

Geothermal Prospect Selection Using Analytical Hierarchy Process (AHP): A Case Study in Sulawesi Island, Indonesia

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ABSTRACT

Analytical Hierarchy Process (AHP) is a Multi Criterion Decision Making (MCDM) Technique. It can handle any complex, multicriterion, and multiperson problems. In AHP, the problems are decomposed into a hierarchically structure and are given the weights according to its importance. Thus, the strength with which one alternative dominates another with respect to a given criterion can be identified. The output is a priority ranking indicating the overall preference for each decision alternative. This paper describes the application of AHP to select a geothermal prospect in Sulawesi Island to be developed in the near future. The alternatives consist of three geothermal prospects. i.e., Suwawa, Pulu, and Marana. Three major criteria are used and applied into those three prospects: Geoscience, Infrastructure, and Social-culture aspects. Under each of these major criteria, there are several subcriteria. Geoscience criterion which consists of Resources, Geothermal System, and Geological Risk Subcriteria is given the highest weight with the assumption that if resources are large and can be developed commercially, then there is no reason not to be exploited; the technology and other infrastructure aspects are no longer an obstacle. The result shows that Suwawa Prospect is the best option to be developed in the near future. The second option or rank is Marana Prospect, and the third is Pulu Prospect. This result is in agreement with the future plan of the development of Sulawesi Island. If the regulation and plan of development were suddenly changed, the goal of this AHP might not be appropriate anymore, and the second or third option might replace the first rank. The benefits of using AHP are (1) the facts and reasons behind the decision are well documented, (2) able to handle quantitative and qualitative inputs, (3) able to accommodate environmental, social and other influences, and (4) able to handle subjective judgments of individuals. Lessons learned from AHP application for geothermal prospect selection could be extended into multi criterion decision making at a group level.

Keywords: AHP, MCDM, geothermal prospect, geological risk

SARI

Proses Analisis Hirarki (AHP) adalah teknik membuat keputusan berbagai kriteria (MCDM). Hal ini dapat menangani berbagai masalah, berbagai kriteria, dan berbagai masalah manusia. Dalam AHP, masalah diuraikan menjadi struktur hirarki dan diberikan beban menurut kepentingannya. Kemudian kekuatan sebagai salah satu kelebihan alternatif lainnya dengan respek terhadap kriteria yang ada dapat diidentifikasi. Keluaran adalah tingkat prioritas yang menunjukkan seluruh kecenderungan untuk setiap alternatif keputusan. Makalah ini menguraikan aplikasi AHP dalam memilih prospek panas bumi di Pulau Sulawesi yang akan dikembangkan dalam waktu dekat. Alternatif di sini terdiri atas tiga prospek panas bumi, yaitu Suwawa, Pulu, dan Marana. Tiga kriteria utama yang digunakan dan diaplikasikan ke dalam tiga prospek tersebut berupa aspek: Geosain, Infrastruktur, dan Sosial-budaya. Di samping tiga kriteria utama terdapat beberapa subkriteria. Kriteria geosain terdiri atas sumber daya, sistem panas bumi, dan bahaya geologi. Subkriteria bahaya geologi memberikan beban tertinggi dengan anggapan apabila sumber dayanya besar dan dapat dikembangkan secara komersial, maka tidak ada alasan untuk tidak dieksploitasi, sedangkan aspek teknologi dan infrastruktur tidak terlalu banyak hambatan. Hasilnya menunjukkan bahwa Prospek Suwawa adalah pilihan terbaik untuk dikembangkan dalam waktu dekat. Pilihan kedua adalah Prospek Marana, dan yang ketiga adalah Prospek Pulu. Hasil tersebut merupakan kesepakatan rencana ke depan untuk pengembangan Pulau Sulawesi. Apabila peraturan dan rencana pengembangan tiba-tiba berubah, maka rencana AHP tersebut tidak layak lagi, dan pilihan kedua atau ketiga dapat menggantikan pilihan

pertama. Keuntungan menggunakan AHP ini adalah (1) alasan dan fakta di balik keputusan terdokumentasi baik, (2) dapat menangani masukan kuantitatif dan kualitatif, (3) dapat mengakomodasi lingkungan dan sosial dan pengaruh lainnya, dan (4) dapat menangani hukum subyektif seseorang. Pelajaran yang dipetik dari aplikasi AHP untuk pemilihan prospek panas bumi dapat dikembangkan menjadi berbagai kriteria keputusan dalam tingkat kelompok.

Kata kunci: AHP, MCDM, prospek panas bumi, bahaya geologi

BACKGROUND

The Indonesian Government has planned to increase the capacity of its geothermal power plants to 9,500 MW by 2025, which is almost eight times the current capacity (Darma *et al.*, 2010). In accordance with the plan, several geothermal prospects have been re-assessed in order to prepare the future development.

The assessment is conducted by Directorate General of Mineral, Coal & Geothermal (Direktorat Jendral Mineral, Batubara dan Panas Bumi or Minerbapabum) under the Ministry of Energy and Mineral Resources (Kementrian Energi dan Sumber Daya Mineral) in collaboration with experts from private consultants, other government institutions or universities from various background of knowledge.

The objectives of the assessment are not only providing information about the resource of a

geothermal prospect in a particular area but also to provide information about which areas to be developed in the near future, for example in the next five years. Hence, geothermal prospects must be ranked to define its priority development. By ranking this priority, it is expected that the government is able to construct a development plan and regulation of an area, including a geothermal prospect development.

Considering that priority rank is a multicriterion decision making which is generated by assessing several factors that can differ significantly and can be conducted by peoples with very different knowledge, therefore the Analytical Hierarchy Process (AHP) method was chosen for ranking processes.

This paper describes the application of AHP in the selection process and priority rank of geothermal prospect in Sulawesi Island. The studied area is shown in Figure 1.

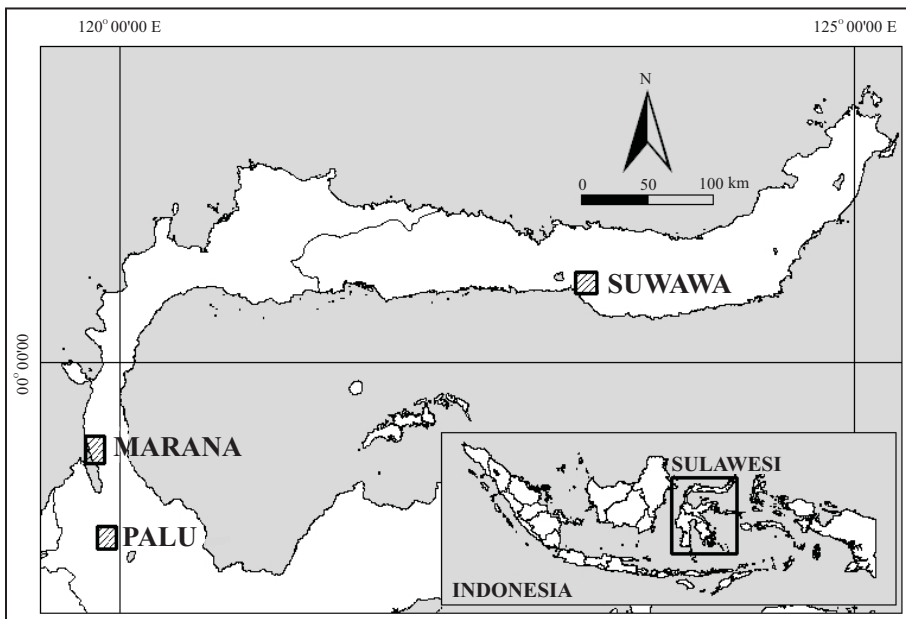


Figure 1. Location map of Suwawa, Marana, and Pulu Geothermal Prospects.

AHP was implemented in this selection process by defining an objective which was formulated in a goal statement “Which prospects are ready to be developed in the next five years, and if the first priority fails to be developed what is the second and third ranks?”

Research data comprise geosciences, infrastructure, and social-culture stability for each geothermal prospect. Geoscience data are surface exploration data which were conducted by Centre for Geological Resources (Pusat Sumber Daya Geologi). These data are given as the highest weight, by considering the assumption that if there is a resource in an area, then the development would be directed to that place. Thus, other data (infrastructure and social culture) are assumed only supporting the acceleration of the development and the feasibility of the project.

METHODOLOGY

AHP is a Multicriterion Decision Making (MCDM) technique. It structures any complex, multicriterion, and multiperson problems hierarchically. It can identify the strength with which one alternative dominates another with respect to a given criterion. The output is the priority rank indicating the overall preference for each decision alternative. The method was developed by T.L. Saaty in the late 70’s. Since then, the simplicity and power of the AHP has been

used in business, government, social studies, R&D, defenses and other domains involving decisions in which choice, prioritization or forecasting is needed (Saaty, 1980; Bhushan and Rai, 2004).

Following the methodology of the AHP described in Bhushan and Rai (2004), the steps of the research can be explained as below.

Decomposing the Problem into a Hierarchy of Goal, Criteria, Subcriteria, and Alternatives

In this study, the problem is structured into four levels: (1) one goal which is the objective of this study as mentioned before, (2) three criteria which are the major factors controlling the goal; those are Geosciences, Infrastructure, and Social-Culture, (3) subcriterion of each major criterion, and (4) the alternatives are Suwawa , Marana, and Pulu Geothermal Prospects. This is the most creative and important part of a decision-making. Structuring the decision problem as a hierarchy is fundamental to the process of the AHP. The structure is shown in Figure 2.

Constructing a pairwise Comparison Matrix of Alternatives on a qualitative Scale based on Expert Judgment

This matrix shows the relative contribution of each criterion. Experts are several geologists/geoscientists who work for the prospect area. The qualitative scale applied in this study is adopted

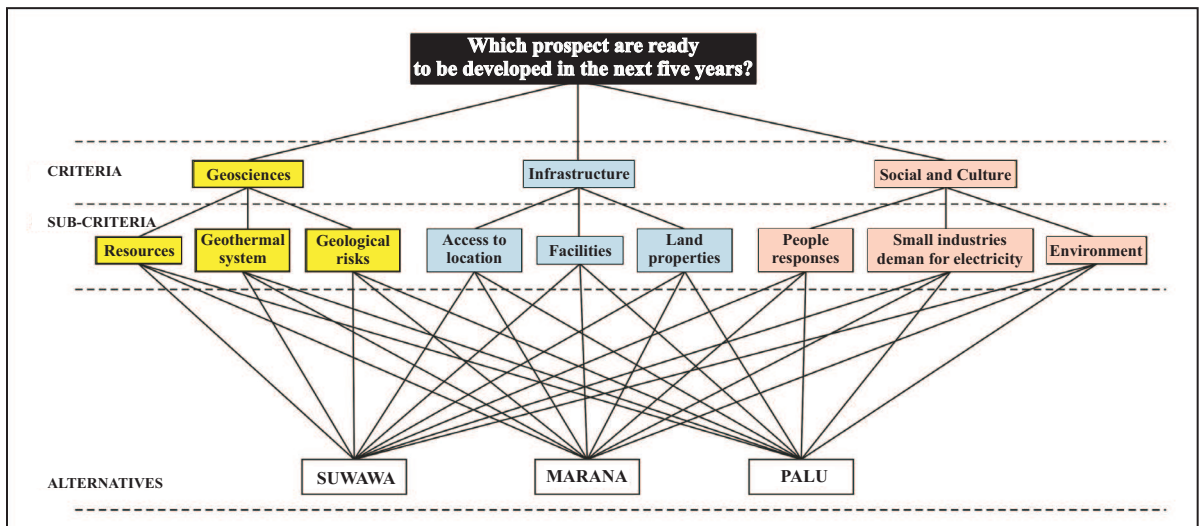


Figure 2. The hierarchical structure of geothermal prospect selection in Sulawesi.

from Otis and Schneidermann (1997) who used this scale method for evaluating hydrocarbon exploration prospects. The scale is shown in Figure 3. The risk factors are expressed as unfavourable, questionable, neutral, encouraging, and favourable. Assessments of encouraging or questionable are based on indirect data that support or do not support the model. Indirect data for instance is lack of significant surface manifestation, whereas assessments of favourable or unfavourable are based on direct data that tend to confirm or disprove the model. The direct data for example are high geothermal gradient from a well.

Calculating the principal Eigen Value for every Matrix

This will result in the weight of each criterion being compared. The weight reflects the relative favourable criteria. By calculating the weight or the Eigen value, the overall ranking of each decision alternative can be obtained.

Evaluating the Consistency of the Matrix

This is conducted by calculating the consistency index, or *CI* as follow :

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

where λ_{max} is the maximum Eigen value of the judgement matrix and *n* is the number of order of the matrix.

RESULTS AND DISCUSSION

Most of the experts involved in the evaluation of pairwise comparison agree that geosciences are the major criteria with the highest weight. This is because the prospects or the criteria being compared in this study are in the stage of exploration. Hence, it is agreed that the resource must first be discovered, whereas other factor such as technology, infrastructure, and social-culture will only support the acceleration of the prospect development. The overall ranking of the prospects are Suwawa Prospect as the first priority to be developed, Marana Prospect is the second rank, and the last or the third is Pulu Prospects. The major difference of the three prospects is the availability of the subsurface information from a shallow temperature gradient well. Suwawa and Marana have two wells (each 250 m depth) but there is no well to be drilled in Pulu yet. Hence, it defines the geology risk in Pulu Prospect. Due to unavailability of direct subsurface data, that are the geothermal gradient data, Pulu prospect is determined as neutral weight scale. On the other hand, drilling in Suwawa (SWW-1) is more promising with a higher temperature gradient, that is 14°C/100 m (Nanlohi and Risdianto, 2006), than Marana Prospect (in MM-2 gradient temperature is 9 °C/100m at 250 m depth) (Nanlohi *et al.*, 2005). Both wells in Suwawa have a good indication of high temperature with strong alteration intensity whereas

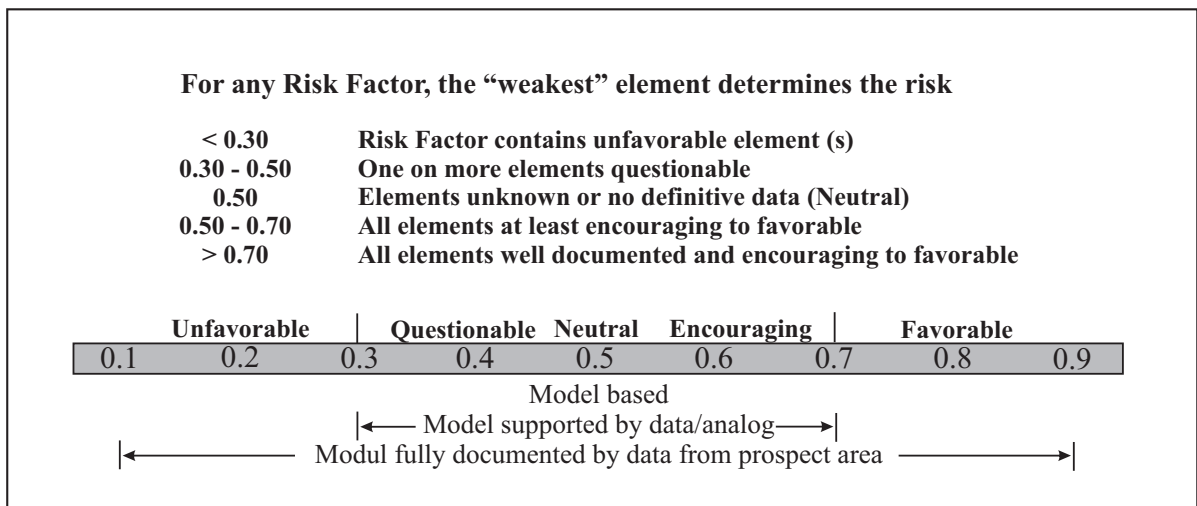


Figure 3. Qualitative scale applied in this study (Otis and Schneidermann, 1997).

in Marana only one well shows a significant indication, that is MM-1 with a very high flow rate (≈ 317 litre/minute) of hot water ($\approx 100^\circ\text{C}$ at 185 m deep). In addition, an other geologic condition is still more favourable in Suwawa than Marana. This argument is supported by geophysical data assessment. The weight or the Eigen value of infrastructure and social culture criteria for all the prospects are similar. They are mostly favourable. Thus the last two criteria contribute less in determining the overall rank or priority of prospect development.

Decomposing the problem into the structural hierarchy is a very critical process. It depends on several factors such as goal, time horizon, stake holder, outcomes, benefit, and cost. The structure which is proposed in Figure 2 may be changed by the change of one of these factors. It can even be changed within a short period of time. However, those changes are going to be well documented and justification can be examined.

The qualitative scale adopted from Otis and Schneidermann (1997) applied in this study is very powerful because it does not only give the value based only a single factor that can be biased or contradictory with other factors. The scale is based on the assessment of several controls that may support each other; therefore the favourability of the criteria can be determined. For example, in geothermal system criterion, there is a subcriteria of reservoir temperature. The predicted reservoir temperature may be obtained from solute, gas, and isotope geothermometer and also from a well measurement. If for example, all the results from various methods supported each other (or similar), *i.e.* high temperature result, with error or differences within $\pm 20^\circ\text{C}$, and also all samples meets the required assumption for its calculation, then the calculated reservoir temperature and its importance are favourable, or between 0.8 to 0.9 in the upper values of the scale. Hence, the subjective judgment of geologists with various background of knowledge can be handled effectively. Furthermore, geologists or geoscientists working in a group to assess a geothermal prospect might be collaborated together to find a better solid agreement for the priority of geothermal prospect development using AHP.

CONCLUSIONS

In summaries, several advantages by using AHP can be mentioned such as (1) the facts and reasons behind the decision are well documented, (2) able to handle quantitative and qualitative inputs, (3) able to accommodate environmental, social and other influences, and (4) able to handle subjective judgments of individuals. In addition, AHP application for geothermal prospect selection may be extended into multicriteria decision making at a group level.

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