Prioritizing the Planning for Sustainable Renewable Energy in South Sulawesi Using ANP Approach

by Ys Akil

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***Abstract*—The government sets a target of at least 23 percent new renewable energy contribution in the national primary energy mix by 2025, thus, renewable energy planning is needed to realize this target. This study aims to establish the best energy source in South Sulawesi as a reference or guide in the decision-making process. A questionnaire was used to collect data, and it was constructed with the criteria of renewable energy assessment. The analytical network process model was presented to rank renewable energy sources in energy development. This method applied a multi perspective approach specifically economy, environment, potential, technology, risk, and social with 3 sub criterions for each perspective. This study also involved six renewable energy sources namely solar, wind, hydro, biomass, biofuel and geothermal, assessed as an alternative. It is identified that potential criterion is the most priority criterion for renewable energy planning with a weight of 0.2452 and the availability of energy sources is the best sub criterion with a weight of 0.4660. The further results revealed that solar energy has a huge potential to generate electricity in South Sulawesi with a weight of 0.2788 and a percentage of 28.6 percent. It is followed by hydro and wind energy in the second and the third ranking.**

Keywords*—*Analytical Network Process (ANP), priority, renewable energy, South Sulawesi

I. Introduction

Energy is an essential factors for sustainable development. The dependence on fossil energy sources, whose the prices are getting higher and causing global warming, should receive more concern from various stakeholders to find innovative solutions by utilizing renewable energy [1]. The development of renewable energy has multi-sectoral impacts, including encouraging energy supply, increasing national energy security, maintaining macro-economic stability, and reducing social and environmental impacts caused by fossil energy [2].

Currently, Indonesia is focusing on developing the use of new and renewable energy in 2025 by 23% and in 2030 by 31% [3]. However, until 2020 the realization of the share of New and Renewable Energy has only reached 11.31% due to some factors such as solar power plant and wind power plant are still constrained by high investment costs, incomplete pricing schemes, and complicated time-consuming licensing processes [4, 5].

South Sulawesi is one of the provinces in Indonesia, with an area of 45.764.53 km2. Sulawesi has a large and diverse potential for renewable energy. As a tropical region, South Sulawesi has a very high potential for renewable energy from solar energy, considering that solar radiation is relatively stable throughout the year. Currently, the new and renewable energy power plant in Sulawesi is dominated by a hydro power plant of 778.16 MW, a solar power plant of 27.62 MW, a wind power plant of 130 MW, and a geothermal power plant of 114.80 MW [6].

In this study, selection of the type of renewable power plant in South Sulawesi is done to get the most appropriate renewable energy alternative to be built in the South Sulawesi area. Multi-Criteria Decision Making (MCDM) method particularly Analytical Network Process [7] is used a basis for decision making. Here, six types of renewable energy sources is analyzed by considering 6 criterion and 18 assessment sub-criterion. ANP method is adopted in this study for some reasons: (1) Selection of renewable energy priorities is a multi-criteria decision problem that is quite complicated because it has many criterion that influence each other, (2) A hierarchical process cannot solve many decision-making problems because it requires interaction and dependence from the highest level. ANP can solve all types of interactions and make more accurate predictions than other MCDM methods [8].

II. Literature Review

In recent years, a number of studies have been done to select energy priority using MCDM model. For example, Reference [9] evaluated renewable energy planning in the Caribbean rural area of Columbia using AHP, where the best alternative is solar energy. Reference [10] used a combination of AHP to search for weighted criterion and VIKOR to find the best alternative in Turkey, with solar energy being the best result. Reference [11] applied fuzzy AHP to select renewable energy in Indonesia with five criterion, the highest yields are obtained from hydro energy, continued by solar, wind and biomass energy. Reference [12] modelled fossil energy and renewable energy priority in Azerbaijan using the AHP and Z-Number methods. The best results are wind energy, followed by solar and natural gas. Another study in [13] determined optimal renewable energy investment using Fuzzy ANP. Next study in [14] identified factors that influence the price of renewable energy through for two different countries namely The United States and Turkey by using ANP method.

III. Methods

This research data used qualitative-quantitative analysis, which was represented by judgment of the experts [15]. It was identified that the selected expert was an expert with deep knowledge of renewable energy. As in [16], the number of experts might be lowered if they have a high level of expertise in the topic under investigation. The data obtained have been distributed and selected by 10 experts, including 6 experts from the Ministry of Energy and Mineral Resources of South Sulawesi Province and 4 experts from State Electricity Company (PT. PLN Persero) UIKL Sulawesi with several criterion namely they have worked for more than 15 years, have educational background in the field of electricity or energy, and have been involved in or run renewable energy projects.

Literature reviews, in-depth interviews, and the completion of expert questionnaires were all used to analyze the data. The distribution of questionnaires took place in two stages: (1) The best criterion assessment questionnaire, (2) Pairwise comparison questionnaire with criterion and alternatives weights.

IV. Analysis Of Data

For prioritization goals, solar energy, biomass energy, geothermal energy, wind energy, hydro energy, and biofuel energy are considered as the main alternatives in this study. Next, to evaluate renewable energy alternatives for South Sulawesi, technology, economic, environmental, potential, risk and social are presented with 18 sub-criterion assessment.

A. Sub-Criterion Description

Many sub-criterion need to be considered in the selection of renewable energy sources. These sub-criterion varied according to references from some literature and the views of experts. Table I summarizes the energy selection criterion, most of the studies based on the literature from similar studies and some of the experts opinions.

TABLE I. Criterion and Sub-Criterion

Criterion	Sub-Criterion	Description	References
Environment	Emissions	Greenhouse gases and pollution (Sox, NOx, PM)	[9] [10] [17] [18] [19] [29] [30] [31]
	Waste	Solid and liquid waste	[11]
	Land use	Area of land required	[9] [10] [11] [28] [29] [31]
Economy	Investment	Equipment costs and maintenance	[9] [10] [30] [31]
	Payback period	Payback time	[10] [22]
	Selling price	Selling price to the electricity provider	Expert
Technology	Efficiency	Technological efficiency	[9] [10] [16] [29]
	Reliability	The ability of the system to cope with failure	[9] [10] [20] [27] [29]
	Technological maturity	Technology development and readiness	[9] [10] [20] [27] [29] [31]
Social	Social acceptance	Acceptance of local residents	[9] [11] [12] [19] [26] [27]
	Jobs creation	Jobs for local residents	[10] [9] [29] [31]
	Government regulation	Government policy and licensing	[28] [29]
Risk	Natural Phenomena	Resistant to natural risks such as storms, earthquakes, and floods	[9]
	Distance to user	Distance from the generator to the resident's house	[11]
	Service life	Age or duration of technology	[9] [10]
Potential	Availability	Stock or availability of energy sources	[12]
	Sustainability	Energy sustainability	[11]
	Operating system	Study of compliance with the electrical load to the system	Expert

TABLE II. ANP Numerical Scale [7]

Definition	Numerical Values
Extreme Dominance	9
Very strong Dominance	7
Strong Dominance	5
Moderate Dominance	3
Equal	1
Compromising between the above values	2,4,6,8

B. ANP (Analytical Network Process)

Saaty introduces ANP as in [7]. This method is a qualitative method approach which is a continuation of the previous method, namely Analytical Hierarchy Process (AHP). ANP is a decision-making method that can handle the dependence of the same cluster and different clusters [20]. This method can make the best decisions to solve many qualitative and quantitative criterion [21]. Compared with other MCDM techniques, ANP uses a network model without setting levels and reviewing explicit relationships in calculations, so that the selection accuracy is higher than others. In addition, this method involves several experts to become a group decision-making process. Thus, the geometric mean is adapted for expert consensus [22].

Some steps for creating ANP model are as follows [5]:

Step-1: Defining and constructing a network model that includes alternatives, criterion, and sub-criterion through a literature review process and interviews 5 experts in the renewable energy field.

Step-2: Creating a pairwise comparison matrix with the ANP numerical scale assessment in the form of a questionnaire distributed to 10 experts. The scores given for pairwise comparisons are in 1-9 scale as seen in Table II. Scores of 2, 4, 6 and 8 are used if the experts wanted to give a score with a bit difference between two categories. Then, the others scores are given if one criterion is more important above others [11].

Step-3: Establishing the eigenvector of the pairwise comparison matrix in the form of priority weights [23].

$$A \cdot w = \lambda max \cdot w \quad (1)$$

where A is a pairwise comparison matrix, λ is a largest eigenvalue, and w is an eigenvector.

Step-4: Checking index consistency. It is consistent if the inconsistency is less than 10% or 0.1. If it is not consistent, then return to the second step. Index consistency can be calculated as follows [5].

$$CI = \frac{\lambda max - n}{n-1} \quad (2)$$

$$CR = \frac{CI}{RI} \quad (3)$$

where λmax is the largest eigenvalue of matrix pairwise comparison n x n, n is the size of the matrix, and RI refers to a random index as seen in Table III.

TABLE III. RI Index [5]

n	1	2	3	4	5	6	7	8	9	10
RI	0.0	0.0	0.58	1.12	1.24	1.32	1.14	1.45	1.49	1.51

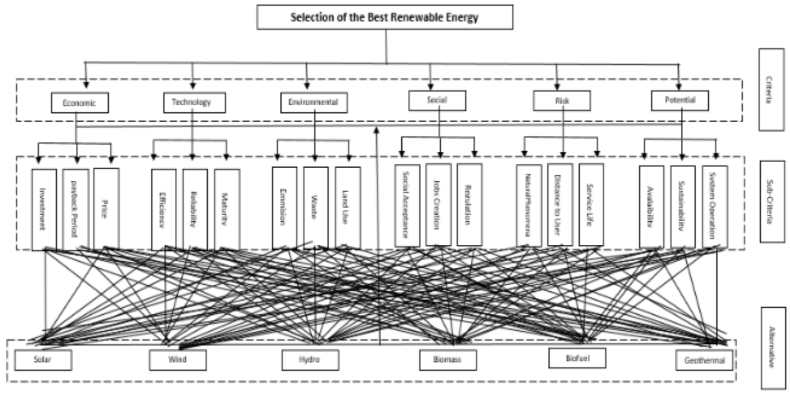

Fig. 1. ANP Framework

Step-5: Modeling a supermatrix as a priority vector from pairwise comparisons between criterion, sub-criterion and alternatives. The supermatrix consists of three steps namely unweighted supermatrix, weighted supermatrix, and limiting supermatrix.

Step-6: The preferred option is chosen by ranking the ANP model. The highest global priority value is the best alternative.

ANP method calculation test can be calculated using as below [24]:

1) Geometric mean

A geometric mean is carried out to find out the results of individual assessments of experts.

$$GM = (R1 * R2 * \ldots * Rn)^{1/n} \quad (4)$$

where GM is the geometric mean, N is the number of respondents, and R is the questionnaire value of n respondents.

2) Rater agreement

The rater agreement shows the respondents' level of agreement with a problem using Kendall's Coefficient of Concordance model. The calculation method is as follows:

1. The total number of rankings for each cluster:

$$Xa = R1 + R2 + \ldots + Rn \quad (5)$$

2. The average value of the total ranking of each cluster:

$$U = \frac{Xa + Xb + \cdots + Xz}{z} \quad (6)$$

3. The sum value of the squared deviations (s):

$$S = (R1-U)^2 + (R2-U)^2 + \ldots + (Rn-U)^2 \quad (7)$$

4. Maximum value of squared deviations (Max S):

$$Max\ S = (n-U)^2 + (2n-U)^2 + \ldots + (Zn-U)^2 \quad (8)$$

5. Kendall's W value:

$$W = \frac{S}{Max\ S} \quad (9)$$

where X is the number of each cluster, R is the ranking weight of each respondent, n is respondents number, z is clusters number, U is the average of total value in each cluster, S is the number value of squared deviations, MaxS is the maximum value of the squared deviations, and W is rater of agreement.

V. Results and Discussion

A. ANP Network Model

The first stage of the ANP method is to create a network framework based on previously identified influence relationships. The network model can be seen in Fig. 1.

B. Inconsistency Value

Consistency test results from the calculation is shown in Table IV. For example, result of the consistency test for solar energy shows that the obtained value is 0.0343 (≤ 0.1), thus, the data means consistent.

TABLE IV. Inconsistency

Cluster	Sub-Cluster	Inconsistency
Alternative	Solar energy	0.0343
	Wind energy	0.0462
	Hydro energy	0.3439
	Biomass energy	0.0270
	Biofuel energy	0.0495
	Geothermal energy	0.0264
Criterion	Economy	0.0080
	Technology	0.0088
	Environment	0.0311
	Social	0.0370
	Risk	0.0085
	Potential	0.0088
Sub Criterion	Investment fee	0.0374
	Payback period	0.0195
	Selling price	0.0195
	Emissions	0.0264
	Waste	0.0316
	Land use	0.0829
	Energy availability	0.0380
	Sustainability	0.0264
	Operating system	0.0195
	Natural phenomena	0.0195
	Distance to user	0.0195
	Service life	0.0264
	Social acceptance	0.0173
	Jobs creation	0.0264
	Government regulation	0.0195
	Technological efficiency	0.0748
	Technological reliability	0.0195
	Technological maturity	0.0264

C. Supermatrix Calculation

The ANP supermatrix calculation is divided into 3 types namely unweighted, weighted, and limiting supermatrix.

1) Unweighted supermatrix

The eigenvector values of each sub-criterion calculated in the pairwise comparison matrix are maintained in the unweighted supermatrix.

2) Weighted supermatrix

The weighted supermatrix is created by multiplying all components elements in of the unweighted super matrix by the relevant cluster weights, resulting in a weighted supermatrix with a sum of one for each column.

3) Limiting supermatrix

A limiting supermatrix is created by multiplying the weighted supermatrix by itself numerous times to increase its weight. The limit matrix has stabilized and the matrix process has come to a halt when the weights in each column have the same value. The results is shown as in Table V.

D. Priority Calculation

The final stage of ANP processing is to establish priorities. There are limiting weights in the priority, which are normalized by cluster weights. The normalized by cluster weight is the ratio between the limiting weight and the total limiting weight with one component, whereas the limiting weight is the weight acquired from the supermatrix limit as seen in Table VI.

1) Alternative Source Rank

The priority weights show the order of priority or the influence of alternatives in evaluating and prioritizing renewable energy sources in South Sulawesi area. From analysis for six types of renewable energy, it is found that solar energy has the highest alternative weight value 0.27886 among other alternatives. Successively the highest to the lowest values are hydro energy with a value of 0.21456, wind energy with a value of 0.18374, geothermal with a value of 0.12999, and biofuel energy with a value of 0.08661 and finally biomass energy with a value of 0.08151 as seen in Table VII.

In general, as Indonesia is located on the equator, solar energy is the greatest solution. As a result, solar energy is a prospective power plant to be built. The western and eastern parts of Indonesia are split by the distribution of sun energy. The majority of locations receive high-intensity solar radiation, with an average daily exposure of roughly 4 kWh/m2 [25]. The availability of solar energy is determined by the region's geographic location, land usage, and temperature variations [32]. Based on data from 18 locations in Indonesia, the western region's solar radiation distribution is estimated to be around 4.5 kWh/m2/day, with a monthly variation of about 10%, and the eastern region's solar radiation distribution is estimated to be around 5.1 kWh/m2/day, with a monthly variation of about 9% [26]. In this way, Sulawesi is estimated to receive about 9% of the distribution of solar radiation.

The result obtained for case South Sulawesi is in line with some past studies such as reported in [20] which found solar energy to be the best renewable energy source in Azerbaijan, and in [9] which found solar energy to be the best priority also for power plant in Columbia. However study in [11] found hydropower is considered to be the best renewable energy source in Indonesia and study in [33] identified the large percentage given by experts was for wind energy.

2) Criterion and Sub-Criterion Rank

Besides alternatives, it can be seen in the table that there are two essential criterion for consideration in the assessment of renewable energy, namely the potential criterion with a value of 0.2452 and the technology criterion with a value of 0.2030. There are three sub-criterion in the potential criterion.

TABLE V. LIMITING SUPERMATRIX

Criteria	Alternative					
	Solar	*Wind*	*Hydro*	*Bio Mass*	*Bio Fuel*	*Geo-thermal*
Economic	0.0435	0.0435	0.0435	0.0435	0.0435	0.0435
Technology	0.0657	0.0657	0.0657	0.0657	0.0657	0.0657
Environment	0.0429	0.0429	0.0429	0.0429	0.0429	0.0429
Social	0.0366	0.0366	0.0366	0.0366	0.0366	0.0366
Risk	0.0261	0.0261	0.0261	0.0261	0.0261	0.0261
Potential	0.0890	0.0890	0.0890	0.0890	0.0890	0.0890

TABLE VI. LIMITING ALL CLUSTER

Cluster	Sub-Cluster	Normalized By Cluster	Limiting
Alternative	Solar energy	0.27886596	0.103749
	Wind energy	0.18374889	0.068362
	Hydro energy	0.21456059	0.079826
	Biomass energy	0.08151754	0.030328
	Biofuel energy	0.08661299	0.032223
	Geothermal energy	0.12999436	0.048363
Criterion	Economy	0.13670111	0.040447
	Technology	0.20306142	0.067177
	Environment	0.13488598	0.045729
	Social	0.10319926	0.034666
	Risk	0.08166671	0.025121
	Potential	0.24520277	0.090184
Sub Criterion	Investment fee	0.42494427	0.017188
	Payback period	0.26352635	0.010659
	Selling price	0.23385495	0.009459
	Emissions	0.37097701	0.021454
	Waste	0.26115073	0.013515
	Land use	0.22252075	0.009232
	Energy availability	0.46609502	0.037601
	Sustainability	0.27623129	0.021140
	Operating system	0.37436278	0.013110
	Natural phenomena	0.31523875	0.009319
	Distance to user	0.35523284	0.006461
	Service life	0.23385602	0.006755
	Social acceptance	0.24760228	0.008530
	Jobs creation	0.25685067	0.009123
	Regulation	0.37436278	0.010456
	Efficiency	0.31523875	0.018181
	Reliability	0.35523284	0.020487
	Maturity	0.23385602	0.013487

TABLE VII. PRIORITY ALTERNATIVE

Alternative	Priority Weight	Percentage (%)	Ranking
Solar energy	0.27886	28.6%	1
Hydro energy	0.21456	22.0%	2
Wind energy	0.18374	18.9%	3
Geothermal energy	0.12999	13.4%	4
Biofuel energy	0.08661	8.9%	5
Biomass energy	0.08151	8.4%	6

All of these sub-criterion, energy availability is the most important sub-criterion with a value of 0.4660 and globally, the priority value of this sub-criteria is also in the highest order of all the existing sub-criteria. Moreover, on the technology criterion, reliability of the technology is the most important sub-criterion with a value of 0.3552.

The results obtained in terms of the criterion are similar to the findings of a research study in [11] which found that the potential of energy source is the most important for main criterion, followed by economics as the second important criterion. In contrast to the study in [34], the environmental effects are more significant. And according to the analysis of the sub-criterion, study in [27] identify that energy efficiency was shown to be the most important sub-criterion. Meanwhile, study in [28] highlighted that the main important sub-criteria were efficiency, investment, and technology.

3) Sensitivity Analysis

The accuracy of the respondents level of agreement in determining the priority of renewable energy sources and the criterion are tested using the rater agreement analysis. Table VIII showed that all expert respondents have a high agreement in alternative assessment, it is indicated by Kendall's W coefficient value of 0.76 which means 76% of respondents agree on the priority order of renewable energy sources in South Sulawesi. The result of the rater agreement is close to 1, which is indicates strong agreement. In addition, the experts also show moderate agreement on the criterion assessment with a value of 0.46 and sub-criterion assessment with a value from 0.12 to 0.21.

TABLE VIII. RATER AGREEMENT

Criterion Assessment	Rater Agreement
Criterion (economic, environment, technology, social, potential, risk)	0.46
Economic (investment, payback period, selling price)	0.26
Environment (emission, waste, land use)	0.16
Technology (efficiency, reliability, maturity)	0.13
Social (social acceptance, jobs creation, regulation)	0.12
Risk (natural phenomena, distance to user, service life)	0.19
Potential (availability, sustainability, system operation)	0.21
Alternative (solar, wind, hydro, geothermal, biomass, biofuel)	0.76

VI. CONCLUSION

The Analytic Network Process is used to identify priorities for developing renewable energy sources in South Sulawesi through the interrelationships between elements divided into six criterion, namely economic, environmental, social, political, potential and technology. It can be concluded that the priority of the best renewable energy sources is solar energy with a weight of 0.278, then hydro energy and wind energy with a weight of 0.214 and 0.183, respectively. The best criterion is the potential with a weight of 0.2452. The best sub-criterion is the availability of energy sources at 0.4660, with a high rater agreement value from the experts at 76%.

The analysis results showed that ANP could be used to generate priority renewable energy sources in South Sulawesi with the linkages and dependencies between the decision elements. The government or investors might utilize the ranking of renewable energies observed in this study as a reference to decide investment priorities for power plants based renewable energies.

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