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COMPARATIVE ANALYSIS OF AHP AND FUZZY AHP FOR SOLAR POWER PLANT SITE SELECTION

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Abstract

Solar power is currently the most promising renewable energy alternative in solving energy problems in the world. This renewable energy is important as it belongs to clean power plant and is able to decrease air pollution as it does not release gas emissions and other pollutants. To build a solar power plant (SPP), both technical and non-technical factors need to be considered so that the selected areas are the right sites. Such a selection is not easy since it involves a lot of criteria in the decision-making process. This study aims to create a multi-criteria decision-making system based on a classical approach namely Analytical Hierarchy Process (AHP) and an artificial intelligence namely Fuzzy Analytical Hierarchy Process (Fuzzy AHP) for the selection of SPP sites. Two Fuzzy AHP analytical tools, namely Chang's Extent Algorithm and Geometric Mean were used to validate the results of priority weighing method of the AHP method. The results showed that the use of AHP classical method was validated by the Fuzzy AHP method. There was no significant difference of decision-making between the two methods in determining the five highest priorities of selection attributes of the SPP. It is expected that designers, investors, and the government use the results of this study as a reference in making such a decision.

Keywords: Analytical hierarchy process, Chang's extent algorithm, Fuzzy AHP, Geometric mean, Multi criteria decision making, Solar power plant.

1. Introduction

Solar power plant (SPP) is a power plant which needs a solar energy conversion device namely solar cell as the energy source [1, 2]. It is believed that solar power is the most promising renewable energy alternative to solve world's current energy issues [3]. The use of renewable energy is important as it is a clean power plant and able to reduce air pollution due to minimum gas emissions and other pollutants [4-6]. In addition, this energy has stable efficiency in comparison with other types of energy; it influences the amount of solar power released [7]. Even though it merely uses solar energy, the amount of solar light is abundant. It is identified that in every hour, the amount of light energy is equal to that of total energy consumed [8].

Previous studies have shown that there are a lot of technical factors to consider when building an SPP, namely: the width of an area, the tilt of the solar panel field, and most importantly, how the solar radiation directly highlights on the area, and what the average temperate of the area is [9-11]. Of all the factors influencing the development of SPP, there are the main ones to be identified prior to the development. Such a determination is easily executed by sorting out the scale of importance. It is necessary to identify the method used to search for the congruity and proper sites of a power plant site with a variety of kinds. To this relation, multi-criteria decision making (MCDM) is a popular method and widely used for the matter [12]. VIKOR, MAUT, ELECTRE, PROMETEE, TOPSIS and AHP are some of the methods categorized into MCDM [13].

One of the most frequently used MCDM methods by researchers is Analytic Hierarchy Process (AHP). It is simply defined as a method to solve complex problems by turning them into a well-structured hierarchical order. AHP is also commonly used to choose the best criteria and to have high priorities by considering other factors as well [14-16]. Additionally, there is a developed AHP method which combines a Fuzzy approach and AHP, namely Fuzzy AHP. Fuzzy AHP works by converting the priorities acquired by the AHP into weighing values determined by the Fuzzy-AHP [17, 18]. The use of supporting multi-criteria decision-making method by Fuzzy-AHP has been widely used in the field of management; however, there have been few studies in utilizing the method, particularly in selecting the site of SPP. Therefore, this study proposed a new method of supporting multi-criteria decision making based on an AR algorithm namely Fuzzy-AHP in selecting the site of solar power plant (SPP). The primary objective of the study was to compare the decision-making method using AHP and that using Fuzzy-AHP employing two popular algorithms namely Chang's Extent algorithm and Geometric Mean. The use of Fuzzy AHP method aims to validate the results of the classical AHP method.

2. Methods

2.1. Fuzzy-AHP method

Multi-Criteria Decision Making (MCDM) is a popular method commonly used to solve problems with various techniques. One of the methods belonging to MCDM is Analytical Hierarchy Process (AHP) [19-21]. AHP is a method to organize complex things into a well-structure hierarchical order. It is usually used to choose the best criteria with high priorities by considering other factors [22, 23]. In the meantime, the theory of Fuzzy, which was firstly introduced by Lotfi A. Zadeh in 1965, aims to describe fuzziness of human thoughts [24, 25]. Experts agree that a subjective method is needed in decision-making and AHP, a subjective MCDM, when combined with Fuzzy, will be able to better problem solving [26, 27]. AHP pays serious attention to scale, types of numbers used, and how to properly combine the priorities resulted from the AHP processes. Therefore, users should make thorough and careful scale to be able to interpret data well [28]. A 1-9 scale for the pairwise comparison is presented in Table 1 as the results of AHP in which the consistency value was checked to identify errors by calculating the consistency ratio (CR) value. CR reveals the random value probability acquired in the pairwise comparison matrix [29, 30].

Calculation stages of AHP refers to those widely used by other researchers [31-33]. The first thing to do was creating pairwise comparison matrix among the criteria. The matrix was in (n x n) where n is the number of criteria. The comparison was performed based on expert judgement by comparing one criterion to another using the scale of AHP. In this step, there is also a comparison process of all the elements for each hierarchy. This step is conducted to identify the level of importance in determining priorities of each sub-factor. Each effective sub-factor has its own relative weight to identify its importance level. Meanwhile, the sub-factors to be prioritized were determined in advance and the relative weighing determination is based on expert judgement published in 25 journals as references of this study.

After we obtain the pairwise matrix, we normalize the matrix by calculating the total value of each column, divide each entry in the matrix by the number of columns, and determine the mean of each line to acquire the relative weight. The matrix normalization aims to obtain the priority level of SPP site selection. After that, we calculate the value of consistency index (CI) and that of consistency ratio (CR) of all the criteria and later calculate the eigen value. The value of CR is retrieved by dividing that of CI with the amount of RI which has been predetermined. The accepted value of CR depends on the matrix size. For instance, the value is 0.05 if the matrix is 3 x 3 and is 0.08 if the matrix is 4 x 4. In the meantime, the value is 0.1 if the CR is above 5 [34]. If the CR value is not in accordance with or above the rule, recalculation of the pairwise comparison matrix should be done. The RI value for the number of different n is presented in Table 2 [35].

Table 1. AHP scale by Saaty [35].

Level of Importance	Definition	Description
1	Equally important compared with others	Two criteria equally contributing to the purpose
3	Moderately more important compared with others	Assessment moderately supports one criterion more compared with the other
5	Strongly more important compared with others	Assessment really supports one criterion more compared with the other
7	Really strongly more important compared with others	Assessment strongly supports one criterion more compared with the other
9	Extremely more important compared with others	Evidence of one criterion above the others has the highest validity
2,4,6,8	Value between two adjacent numbers	When compromise is needed
Opposite	Value for the opposite comparison	If criterion *i* has one of the above numbers compared with criterion *j*, then j has the opposite value compared to *i*.

Table 2. Random Index (RI) value.

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

In Fuzzy AHP, the weight of pairwise comparison matrix with the scale of Triangular Fuzzy Number (TFN) is calculated and used to rank the criteria and available alternatives. Therefore, the weight determination of the matrix really influences the step. The AHP scale previously acquired is converted into fuzzification scale as presented in Table 3 [36]. The number of TFN is represented by (l, m, u) in which $l \leq m \leq u$. When $l = m = u$, it is considered non-fuzzy [37], so that the scale of AHP converted into that of TFN can be made into pairwise comparison matrix as follows [38]:

$$\tilde{A} = (\tilde{a}_{ij})_{nxn} = \begin{pmatrix} (1,1,1) & (l_{12}, m_{12}, u_{12}) & \cdots (l_{1n}, m_{1n}, u_{1n}) \\ (l_{21}, m_{21}, u_{21}) & (1,1,1) & \vdots (l_{2n}, m_{2n}, u_{2n}) \\ \vdots & \vdots & \vdots \quad \vdots \\ (l_{n1}, m_{n1}, u_{n1}) & (l_{n2}, m_{n2}, u_{n2}) & \cdots \quad (1,1,1) \end{pmatrix} \tag{1}$$

In which $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij}) = \tilde{a}_{ji}{}^{-1} = \left(\frac{1}{u_{ji}}, \frac{1}{m_{ji}}, \frac{1}{l_{ji}}\right)$ where i, j = 1,...,n and $i \neq j$.

Table 3. Scale of AHP and Triangular Fuzzy Number (TFN).

Scale of AHP	Linguistic Variables	Scale of TFN	Opposite
1	Equally important	(1,1,1)	$(1, 1, 1)$
2	The scale is between equal and slightly more important	(1,2,3)	$\left(\frac{1}{3}, \frac{1}{2}, 1\right)$
3	Slightly more imporant	(2,3,4)	$\left(\frac{1}{4}, \frac{1}{3}, \frac{1}{2}\right)$
4	The scale is between slightly more important and more important	(3,4,5)	$\left(\frac{1}{5}, \frac{1}{4}, \frac{1}{3}\right)$
5	More important	(4,5,6)	$\left(\frac{1}{6}, \frac{1}{5}, \frac{1}{4}\right)$
6	The scale is between more important and really more important	(5,6,7)	$\left(\frac{1}{7}, \frac{1}{6}, \frac{1}{5}\right)$
7	Really more important	(6,7,8)	$\left(\frac{1}{8}, \frac{1}{7}, \frac{1}{6}\right)$
8	The scale is between really more important and absolutely more important	(7,8,9)	$\left(\frac{1}{9}, \frac{1}{8}, \frac{1}{7}\right)$
9	Absolutely more important	(8,9,9)	$\left(\frac{1}{9}, \frac{1}{9}, \frac{1}{8}\right)$

2.2. Fuzzy synthetic extent (Chang's extent method)

The value of fuzzy synthetic extent is used to obtain widening of an object and synthesis of Fuzzy AHP pairwise comparison, so that the value of extent analysis M is acquired, represented as M_{gi}^{1}, M_{gi}^{2}. Following are the steps of extent analysis model [37]:

a. Value of fuzzy synthetic extent for i-object is defined as Eq. (2).

$$Si = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{j=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \tag{2}$$

To obtain M_{gi}^{j}, the summation operation of fuzzy extent analysis *M* for the matrix is done. The operation of each TFN in each line is in equation (3).

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} lj, \sum_{j=1}^{m} mj, \sum_{j=1}^{m} uj\right) \tag{3}$$

where i = 1, 2,..., n. Meanwhile, to obtain the value of $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}$ summation opreation for all the TFN is done M_{gi}^{j} (j = 1,2,...,m).

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right] = \left[\sum_{i=1}^{n} \sum_{j=1}^{m} l_{ij}, \sum_{i=1}^{n} \sum_{j=1}^{m} m_{ij}, \sum_{i=1}^{n} \sum_{j=1}^{m} u_{ij},\right] \tag{4}$$

So that to calculate invers of the initial equation, the following equation is needed (5).

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_1}, \frac{1}{\sum_{i=1}^{n} m_1}, \frac{1}{\sum_{i=1}^{n} l_1}\right) \tag{5}$$

b. Comparative calculation of possibility levels among fuzzy numbers. This comparison is used for weighing values of each criterion. For two TFN namely $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u2)$ with the possibility of $S_2 \geq S_1$, here is the definition:

$$V(M_2 \geq M_1) = \begin{cases} 1 & , if\ m_2 \geq m_1 \\ 0 & , if\ l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & , for\ other \end{cases} \tag{6}$$

To compare M_1 and M_2, we need the value of $V(M_1 \geq M_2)$ and that of $V(M_2 \geq M_1)$. After the fuzzy synthetic value is compared, the minimum value is calculated using the following Eq. (7).

$$D'(A_i) = min\, V\,(S_i \geq S_k) \tag{7}$$

where, k = 1, 2,...., n; $k \neq i$, so that the weighing vector for easier interpretation is defined as follows.

$$W' = [d'(A_1), d'(A_2), \ldots., d'(A_n)]^T \tag{8}$$

where Ai (i = 1, 2,..., n) is n element and $d'(A_i)$ is the value representing relative choices of each decision attribute.

c. Weighing normalization. This process aims to normalize weights in order that the value of vector weight be turned into an analog consisting of non-fuzzy value with the following Eq. (9).

$$d(A_i) = \frac{d'(A_i)}{\sum_{i=1}^{n} d'(A_i)} \tag{9}$$

2.3. Buckley's fuzzy-AHP algorithm (Geometric mean method)

Buckley's Fuzzy AHP algorithm is used to determine weighing criteria as it is more practical in expanding to fuzzy cases and to make sure single solutions for the matrix comparison. In Buckley's method, negative scoring elements are treated as the opposite order of the positive fuzzy numbers [39]. To calculate the weight of W_i, we use Geometric mean method easily by expanding positive reciprocal fuzzy matrix *A* = [a_{ij}]. Following are the steps of ranking each criterion using the method [40, 41]:

a. Calcualting geometric mean of each line as:

$$r_i = \left(\prod_{j=1}^{m} a_{ij}\right)^{\frac{1}{m}} \tag{10}$$

where $\tilde{a}_{ij}$ is the fuzzy comparative value of criterion *i* on criterion *j*, so that $\tilde{r}_i$ is geometric mean of fuzzy comparative value of criterion *i* for each criterion. The results of fuzzy geometric mean $\tilde{r}_i$ is written as follows.

$$\tilde{r}_i = (l_{ri}, m_{ri}, u_{ri}) = \left[\left(\prod_{j=1}^{n} l_{ij}\right)^{\frac{1}{n}}, \left(\prod_{j=1}^{n} m_{ij}\right)^{\frac{1}{n}}, \left(\prod_{j=1}^{n} u_{ij}\right)^{\frac{1}{n}}\right] \tag{11}$$

On other words, to determine the level of importance of geometric mean in each line, we need to take the square root of *n* from the multiplication of values of cells on the matrix line, where *n* is the number of criteria/ alternatives. When $W_i = r_i / (r_1+....+r_m)$, if *A* is consistent, the geometric mean method always results in the same weight with the technique of λ_{max} Saaty and if $m = 3$, both the methods calculate the same weight [42]. This is proven that when $m > 3$, the numeric results for weight in both procedures are close to each other.

b. Calculating the fuzzy weight of each criterion with the following equation.

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \ldots \oplus \tilde{r}_n)^{-1} \tag{12}$$

Or in other words, vertically summing the bottom value (*l*), middle value (*m*), and top value (*u*) for each criterion importance level. For each criterion, the bottom value is divided by the number of top values, and the middle value is divided by the number of middle values, and the top value is divided by the number of bottom values.

c. Defuzzification which involves shifting from the output in a form of fuzzy $\tilde{w}_i$ into output with single value (*crisp*) w_i. After identifying the crisp value of each criterion, we normalize the value by summing all the crisp values with each of the crisp values in each criterion divided by the summation of the crisp value.

3. Results and Discussion

3.1. Results

The proposed model in this study aims to give selection consideration for SPP sites. The decision of proper sites of the SPP is both important and strategic as it affects the amount of energy resulted as well as gives high economic value. The first step of the model development is identifying factors affecting decisions in selecting the SPP site through literature survey. The complete description of each factor is presented in Table 4. In total, there are 15 factors used by experts for considering the site selection of SPP. However, the decision making is likely to face difficulties especially in making priorities. Therefore, simplification is necessary.

Table 4. Important factors in considering site selection of SPP based on literature survey.

No.	Factor	Description
1.	Temperature	Temperature is one of the effective sub-factors affecting solar panel efficiency [43]. The ideal operational temperature is 25ºC, but it usually gets higher when operating [44].
2.	Solar Radiation	Selecting an area with the most solar light crucially affects the desired efficiency. The amount of solar radiation depends on the position of the solar light entry angle, dust, and humidity [45-47].
3.	Emission Gas	When in development, operation, or even under reconstruction, the incoming and outcoming transportation of the SPP will release emission gas. Therefore, areas with low pollution are significantly considered [11].
4.	Water Source	Water availability is also a crucial factor in SPP, especially around dry areas [45].
5.	Land	SPP needs to be developed far from used areas [46]. The land width should also be an effectiveness reason for the SPP [46, 48, 49]. The width should cover the planned SPP area. Generally, a 2-hectare area per MWDC is needed for the site close to the equator.
6.	Tilt	If the land does not feel the tilt requirement, excavation or charging operation in the area will have loss in terms of time and cost [11]. At the same time, it is important to build facilities in a stable area. Within this context, there is no criterion of land tilt with the most suitable solar system plant installation in the relevant regulation [43, 45-49]. In this study, areas with tilt level less than 20% or 3-10% are the subjects of optimum site for SPP. In the analysis, those with more than 20% of tilt level is considered unsuitable [43, 44].
7.	Angle	Viewing flat or steep areas helps to reduce high construction cost [11, 43, 44, 48]. In SPP design, the angle is usually 90º minus the sun elevation angle. This is to maintain the orientation to the solar panel [50].
8.	Road Access	Closer access to the main road gives efficiency as it avoids additional cost for infrastructure. The SPP site had better be close to the main road for better access [44-49]. It is suggested that the distance be 500 m to the road [11].
9.	Distance to the Transmission Line	Close access to the transmission line is able to avoid power loss and additional construction cost [44-49]. The site should be within 3 KM away to the power transmission line [11].
10.	Distance to the City	It is recommended that the SPP sites not be on city centres or villages as it is possible to disturb the people living in the areas and constraint growth of the areas [44-49].
11.	Land Cost	It is recommended that the sites be 200 m from the city [11] and consider the price of the land for the SPP development [44, 48, 51].
12.	Construction Cost	SPP needs good infrastructure system such as main roads, transmission line accessibility, clean water sources, and other infrastructure, particularly with low cost [44, 48].
13.	Operation and Maintenance	This factor considers cost to use for tools and equipment, material, and workers involved [52].
14.	Acceptance of the Society	Big construction is a certain area usually received rejection from the local people due to lack of socialization of the benefits as well as environmental awareness. Therefore, this aspect is in need of serious consideration prior to the construction [51, 52].
15.	Habitat	Solar panel needs to be located far from habitat existence. A solar panel which seems like a lake for birds usually disturbs their migration line causing death to some of them [47].

In this study, there are only 5 predominantly main factors selected by previous researchers. Those five factors include climate, environment, topography, site, and economy (see Table 5). Effective sub-factors for each criterion are created to determine the priorities using both AHP and Fuzzy-AHP.

Table 5. Selection criteria for SPP development.

No.	Effective Factor	Code	Effective Sub-Factors	Code
1	Climate	CL	Temperature Solar radiation	TP SR
2	Environment	EN	Gas emission Water sources Land	GE WR LD
3	Topography	TO	Tilt (ground tilt) Angle's aspect (tilt angle's) Road access	TI AA RA
4	Site	LO	Distance with transmission line Distance to city	DT DC
5	Economy	EC	Land Cost Construction Cost Operation and Maintenance	LC CC OM

The next step is to determine the priority order of each sub-factor. There are 13 sub-factors to be analysed using AHP conventional method in which each criterion has no certainty as to whether it affects the amount of energy or it does not affect with the same level of influence. Table 6 shows the calculation process in determining the impact level of the criteria through pairwise comparison in the AHP scale. To obtain the value of CI and CR, we normalize the matrix and calculate the value. The value of CI is 0.143 and that of CR is 0.092. The matrix is considered consistent if the CR value is less than 10% (CR 0.1). Therefore, it can be concluded that the pairwise comparison matrix is consistent. Figure 1 shows the priority order of effective sub-factors acquired by the AHP method. The attribute of solar radiation (SR) appears to be the main priority in deciding the site of SPP, while that of land cost (LC) is the least prioritized. In the meantime, such attributes as tilt (TI), land (LD), gas emission (GE), and construction cost (CC) have equal priority value. This stage is actually conducted to be able to be compared with decision making process using Fuzzy-AHP.

Table 6. Pairwise comparison of AHP scale.

Sub-factors	TP	SR	GE	WR	LD	TI	AA	LA	DT	DC	LC	CC	OM
TP	1	1	3	3	3	3	3	3	3	3	3	3	3
SR	1	1	3	3	3	3	3	5	5	5	3	3	5
GE	1/3	1/3	1	1	1	1/2	1/3	1	1	5	1	1	1
WR	1/3	1/3	1	1	1/3	1/3	1/3	2	2	2	3	1	3
LD	1/3	1/3	1	3	1	1	1/3	2	2	2	3	1	3
TI	1/3	1/3	2	3	1	1	1	3	3	1/2	3	1/2	1/3
AA	1/3	1/3	3	3	3	1	1	2	2	3	3	3	3
LA	1/3	1/5	1	1/2	1/2	1/3	1/2	1	1	1	2	2	2
DT	1/3	1/5	1	1/2	1/2	1/3	1/2	1	1	1	2	2	1
DC	1/3	1/5	1/5	1/2	1/2	2	1/3	1	1	1	2	1/2	3
LC	1/3	1/3	1	1/3	1/3	1/3	1/3	1/2	1/2	1/2	1	1	1
CC	1/3	1/3	1	1	1	2	1/3	1/2	1/2	2	1	1	3
OM	1/3	1/5	1	1/3	1/3	3	1/3	1/2	1	1/3	1	1/3	1
Pairwise comparison matrix normalization results													
TP	0.176	0.195	0.156	0.149	0.194	0.168	0.265	0.133	0.130	0.114	0.107	0.155	0.102

SR	0,176	0,195	0,156	0,149	0,194	0,168	0,265	0,222	0,217	0,190	0,107	0,155	0,170
GE	0,059	0,065	0,052	0,050	0,065	0,028	0,029	0,044	0,043	0,190	0,036	0,052	0,034
WR	0,059	0,065	0,052	0,050	0,022	0,019	0,029	0,089	0,087	0,076	0,107	0,052	0,102
LD	0,059	0,065	0,052	0,149	0,065	0,056	0,029	0,089	0,087	0,076	0,107	0,052	0,102
TI	0,059	0,065	0,104	0,149	0,065	0,056	0,088	0,133	0,130	0,019	0,107	0,026	0,011
AA	0,059	0,065	0,156	0,149	0,194	0,056	0,088	0,089	0,087	0,114	0,107	0,155	0,102
LA	0,059	0,039	0,052	0,025	0,032	0,019	0,044	0,044	0,043	0,038	0,071	0,103	0,068
DT	0,059	0,039	0,052	0,025	0,032	0,019	0,044	0,044	0,043	0,038	0,071	0,103	0,034
DC	0,059	0,039	0,010	0,025	0,032	0,112	0,029	0,044	0,043	0,038	0,071	0,026	0,102
LC	0,059	0,065	0,052	0,017	0,022	0,019	0,029	0,022	0,022	0,019	0,036	0,052	0,034
CC	0,059	0,065	0,052	0,050	0,065	0,112	0,029	0,022	0,022	0,076	0,036	0,052	0,102
OM	0,059	0,039	0,052	0,017	0,022	0,168	0,029	0,022	0,043	0,013	0,036	0,017	0,034

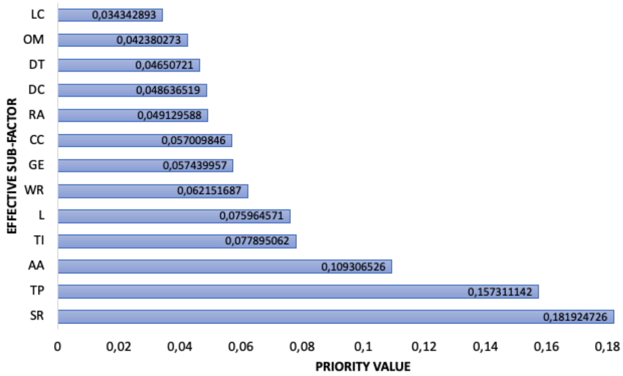
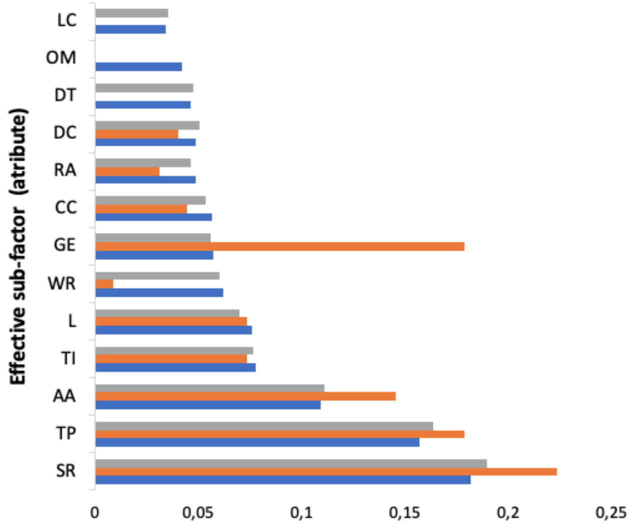


Fig. 1. Priority value of SPP site selection based on AHP.

Priority determination using Fuzzy AHP method starts with pairwise comparison triangular fuzzy number matrix as shown in Table 7. Like the previous stages, this stage aims at evaluating all the criteria by making inter-criterion pairwise comparison. Decision making begins with choosing linguistic expressions translated into triangular fuzzy number matrix. The weigh value of each criterion on the AHP matrix is converted into triangular fuzzy number (TFN) whose weighing refers to the explanation in Table 3. Using Chang's Extent algorithm, we need to identify the value of fuzzy synthetic extent (Si) in accordance with Eqs. (2), (6)-(9) to reach possibility level of each two TFN numbers. Weight of the priority level of each sub-factor can be obtained by determining the minimum fuzzy value and priority vector. The geometric mean method tends to be simple and preferred by designers due to its simplicity. By following Eqs. (10)-(12), we are going to acquire the weight value and priority level of the SPP Site selection. Figure 2 shows the comparison of priority weight value using AHP and Fuzzy-AHP with Chang's Extent algorithm and that using Fuzzy-AHP with geometric mean algorithm.

Table 7. Pairwise comparison triangular fuzzy number matrix.

	SH	RM	GE	…..	CC	OM
SH	(1, 1, 1)	(1, 1, 1)	(2, 3, 4)	…..	(2, 3, 4)	(2, 3, 4)
RM	(1, 1, 1)	(1, 1, 1)	(2, 3, 4)	…..	(2, 3, 4)	(4, 5, 6)
GE	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(1, 1, 1)	…..	(1, 1, 1)	(1, 1, 1)
…..	…..	…..	…..	…..	…..	…..
CC	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(1, 1, 1)	…..	(1, 1, 1)	(2, 3, 4)
OM	(1/4, 1/3, 1/2)	(1/6, 1/5, 1/4)	(1, 1, 1)	…..	(1/4, 1/3, 1/2)	(1, 1, 1)



	SR	TP	AA	TI	L	WR	GE	CC	RA	DC	DT	OM	LC
Geometric Mean	0,19	0,1636	0,1112	0,0764	0,0698	0,0605	0,0564	0,0538	0,0465	0,0508	0,0478	0	0,0357
Chang's Extent	0,2237	0,1789	0,1454	0,0738	0,0738	0,0089	0,1789	0,0447	0,0313	0,0402	0	0	0
AHP	0,1819	0,1573	0,1093	0,0778	0,0759	0,0621	0,0574	0,057	0,0491	0,0486	0,0465	0,0423	0,0343

Fig. 2. Comparison of decision making among three different methods.

3.2. Discussion

An increasing need of power consumption demands humans to innovate in searching renewable energy source alternatives; one of which is SPP. Within the context of this study, the site selection of SPP is one of the important decision-making processes as incorrect site selection leads to negative impacts for the government, private sectors, even the people living around the area. There are several quantitative and qualitative attributes to determine the main factors of the development. This study proposes a performance test of two MCDM methods in selecting SPP site namely AHP classical method and Fuzzy AHP AI-based method as the validator of the classical method. Ideally, the selection of main and sub-factors of the attributes is conducted through direct discussion with experts; however, due to the pandemic, such categorization is performed through literature survey from international journals. This type of searching appears to have its advantages as it enables the researchers to have global perspective from international experts. This technique is also not a new way as previous studies showed so [53, 54].

AHP classical method has been proven to be one of the best methods in solving multi-criteria issues; while AI-based method is the follow-up synthesis from the AHP whenever there are uncertainties in the decision-making results. AHP is considered the right method to choose in selecting the SPP site in order to consider technical and non-technical factors to be evaluated by linguistic variables. Through pairwise comparison, the method has been able to make the best decision in selecting the site. Furthermore, validation of the results of the AHP is needed as the results involve fuzzy variables in need of deviation evaluation. The Fuzzy AHP method has been proven to successfully synthesize experts' opinions to identify weight of each criterion. The method is also able to capture human uncertain thoughts through well-structured stages and simple processes. As both AHP and Fuzzy AHP have been recognized to have high skills in MCDM, it supports the fact that the stronger experts' opinions get, the higher the acceptance level of the opinions [55].

Selecting the main priorities in selection the SPP through AHP and validated by Fuzzy AHP is effective as the results of both the methods share the same priorities. Both the methods relatively give consistent decisions particularly on the top five priorities namely solar radiation, temperature, angle's aspect, tilt (ground tilt), and land use. It is quite obvious that all the five factors are closely relating to technical aspects. Solar radiation aspect is the most prioritized as the solar cell module will be higher when having optimum amount of solar light. Economically, photovoltaic system needs as much as 100 kWh/m^2 solar light per year [56]. Inconsistence and variability of the solar radiation will always be an obstacle in locating the SPP [57], so that surveyors of the site need to make sure that the solar radiation is consistent. The idea solar radiation condition at 1,000 W/m^2 and the temperature of solar cell at 25 C is difficult to reach at the SPP site as the solar lighting is influence by weather; the energy supplied by the solar panel module only reaches 30% of the expected outcome [58]. In addition, ground tilt also belongs to the top priorities as an area to be the SPP site should be free of constraints blocking the solar light. Therefore, tree and other object removal is commonly needed. The PV panel is usually equipped with steel and aluminium supports 1 M above the ground. Therefore, the ground tilt cannot be more than 5%. Even when there are trees around the SPP, they cannot be higher than 1 M [59].

Other top prioritized factors in deciding the site of SPP are angle's aspect and land use. First of all, right angles are going to influence the optimum. amount of solar energy. In some countries, the angles need to be adjusted in accordance with the season they are having. One of the most effective ways to shift the angle is using active sun tracker as the device will be able to automatically adjust the angles and orientation of the solar panels regularly. However, as the device is costly, seasonal adjustment is preferred [60]. Secondly, land use factor is also crucial despite its complexity relating to the government policies and socio-cultural elements. Rejection from the local people frequently occurs as the land use has to take over farming or other productive areas. To this relation, researchers are advised to have a public acceptance study prior to the development of SPP. It is shown that the public behaviours regarding the issue are closely related to socio-cultural aspects rather than low carbon energy issues [61].

4. Conclusion

The improvement of people's well-being is correlated with the increasing amount of power need. This leads to the need of various alternatives in order to reduce pollution from the conventional power plants. One of the most widely developed technologies is solar power plant (SPP). However, to select the best site of SPP is such a difficult decision-making process. To this relation, a Multi-Criteria Decision Making (MCDM) method based on AHP and Fuzzy AHP in supporting the SPP site selection is developed and evaluated. The performance of both classical AHP and Fuzzy AHP methods has proven to show the best method in MCDM problem solving. Both the methods give consistent results of top five priorities of the SPP site selection criteria. Some of the highest priority attributes are solar radiation, temperature, ground tilt, angle’s aspect, and land use. Both the AHP and Fuzzy AHP methods are practical, flexible, and easy to use as a feasibility analysis tool. The result of this study gives a an important refence in revealing important factors to consider in SPP development. The results can also be an important reference for designers and investors of SPP. It is also expected that the results of this study are able to help the government and power companies in formulating their policies regarding the new sites of SPP.

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