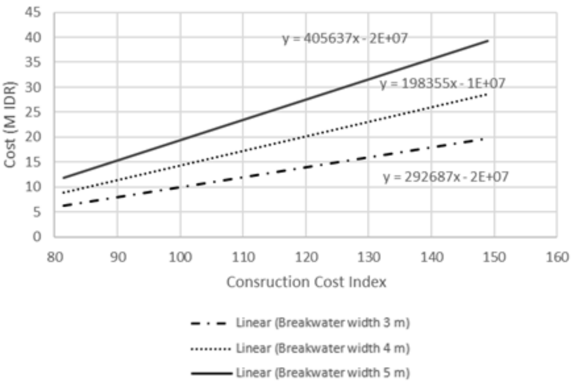



Figure 6. Estimated Cost of Breakwater Structure

Table 10. Breakwater Cost

| Alternatives | Status | Length (m) | Cost (million IDR) |
|---|---|---|---|
| A1 : Teres | Required | 450 | 6,287.44 |
| A2 : Tasikona 1 | Required | 150 | 2,095.81 |
| A3 : Tasikona 2 | Required | 600 | 8,383.26 |
| A4 : Tasikona 3 | Required | 600 | 8,383.26 |
| A5 : Panaf | Not Required | - | - |

Notably, the paving block road incurs the highest cost. Applying the Kupang Construction Index Cost of 88.75 and considering asphalt as the chosen road material for Kupang GEPP, Table 9 presents the projected costs for roadwork across all alternative locations.

## Breakwater Cost

A breakwater serves as a protective barrier shielding port infrastructure and ships from swells [45]. Breakwater is designed with several sloping-type breakwaters: (a) rubble-mound breakwater; (b) multilayer rubble mound breakwater; (c) multilayer rubble-mound breakwater armored with concrete blocks; (d) block-mound breakwater; (e) submerged breakwater; (f) reshaping (berm) breakwater.

Most potential locations for Kupang GEPP were found in the island's southern region, except for Panaf, as indicated in Figure 5. This figure highlights the specific area along the southern coast of Kupang Regency with significant wave potential.

The cost estimate for the breakwater at Kupang GEPP, using a sloping (mound) design, factored in the breakwater's height. The per-meter costs were determined by analyzing the Construction Cost Index from similar prior projects, as outlined in Figure 6.

A protective breakwater structure is essential to ensure the safe passage of the natural gas supply ship to Kupang GEPP, which must navigate through high-wave areas. This structure becomes crucial, particularly in open waters, safeguarding the ship and the plant from potential high wave impact during operational stages. The estimated costs for the breakwater structure based on its length for each alternative location are detailed in Table 10.

## Value-Based Decision (VBD)

VBD was applied by comparing the costs obtained for each alternative with the function obtained to select the highest possible option considering both function and cost [46][47]. The analysis using the following steps:

1. Calculate the total costs in Table 11 by summing up the estimated costs from Table 8 to Table 10 for land acquisition, power plant structure, cut and fill, road works, and breakwater.
2. Determine the assessment scale for costs on a scale of 1 to 9 with a value of 150,000 to 195,000, as shown in Table 12.
3. The cost scale for each alternative is obtained according to
4.
5. Table 11, where A1 = 5, A2 = 6, A3 = 0 and use 1 instead, A4 = 3, and A5 = 8.
6. Create a pair-by-pair comparison chart for each option. Refer to the cost scale depicted in Table 13.

Table 11. Cost Estimate Rating

| Alternatives | Cost 1 Land Acquisition | Cost 2 Power Plant Structure | Cost 3 Cut and Fill | Cost 4 Road Works | Cost 5 Breakwater | Total Cost | Score |
|---|---|---|---|---|---|---|---|
| A1 : Teres | 1,350.00 | 112,000.00 | 27,583.95 | 26,442.00 | 6,287.44 | 173,663.39 | 5 |
| A2 : Tasikona 1 | 1,350.00 | 112,000.00 | 17,847.85 | 39,053.00 | 2,095.81 | 172,346.67 | 6 |
| A3 : Tasikona 2 | 1,350.00 | 112,000.00 | 47,776.52 | 28,883.00 | 8,383.26 | 198,392.78 | 1 |
| A4 : Tasikona 3 | 1,350.00 | 112,000.00 | 27,782.60 | 35,799.00 | 8,383.26 | 185,314.86 | 3 |
| A5 : Panaf | 1,350.00 | 112,000.00 | 30,718.77 | 13,831.00 | - | 157,899.77 | 8 |

Where Ax compared to Ay is Axy = Ax/Ay so that A1 compared to A1 = 5/5 = 1, A1 compared to A2 = 5/6 = 0.833, A1 compared to A4 = 5/3 = 1.667, A1 compared to A5 = 5/8 = 0.625, A2 versus A1 = 6/5 = 1.2, and so on.

7. Compute the loss cost by summing the maximum and minimum values of the cost rating (Σ) among alternatives 1 to 5 and then subtracting the specific alternative's cost rating (Σ). For instance, if the maximum rating cost (Σ) is 1.739 and the minimum rating cost (Σ) is 0.217, the calculation for Loss A1 would be 1.739 + 0.217 – 1.087, resulting in 0.870.
8. Calculate the cost rating (Σ) where the value in Step 4 is divided by the total scale to obtain Table 14. Example rating score in A1 column = score value on the X-axis A1 and Y-axis A1 (A1, A1) divided by the total score in that column = 1/4.6 = 0.217.
9. Cost Normalization (Pr) is computed by comparing the alternative loss against the total loss ($Loss_n$ / Total Loss), as detailed in Table 15. This value is derived from the Function Normalization (Fs) division by the Cost Normalization (Pr) value. A value greater than 1 signifies that the achieved function surpasses the incurred costs. A value of 1 indicates parity between the obtained function and the costs incurred. When the value is less than 1, the achieved function falls short of the costs incurred. A higher value signifies a greater number of functions accomplished with fewer costs compared to other alternatives.

Based on the GIS, AHP, and VBD, the rank and feasibility of the alternative location were determined based on the value generated from the comparison between function and cost rating.

Table 12. Cost Scale

| Scale | Cost |
|---|---|
| 1 | 195,000 |
| 2 | 190,000 |
| 3 | 185,000 |
| 4 | 180,000 |
| 5 | 175,000 |
| 6 | 170,000 |
| 7 | 165,000 |
| 8 | 160,000 |
| 9 | 155,000 |
| 10 | 150,000 |

Table 13. Pairwise Comparison of Cost Scale

| Alternatives | Alternatives | | | | |
|---|---|---|---|---|---|
| | A1 | A2 | A3 | A4 | A5 |
| A1 | 1 | 0.833 | 5 | 1.667 | 0.625 |
| A2 | 1.2 | 1 | 6 | 2 | 0.75 |
| A3 | 0.2 | 0.167 | 1 | 0.333 | 0.125 |
| A4 | 0.6 | 0.5 | 3 | 1 | 0.375 |
| A5 | 1.6 | 1.333 | 8 | 2.667 | 1 |
| Total | 4.6 | 3.833 | 23 | 7.667 | 2.875 |

Table 14. Cost Rating of Each Alternative

| Alternatives | Cost Rating | | | | | Total |
|---|---|---|---|---|---|---|
| | A1 | A2 | A3 | A4 | A5 | |
| A1 | 0.217 | 0.217 | 0.217 | 0.217 | 0.217 | 1.087 |
| A2 | 0.261 | 0.261 | 0.261 | 0.261 | 0.261 | 1.304 |
| A3 | 0.043 | 0.043 | 0.043 | 0.043 | 0.043 | 0.217 |
| A4 | 0.130 | 0.130 | 0.130 | 0.130 | 0.130 | 0.652 |
| A5 | 0.348 | 0.348 | 0.348 | 0.348 | 0.348 | 1.739 |

Table 15. Cost Normalization of Each Alternative

| Alternatives | Σ | Loss | Cost (Pr) |
|---|---|---|---|
| A1 : Teres | 1.087 | 0.870 | 0.182 |
| A2 : Tasikona 1 | 1.304 | 0.652 | 0.136 |
| A3 : Tasikona 2 | 0.217 | 1.739 | 0.364 |
| A4 : Tasikona 3 | 0.652 | 1.304 | 0.273 |
| A5 : Panaf | 1.739 | 0.217 | 0.045 |
| | Total | 4.782 | 1.000 |

The function/criteria rating was then normalized by comparing the criteria rating of each alternative location with the total rating criteria of all alternative locations to get the normalization function value (Fs). Normalization was also carried out on the civil cost (Pr) through evaluating each alternative location's cost rating in relation to the total cost rating of all locations.

Table 16 and Figure 7 show the VBD values of alternative 1 to alternative 5, to determine whether each alternative location was feasible or not. The site is viable if the value is larger than 1. On the contrary, the site is not feasible if the value is less than 1. Based on the VBD values, the only feasible locations are alternatives 1 and 5, which have value ratings of 1.041 and 7.087 respectively.

Alternative 5, Panaf, emerges as the most favorable site for Kupang GEPP with a value of 7.087, significantly surpassing the values of the other four alternatives. This substantial lead aligns with the value-based decision principle, making it the preferred choice. Considering an equivalent cost, Alternative 5 not only meets but also exceeds the functionalities offered by the other alternatives.

Every organization strives to attain functions that rationalize the incurred costs. The proposed location is considered unfeasible if the costs surpass the functions or benefits obtained from an alternative. The method provides consistency and coherence in long-term organizational strategies, allowing for establishing feasibility limits in location selection by carefully balancing costs and functions.

Table 16. Value-Based Decision Rating

| Alternatives | Cost (Pr) | Function (Fs) | Value | Rank |
|---|---|---|---|---|
| A1 : Teres | 0.182 | 0.189 | 1.041 | 2nd |
| A2 : Tasikona 1 | 0.136 | 0.132 | 0.967 | 3rd |
| A3 : Tasikona 2 | 0.364 | 0.184 | 0.507 | 5th |
| A4 : Tasikona 3 | 0.273 | 0.172 | 0.632 | 4th |
| A5 : Panaf | 0.045 | 0.322 | 7.087 | 1st |

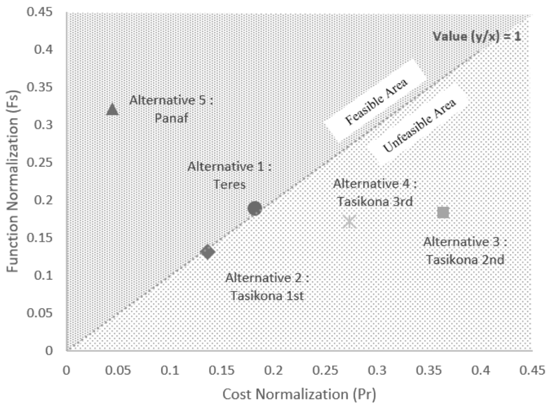



Figure 7. The Value-Based Decision Graph

However, the weakness lies in subjective assessments, necessitating expertise for objectivity, and the lengthy procedural steps involved.

The study has a similar result compared to the previous study that discussed the suitable material selection in buildings [48] and improves the site selection process by incorporating GIS AHP and VBD methodologies, with a specific focus on improving cost-related criteria. Decision-makers can choose the optimum location based on specified criteria and financial considerations gleaned from GIS data much more effectively when GIS, AHP, and VBD are employed.

## CONCLUSION

The evaluation of the site selection criterion produced subjective conclusions and depended on the experience of each engineer. In this study, GIS, AHP, VBD methodologies were concurrently applied to enhance the effectiveness of site selection assessment for Kupang GEPP 40 MW. Based on the site selection method using GIS AHP and VBD, it can be concluded that only alternative 1 and alternative 5 are considered feasible. Alternative 5, Panaf, emerges as the most favorable site for Kupang GEPP.

However, this study has some limitations due to the scarcity of empirical data and relevant references. The scope of this study is confined to GEPP projects, which exhibit distinct differences from other thermal power plants like coal-fired or geothermal ones. The focus also remains solely on civil work, excluding considerations for the natural gas fuel supply chain and the overall Engineering, Procurement, and Construction (EPC) costs associated with the project.

To overcome these limitations, future research is recommended. This involves extending the model's application to encompass other thermal power plants, incorporating variables related to the fuel supply chain and EPC costs. Including additional criteria, such as power plant operational considerations and environmental aspects, is crucial for achieving a comprehensive site selection outcome. Furthermore, including economic factors associated with connecting the power plant to the grid and involving a broader range of stakeholders as study respondents would be beneficial. Additional research employing more detailed data is necessary to enhance the efficacy of future site selection methods. This inclusive approach ensures a well-rounded assessment, considering technical and economic perspectives and environmental factors.

## ACKNOWLEDGMENT

The authors express sincere gratitude to PT PLN (Persero) for their engineers' data and assessment of the Thermal Power Plant Site Selection criteria.

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