



A Validation of the Analytical Hierarchy Process (AHP) for Ranking Geothermal Potential for Next PLN's Project: An Academic Expert Perspective

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Abstract. The study evaluates the geothermal potential of Indonesia using the Analytical Hierarchy Process (AHP). AHP was employed to rank geothermal sites for development, considering criteria such as resource potential, infrastructure readiness, economic feasibility, and socio - cultural impacts. Academic expert judgment, while inherently subjective, is incorporated to provide structured comparisons among multiple geothermal fields. This study highlights the application of AHP in providing transparent, objective rankings for geothermal site prioritization, which is essential for strategic planning in Indonesia's energy transition. The results suggest that economic feasibility and resource potential are key drivers in geothermal field selection, particularly for the Ulumbu and Tulehu fields that owned by PT PLN (Persero). These findings have direct implications for future geothermal investments and policy decisions in Indonesia. The study highlights the potential of AHP method in guiding policy and investment decisions for geothermal energy development PLN's geothermal fields for further study.

Keywords: *analytical hierarchy process, geothermal prospect, geothermal field, multi criteria decision analysis, energy investment, energy policy.*

1 Introduction

Indonesia holds roughly 40% of the world's geothermal reserves, positioning it as a pivotal player in the global shift towards cleaner energy based as highlighted by the Ministry of Energy and Mineral Resources (Kementerian ESDM) [1]. However, realizing the full potential of this resource requires a well-structured and strategic approach for evaluating and prioritizing geothermal sites for development.

The Analytical Hierarchy Process (AHP) is one of the most robust decision-making framework that assists in validate complex scenarios with multiple competing factors. In the context of geothermal energy, AHP is especially valuable for evaluating a variety of elements or criteria such as resource, infrastructure readiness, economic feasibility, and socio-culture factors. This paper validate the application of AHP to rank criteria of geothermal sites that

owned by PT PLN (Persero) as a foundation for further study, incorporating insights from academic experts within the field.

The primary objective of this study is to construct and validate AHP model for ranking geothermal development priorities for PT PLN (Persero) that stated in *Rencana Usaha Penyediaan Tenaga Listrik (RUPTL) 2025 – 2034* [2]. The structured approach provided by AHP offers a valuable resource for policymakers, researchers, and energy developers seeking to prioritize investments in geothermal energy development especially for PT PLN (Persero) to decide which future sites that should prioritized, due to limited internal resources and others framework for enhancing strategic investment decision across Indonesia's geothermal landscape.

2 Methodology

The Analytical Hierarchy Process (AHP) is a robust decision-making framework developed by Thomas L. Saaty in [3] to address complex, multi-criteria decision problems. The method has become a cornerstone in fields such as engineering, economics, management, and environmental science, particularly for solving problems where decision-makers need to evaluate a set of alternatives based on multiple conflicting criteria.

AHP works by decomposing a decision problem into a hierarchy, with the overall goal at the top, followed by criteria and sub-criteria, and finally, the alternatives at the bottom. Each level of the hierarchy allows decision-makers to focus on specific aspects of the problem, simplifying the analysis and enabling a clearer comparison of alternatives. The method involves pairwise comparisons, where decision-makers validate the relative importance of two criteria or alternatives at a time, assigning values based on a scale from 1 to 5, with 1 indicating equal importance and 5 indicating one is significantly more important than the other.

One of the primary strengths of AHP is its ability to provide a structured approach to decision-making while incorporating both qualitative and quantitative data. that generates weightings for each criterion based on the comparisons, allowing for the calculation of the relative importance of each factor.

The method is especially robust in scenarios where there is uncertainty or a lack of complete information, as in this study allows academic experts to make subjective judgments in a structured way. By quantifying academic expert opinions, AHP provides a transparent mechanism to resolve disagreements and combine diverse viewpoints. Additionally, it can be combined with other techniques, such as fuzzy logic or multi-objective optimization, to address specific challenges in decision-making that stated by Vaidya & Kumar in [4].

The application of the AHP in geothermal energy research represents a valuable method for evaluating the feasibility and ranking of potential geothermal sites. Given the complex nature of geothermal projects, which involve a range of technical, economic, environmental, and socio-cultural factors, AHP provides an ideal framework for decision-making by offering a systematic approach to validate multiple criteria simultaneously.

In geothermal site evaluation, AHP is used to compare various geothermal fields based on factors such as resource potential, infrastructure readiness, economic feasibility, and environmental impact. These criteria are essential in determining which geothermal sites should be prioritized for development, as each one presents unique challenges and opportunities.

An example of AHP's application in geothermal research is its use in geothermal sector, where the method has been employed to rank various aspect in geothermal such as validate potential field, prioritized project etc. They are Yunan *et, al* [5], Umami and Zain [6], Putriyana *et, al* [7], Rimantho *et, al* [8], Nhi *et, al* [9], Raos *et, al* [10], Suryantini and Wibowo [11].

Identification of Criteria

The first step in the AHP process is identifying the relevant criteria for evaluation (see Figure 1). In this study, the following four main criteria were selected, based on literature [10] and academic expert input:

1. Resource (R): The estimated energy output of the geothermal field, including factors such as reservoir temperature, fluid type, and resource/reserve and geological hazard.
2. Infrastructure Readiness (IR): The availability of supporting infrastructure such as proximity to the electrical grid, power plant capacity, existing well infrastructure, access to transportation such as port and access to nearer city.
3. Economic Feasibility (EF): The financial viability of developing the geothermal field, considering factors like capital expenditure and avoided cost of another power generation as comparison.
4. Socio - cultural (SC): The possibility of local communities rejection, electricity demand and forest status that need a further permission to government.

Identification of Sub-Criteria

Each of these main criteria was further broken down into sub-criteria to refine the analysis. Resource (R) criterion was divided into Reservoir Temperature (RT) , Fluid Type (FT), Resource / Reserve Potential (RP), and Geological Hazard (GH). Similarly, the Infrastructure Readiness (IR) criterion was broken down into Proximity to the electrical grid (EG), Power Plant Capacity (PC), Existing Well

Infrastructure (WI), and Supporting Infrastructure (SI). For economic feasibility (FF), criterion was cascade into Capital Expenditure (CE) and Avoided Cost (AC). Last criterion is Socio - Cultural (SC), was broken down into Possibility of Local Communities Rejection (CR), Growth Sales (GS), and Forest Status (FS)

Pairwise Comparison

Once the criteria and sub-criteria were identified, academic experts in the field of geothermal energy were asked to perform a pairwise comparison of the criteria and sub-criteria using the 1-5 scale of AHP. The scale ranges from 1 (equal importance) to 5 (extremely more important). The comparison matrix was used to derive priority weights for each criterion and sub-criterion.

The comparisons were made using data collected from academic publications, government reports, and academic expert opinion. These weights were then used to rank the criterion and make a validation with a PLN’s geothermal field that already operated which is Ulumbu Field and next PLN’s project which is Tulehu Field.

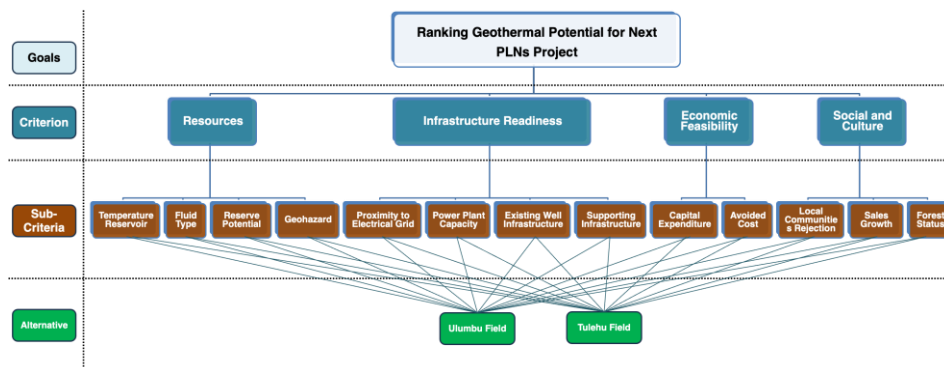


Figure 1 The hierarchical structure of ranking geothermal potential for next PLN’s Project as Ulumbu field as a validator and Tulehu field as a comparison.

Data Collection and Validation

Data on the geothermal sites’ characteristics were collected from internal document of PLN, government energy reports, geothermal development agencies, and academic studies. The validity of the data was ensured by consulting with several academic experts in geothermal energy who provided insights into both qualitative and quantitative aspects of each site’s potential.

Calculating Eigen Value for every criterion and sub-criteria

Every criterion and sub-criteria must be calculated for Eigen Value that presents the relative weight or importance of a criterion or alternative, calculated from pairwise comparisons, indicating its contribution to the overall decision-making process in hierarchical models.

Find Consistency from Criterion and Sub-Criteria

The Consistency Index (*CI*) in AHP measures the consistency of pairwise comparisons, reflecting the degree to which decision-makers' judgments align with logical transitivity, ensuring reliable and accurate decision-making, as follow :

$$CI = (\lambda_{max} - n)/(n - 1) \quad (1)$$

where λ_{max} represent the maximum Eigen value of the criterion or sub-criteria and n represents the number of order of the matrix.

3 Result and Discussion

The majority of the academic experts involved in the pairwise comparison process agree that economic feasibility is the most considered criterion with the highest weight, even it just has a small difference with resources criterion (see Table 1). These criteria are consistence that shows by the value of *CI* is below 10% (see Table 2) that calculated from equation (1). This consensus stems from the fact that the Ulumbu fields is currently in the production phase, in contrast Tulehu field is in exploration phase. As such, the discovery and understanding of the resource are deemed crucial, while factors like infrastructure, and socio - cultural aspects are seen as third and fourth, primarily contributing to the acceleration of development once the resource and economic feasibility are identified.

Table 1 The Result of pair-wise comparison matrix

Criteria	R	IR	EF	SC
Resources (R)	1.00	2.51	0.75	2.46
Infrastructure Readiness (IR)	0.40	1.00	0.52	1.69
Economic Feasibility (EF)	1.33	1.92	1.00	2.01
Socio - Cultural (SC)	0.41	0.59	0.50	1.00

Table 2 Normalized of pair-wise comparison matrix and prioritized matrix and Consistency Index (CI) calculation

Criteria	R	IR	EF	SC	Total
Resources (R)	0.32	0.42	0.27	0.34	1.35

Criteria	R	IR	EF	SC	Total
Infrastructure Readiness (IR)	0.13	0.17	0.19	0.24	0.72
Economic Feasibility (EF)	0.42	0.32	0.36	0.28	1.39
Socio - Cultural (SC)	0.13	0.10	0.18	0.14	0.55
Priority	0.34	0.18	0.35	0.14	1.00
Eigen Value	1.06	1.08	0.96	0.98	4.08
CI	0.02574713				
RI	0.9				
CR	0.02860793				

← Matrix Size = 4
← Consistent

Based on the evaluation of pair wise comparison and internal data of Ulumbu and Tulehu fields, the geothermal fields are ranked as follows: Ulumbu field is prioritized as the first, followed by the Tulehu field in second place (see Table 3). This ranking reflects the successful outcome of Ulumbu's tender process, which aligns with the conclusions derived from the AHP, establishing it as the top priority for development by PLN. In contrast, the Tulehu field is currently in the process of securing funding and establishing partnerships for the execution of exploration and production activities. Criteria, sub-criteria and AHP method can be applied to next PLN's further project to make more accurate decision-making.

Table 3 The Evaluation of Ulumbu and Tulehu Field based on internal data and comparison pair wise matrix value

No	Field	Status	Resource	Economic Readiness	Priority
1	Ulumbu	Production	0.68	0.33	1
2	Tulehu	Exploration	0.34	0.21	2

Breaking down the problem into a hierarchical structure is a crucial step in the decision-making process. This step is influenced by various factors, including the objective, time frame, another stakeholders as respondent, expected outcomes, benefits, and costs. The proposed structure, as illustrated in Figure 1 may need to be adjusted if any of these factors change. Such modifications can occur within a short timeframe, but it is important that all changes are thoroughly documented, and the rationale behind them can be reviewed and validated.

4 Discussion

In summary, the Analytical Hierarchy Process (AHP) offers several advantages, including: (1) providing comprehensive documentation of the facts and rationale behind decision-making, (2) accommodating both quantitative and qualitative data, (3) incorporating environmental, socio-cultural, and other relevant influences, and (4) addressing subjective judgments from individuals. Furthermore, AHP can be extended to multi-criteria decision-making at the group level, enabling collaborative evaluation. Additionally, AHP and all criteria and

sub-criteria serves as an effective tool for ranking geothermal fields owned by PLN, facilitating the prioritization of sites for future development.

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