Discover the Priorities of Renewable Sources Potential for Energy Sustainability in Indonesia

電力需要の増加が続くインドネシアで再生可能エネルギー（地熱、太陽光、風力）による発電に適した場所を、各種データの解析から突き止める。

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Abstract

Currently, the study of renewable energy potential for energy sustainability becomes an important issue to be discussed. When deciding the site locations for developing renewable energy in Indonesia, it requires the renewable energy resource maps for future introduction of renewable energy. The objectives of this paper are to identify and to rank the priorities of renewable energy sources using Analytical Hierarchy Process (AHP) and Geographical Information System (GIS) for 30 provinces in Indonesia. This study identifies the energy alternative that focuses on solar, wind and geothermal, based on a previous work by the author. The results show that geothermal is the best criterion, followed by solar and wind with weight value of 0.72, 0.22, 0.06 respectively. Resource maps generated identify the high, moderate and low suitability sites to rank the priority decision of renewable energy development for Indonesia. The proposed methodology is useful to discover Indonesia's site priority of renewable energy resources for energy sustainability. The output of this study can be used for decision making to prioritize areas of development in renewable energy for the cases of other countries.

Keywords renewable, energy, Indonesia

Introduction

Indonesia is the world's largest archipelagic state. It is located between 95º to 141º of longitude and between 6º North to 11º South of latitude. It consists of many islands: There are 5 big islands (Sumatera, Kalimantan, Java, Sulawesi and Papua), other smaller islands such as Bali, Ambon, Lombok, Nusa Tenggara, as well as thousands of tiny islands that surround the mainland. It has population over 238 million people.

The energy demand due to population growth is increasing by year, and Indonesia is experiencing energy power shortage. However, Indonesia has many energy resources which are abundant and can increase the energy sustainability. On the purpose to make decision for energy development among the site selection, it is essential to generate resource maps of suitable site locations to make priority decision for renewable energy development in this wide country.

Due to the availability of data, this study is focusing on theoretical potential as a criteria based on a previous study by the author in solar irradiation, wind speed and geothermal resources (Nagasaka and Rumbayan, 2013).

This study presents the spatial multi criteria decision making by combining AHP and GIS to prioritize the site for renewable energy development in the wide country such as Indonesia that has many alternatives of renewable energy resources available.

There are many different methods of multi criteria decision making and the most known is AHP. The AHP is developed by Saaty. The principles utilized in AHP to solve problem are to construct hierarchies. The hierarchy allows to assess the contribution of individual criterion at lower levels to criterion at higher levels of the hierarchy. The strength of the AHP approach is based on breaking the complex decision problem in a logical manner into small but related sub-problems in the form of levels of a hierarchy. The hierarchical structure of the AHP model permits decision maker (DM) to compare the different prioritization criteria and alternatives more effectively (Saaty, 1990).

Geographical information system (GIS) is a system that captures, stores, analyzes, manages and presents data that are linked to locations. GIS takes the number from databases and puts the information in the map as features. The ability to separate information in layers, and then combine it with other layers of information is the reason why GIS holds such a great potential as research and decision making tools (Foote and Lynch, 2000).

The combination of GIS and AHP techniques for analyzing land use suitability in Vietnam (Nguyen et al, 2001), site suitability evaluation for ecotourism in Thailand (Bunruamkaew and Murayama, 2011), evaluation of eco-environment quality in China (Ying, et al, 2007) have been reported. It was proved that the integration of AHP and GIS can be a powerful tool in order to develop spatial decision making.

Methodology

Using the data collected and the resulting maps for each resources (solar, wind and geothermal), this study is conducted to generate the site priority for renewable energy development in Indonesia and generate resource maps by combining AHP and GIS method. The method used is shown in the Fig. 1.

The following processes are described in detail as:

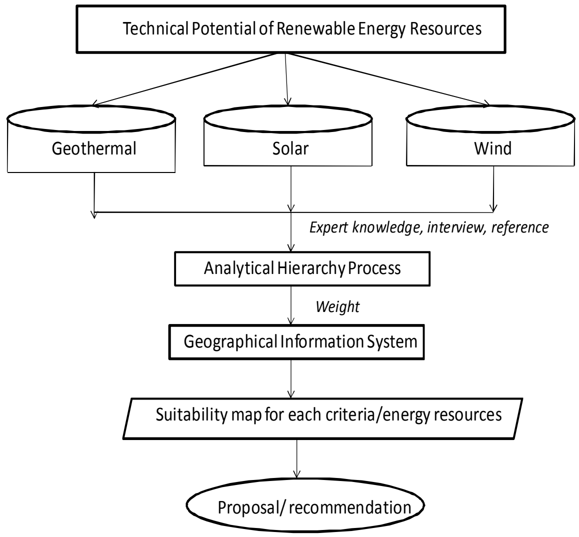

Fig. 1. Schematic of the methodology used

1. Collect the data
2. Develop database for each resources (solar, wind, geothermal)
3. Generate thematic resource in GIS environment.
4. Determine criteria score (x_i) for each resources mapping unit.
5. Recommendation for prioritizing the site of renewable energy development (based on theoretical potential)

The process can be divided in two phases, firstly using AHP method, then secondly apply the result of AHP into GIS environment.

The detail of procedures by using AHP method is described as follows:

1. <u>Define the objective of decision making</u> (in this study, the recommendation for the priority of renewable sources potential in Indonesia).
2. <u>Develop the model of AHP based on decision model</u>. The AHP model consists of goal, criteria, and sub criteria in different levels. Applying this step to rank or prioritize the decision making for

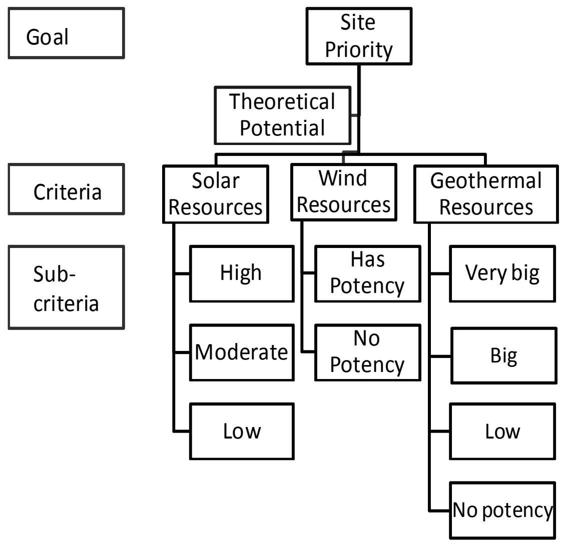

Fig. 2. Development of the AHP model

site suitability for renewable sources potential. The AHP model in this study was developed as shown in Fig. 2.

3. Define the pair of criteria (matrix). Within each level of the hierarchy, the relative importance between each pair of criteria (or among pairs of sub-criteria relating to an upper single criterion) to overall goal is evaluated. A nine-point scale proposed by Satty is used for these evaluation based on expert opinions.

A brainstorming session was conducted among a expert group to assign the values in the matrix as per Saaty's scale that is presented in Table 1.

Table 1. Saaty's scale of preferences in the pair-wise comparison process (Saaty, 1980)

Numerical Rating	Verbal judgments of preferences between alternatives i and alternatives j
1	i is equally important to j
3	i is slightly more important than j
5	i is strongly more important than j
7	i is very strongly more important than j
9	i is extremely more important than j
2, 4, 6, 8	Intermediate values

Pair-wise comparison matrix of criteria is shown in Table 2. The matrices of judgments corresponding to the pair-wise comparison of elements at each level of the hierarchy are presented. Pair-wise comparison of sub-criteria and local weight for solar, geothermal and wind are presented in Table 3, 4 and 5 respectively.

In this study, all scores can be assembled in a pair wise comparison matrix with 1s on the diagonal (e.g., geothermal to geothermal is 1) and reciprocal scores in the lower left triangle (e.g., if geothermal to solar is 5, and then solar to geothermal is 1/5). Pair-wise comparisons generated for the levels of the hierarchy contain expert opinions regarding the relative importance of criterion. The next step in the AHP requires an evaluation of the pair-wise comparison matrices using measurement theory. A standardized eigenvector is extracted from each comparison matrix, allowing us to assign weight to criteria, sub-criteria. These weights allow us to assemble a suitable value for each resources mapping unit.

The weight can be obtained by normalizing the vector in each column of the matrix (dividing each entry of the column by the column total) and averaging over the rows of the resulting matrix as shown at last column for criteria (Table 2) and for sub-criteria (Table 3, 4 and 5).

The score (x_i) and weight (w_i) for criteria (hierarchy 1) and sub criteria (hierarchy 2) are presented in Table 6.

4. Consistency check. It is necessary to know whether the pair-wise comparison has been consistent in order to accept the results of the weighting. The parameter that is used to check this is called the Consistency Ratio. A consistency check is performed by adopting the following procedure using Equations 1, 2 and 3:

The dominant or principal eigenvector of a matrix is an eigenvector corresponding to the eigen value of largest magnitude (for real numbers, largest absolute value) of that matrix. Calculate the eigen value of λ_{max} as:

$$\lambda max = \frac{1}{n}\sum_{i=1}^{n}\frac{(AW)i}{w_i} \quad (1)$$

where A is the matrix, W is the corresponding eigenvector of λ_{max} and w_i (i= 1, 2, …, n) is the weight value for ranking.

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

Where CI is the consistency index; while λ_{max} is the eigen value and n is the order of the matrix. According to Xu (2002), the bigger CI occurred, the worse consistency the matrix has. It is found the value of CI in this research was pretty good in 0.06. Then, the consistency ratio (CR) was calculated by using Eq.3:

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

Where RI (Random Index) is the average of the resulting consistency index depending on the order of the matrix. It is found that consistency ratio is equal to 0.04. The result below 0.1 shows the consistency of pair wise matrix.

In this study, the consistency check for hierarchy 1 (criteria) is performed as above procedure and presented as follows:

$$\begin{bmatrix} 1 & 5 & 9 \\ 1/5 & 1 & 5 \\ 1/9 & 1/5 & 1 \end{bmatrix} \begin{bmatrix} 0.72 \\ 0.22 \\ 0.06 \end{bmatrix} = \lambda_{max} \begin{bmatrix} 0.72 \\ 0.22 \\ 0.06 \end{bmatrix}$$

From calculation using Eq.1, it is found that eigenvector of AHP model in this research, λ_{max} = 3.12. In order to keep the consistency of the judgment matrix, its consistency should be tested by using Eq. 2 and Eq. 3.

The similar ways to prove the consistency index of judgment are applied for the pair wise of sub criteria matrix (in Table 3, 4 and 5). The result indicates that the pair wise matrix for sub criteria of solar, wind and geothermal are below 0.1. Then the local weight for criteria at level 1 are multiplied the local weight for criteria at level 2. Then the total weight is calculated by using Eq. 4.

$$S = \sum_{i}^{n} w_i x_i \quad (4)$$

where, S: Suitability index, w_i: weight of criterion *i*, and x_i: score of criterion *i.*

In the second phase, the result of weight or priority of criteria where used as input in GIS in the spatial analysis at GIS environment to overlay the map, as shown in Fig.3.

The entire resource databases which consist of solar, wind, geothermal data are formed in polygon format for 30 provinces as boundary in digital map available. The solar irradiation data for 33 provinces are taken from NASA database as monthly average (http://eosweb.larc.nasa.gov); wind speed data also taken from NASA database; the geothermal resources potential data are taken from Pertamina, an energy company of Indonesia.

The previous study about solar irradiation potential, wind energy analysis and geothermal potential analysis were conducted by authors and presented as

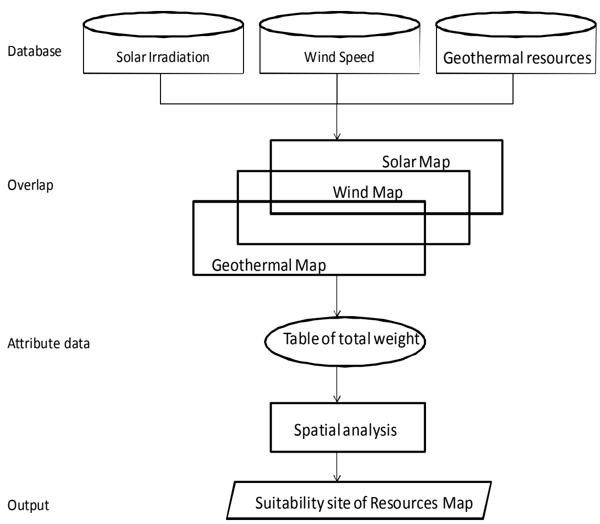

Fig. 3. Develop GIS method used in this study

solar mapping, wind mapping and geothermal mapping for 33 provinces in Indonesia based on data available.

In this study, we overlay all the solar irradiation data, wind velocity data, and geothermal resources potential data which are based on geographical data and AHP model, by using GIS.

Results and Discussions

The result of calculation local weight for hierarchy 1 and the total weight for hierarchy 2 (sub-criteria) are presented in Table 6. All the pair wise matrix indicates at below 10%, therefore there is no review for pair wise that is built based on expert opinions and decision maker references.

In this study the AHP model was built to identify the weight of criteria for two hierarchies. Then the overall weights were obtained based on AHP method. AHP as a well-known criteria decision making was used to define the weight of potential of resources. The scores and weight of solar, wind, geothermal potential for 30 provinces in Indonesia are presented in Table 7.

GIS enables to generate a theoretical potential resources map based on overlapping solar energy map (Fig. 4), wind map (Fig. 5) and geothermal potential map (Fig. 6).

The resource map by combining the AHP and GIS to show the suitability site of renewable energy resources for the entire Indonesia is shown in Fig. 7.

The GIS technology is used to assist the determination of finding the potential for entire Indonesia (33 provinces). Based on the weight calculation from multi criteria decision making using AHP method, the attribute of rank prioritization of resources map is classified in 3 classes, i. e highly suitable (>0.2), suitable (0.1-0.2) and low suitable (<0.1) and the map is generated in GIS environment.

Basically, the high suitability sites of renewable energy potential are found in provinces of Aceh, Medan, Jambi, Semarang, Surabaya, Bali, Lombok, Kupang, Manado and Ambon as shown in Table 7.

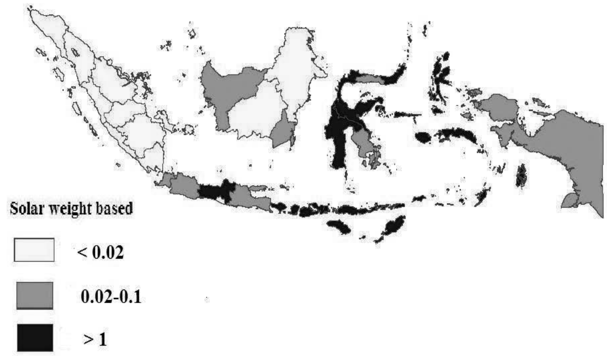

Fig. 4 Indonesia's Solar Irradiation Map

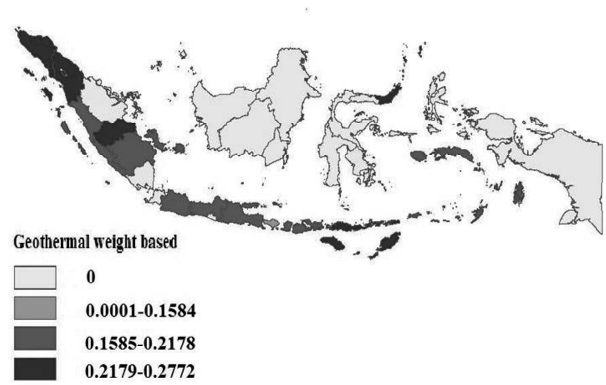

Fig. 5 Indonesia's Geothermal Resources Map

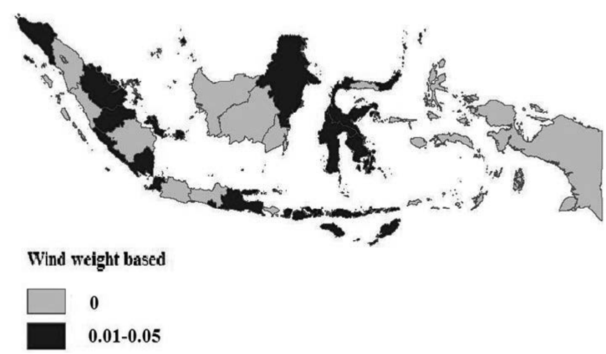

Fig. 6 Indonesia's Wind Resources Map

In Fig. 7, the color indicates that the darkest shows the high suitability for priority of renewable energy development based on theoretical potential criteria.

Conclusions

The result of this current study found that geothermal is the best choice, followed by solar and wind alternatives with weight value of 0.72, 0.22, 0.06 respectively. Resources maps generated identify the high and moderate suitability sites to prioritize decision of renewable energy development for Indonesia. The proposed methodology was useful to discover and identify the renewable energy resources site for energy sustainability in Indonesia.

The output of this study can be used for decision making to define the priority of renewable energy sources potential for the cases of other countries. The method in this study is also relevant to site selections to find priority of renewable energy development as the objective for other countries.

For further study, it is planned to add other criteria for renewable energy options, such as hydro and biomass energy to be analyzed by using AHP and GIS for discovering the priority of renewable sources potential for energy sustainability in Indonesia.

Table 2. Weight of Criteria

Criteria	High	Moderate	Low	Weight
Geothermal	1	5	9	0.72
Solar	1/5	1	5	0.22
Wind	1/9	1/5	1	0.06

Table 3. Pair-Wise Comparison of Sub-Criteria and Local Weight for Solar

Sub Criteria For Solar	High	Moderate	Low	Local weight (w_i)
High	1	5	9	0.72
Moderate	1/5	1	5	0.22
Low	1/9	1/5	1	0.06

Table 4. Pair-Wise Comparison of Sub-Criteria and Local Weight for Geothermal

Sub Criteria For Geothermal	Very big	Big	Low	No	Local Weight (w_i)
Very big	1	5	7	9	0.68
Big	1/5	1	1/7	7	0.22
Low	1/7	1/5	1	5	0.12
No	1/9	1/7	1/5	1	0.04

Table 5. Pair-Wise Comparison of Sub-Criteria and Local Weight for Wind

Sub Criteria For Wind	Has Potency	No Potency	Local Weight (w_i)
Has Potency	1	9	1
No Potency	1/9	1	0

Table 6. Score and Weight of Criteria in Priority Site of Renewable Sources Potential Analysis

Criteria-Hierarchy 1	x_i	Criteria Hierarchy 2	w_i	Local weight (w_i)
Solar Resources	0.22	High	0.72	0.15
		Moderate	0.22	0.05
		Low	0.06	0.01
Wind Resources	0.06	Has Potency	1	0.06
		No Potency	0	0
Geothermal	0.72	Very big	0.68	0.49
		Big	0.16	0.16
		Low	0.12	0.09
		No potency	0.04	0

Table 7. Score and Weight of Solar, Wind, Geothermal Resources Potential for 33 Provinces in Indonesia

Provinces	Solar Weight ($w_1.x_i$)	Wind weight ($w_2.x_2$)	Geothermal weight ($w_3.x_3$)	Total weight
Aceh	0.01	0.05	0.45	0.51
Medan	0.01	0	0.45	0.46
Padang	0.01	0	0.11	0.12
Riau	0.01	0.05	0	0.06
Kepulauan Riau	0.01	0.05	0	0.06
Jambi	0.01	0.05	0.45	0.51
Palembang	0.01	0	0.11	0.12
Bengkulu	0.01	0.05	0.11	0.17
Lampung	0.01	0.05	0	0.06
Belitung	0.01	0.05	0.11	0.17

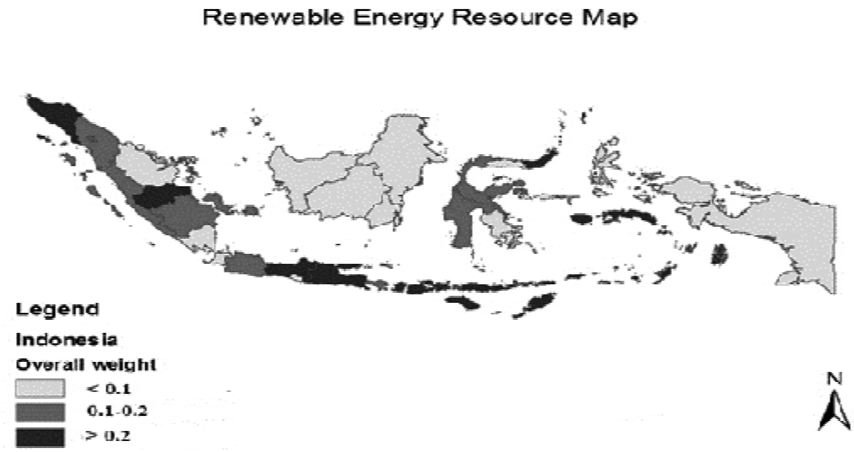

Fig. 7 Indonesia's Priority Site Map of Renewable Resources Potential

Table 7. (continued)

Provinces	Solar Weight ($w_1.x_i$)	Wind weight ($w_2.x_2$)	Geothermal weight ($w_3.x_3$)	Total weight
Jakarta	0.07	0	0	0.07
Bandung	0.07	0	0.11	0.18
Semarang	0.13	0	0.11	0.24
Yogyakarta	0.01	0.05	0	0.06
Surabaya	0.07	0.05	0.11	0.23
Banten	0.07	0.05	0	0.12
Bali	0.13	0	0.08	0.21
Lombok	0.13	0.05	0.45	0.29
Kupang	0.13	0.05	0.11	0.63
Pontianak	0.07	0	0	0.07
Palangkaraya	0.01	0	0	0.01
Banjarmasin	0.07	0	0	0.07
Samarinda	0.01	0.05	0	0.06
Manado	0.13	0.05	0.45	0.63
Palu	0.13	0.05	0	0.18
Makasar	0.13	0.05	0	0.18
Mamuju	0.13	0.05	0	0.18
Kendari	0.07	0.05	0	0.12
Gorontalo	0.07	0	0	0.07
Ambon	0.13	0	0.11	0.24
Ternate	0.13	0	0	0.13
Jayapura	0.07	0	0	0.07
Papua Barat	0.07	0	0	0.07

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