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FUZZY AHP AND ITS APPLICATION TO SUSTAINABLE ENERGY PLANNING DECISION PROBLEM

Liana Najib[1] and Lazim Abdullah[2]
[1] Faculty of Computer & Mathematical Sciences, Universiti Teknologi Mara Kedah, 08400 Merbok, Malaysia, [2] Faculty of Ocean Engineering Technology & Informatics, Universiti Malaysia Terengganu, 21030 Kuala Terengganu, Terengganu, Malaysia.
([1] liananajib@uitm.edu.my, [2] lazim_m@umt.edu.my)

The uncertainty during the decision-making process lead to difficulty in understanding the situation of the problems occurs. However, there are lots of mathematical tools that described the multiplicity, complexity and sensitivity of the human thoughts in the decision process todays. To deal with uncertainties of information, the fuzzy set theory is introduced. Thus, the aim of the paper is to evaluate the alternatives selection with respect to sustainable energy planning problems using fuzzy multi criteria decision-making. In this paper, the fuzzy analytic hierarchy process is applied to conduct the relative weights priority of energy planning selection. The study suggests that Combined Heat and Power (CHP) system is recommended for the sustainable energy planning decision compared to other options of energy.

***Keywords*:** energy planning, fuzzy analytic hierarchy process, fuzzy sets, decision-making

1. Introduction

In the 1960s, Zadeh (1965) define a fuzzy sets theory to mathematically deal with the uncertainty and ambiguity of human thought via approximate information to generate decisions. Bouchon-Meunier et al., (1997) stated that the fuzzy sets generate human natural description of the knowledge. Over the past four decades, fuzzy set theory has gained its popularity and the increasing numbers of published research in this theory began to appear. It has further been used to develop formalized tools to deal with the imprecision to a wide variety of multi-criteria decision-making (MCDM) problems. With this popularity, fuzzy sets are well-known as the most adaptable in mathematical tools for modeling uncertainty measurements in the system. A major contribution of fuzzy sets theory is the capability and feasibility of representing the vague information. At times, the decision makers (DMs) are usually unable to explicitly explain the uncertainty due to fuzzy nature of the decision-making process. Furthermore, the usage of subjective preference scales of information judgement will lead to human desire error. This point motivates the researchers to introduce the implementation of interval or fuzzy judgements instead of crisp numbers (Bozbura & Beskese, 2007). The information involved in the decision-making problem may not be appropriate to express them by exact numerical values. It is more suitable to describe them by means of linguistic variables. Hence, linguistic information has frequently been applied to MCDM problems (Zhang et al., 2011). Then, the a well-known MCDM method which is analytic hierachy process (AHP) is extended using the basis concept of fuzzy sets theory known as Fuzzy Analytic Hierarchy Process (FAHP).

To date, the FAHP method is widely applied in MCDM problems such as sustainable energy (Ren and Dong, 2018; Wu et al., 2018; Solangi et al., 2019) or energy planning (Luthra et al., 2015) due to its simultaneously consideration of the reliable and non-reliable solutions, and feasible computation procedures. Recently, Solangi et al. (2021) used FAHP method to overcome the renewable energy barriers which obstruct the development of renewable energy technologies in Pakistan. In Malaysia, the primary energy sources such as crude oil, natural gas and conventional fuels are extremely limited resources as the geological process thorough solar energy accumulation over millions of years. This results on energy fluctuations in reserves and prices due to increase costs of power station (Al-Mofleh et al., 2009). Besides, the government's energy policy also need to tackle the challenges on optimizing resources, environmental issues such as global warming and demanding management due to economic growth. The rises of energy issues have made the sustainable energy planning as a prime solution to secure the energy demands and depletes resources. Therefore, it is compulsory to greatly preserve the energy resources to improve the sustainability, efficiency and realibility of energy development and minimize negative impact on environmental on energy supply chain. In this study, a sustainable energy planning decision problem is applied to FAHP method. This paper proceeds as follows. An overview of FAHP method is presented in Section 2. The implementation of FAHP with illustrative computation is presented in Section 3. Finally, a short conclusion is given in Section 4.

2. An Overview of Fuzzy Analytic Hierarcy Process (FAHP)

Let $X = \{x_1, x_2, ..., x_n\}$ be an object set, $U = \{u_1, u_2, ..., u_n\}$ be goal set. According to Chang (1992; 1996) each object is taken and extent analysis for each goal g_i is performed, respectively. Therefore, m extent analysis values for each object can be obtained by $M_{g_i}^{i}, M_{g_i}^{2}, ..., M_{g_i}^{m},\ \ i = 1, 2, ..., n$ where all then $M_{g_i}^{i}\ (j = 1, 2, ..., n)$ are triangular fuzzy numbers (TFN) whose parameters are l, m and u.
The steps of Chang's (1992; 1996) extent analysis can be described as the following followed by Lambda-max computation by Najib and Abdullah (2013) for consistency test.

Step 1: Constructing a hierarchical diagram of MCDM problem.

Step 2: Linguistic variable for pair-wise comparison matrices. The TFN and its reciprocated values are given in Table 1.

Table 1: Fuzzy Conversion Scale (Chang, 1992; Bozbura and Beskese, 2007)

Linguistic scale	TFN scale	TFN reciprocal scale
Just equal (E)	(1,1,1)	(1,1,1)
Equally important (EI)	(1/2,1,3/2)	(2/3,1,2)
Weakly more important (WMI)	(1,3/2,2)	(1/2,2/3,1)
Strongly more important (SMI)	(3/2,2,5/2)	(2/5,1/2,2/3)
Very strongly more important (VSMI)	(2,5/2,3)	(1/3,2/5,1/2)
Absolutely more important (AMI)	(5/2,3,7/2)	(2/7,1/3,2/5)

Step 3: In this step, the consistency test of the pair-wise comparison matrices is calculated by (1) (Najib and Abdullah, 2013).

$$\lambda_{\max} = Det\left[\begin{vmatrix} 1-\lambda & \frac{(l+m+u)_{12}}{3} & \cdots & \frac{(l+m+u)_{n}}{3} \\ \frac{(l+m+u)_{21}}{3} & 1-\lambda & \cdots & \frac{(l+m+u)_{n}}{3} \\ \vdots & \cdots & 1-\lambda & \vdots \\ \frac{(l+m+u)_{n}}{3} & \cdots & \cdots & 1-\lambda \end{vmatrix}\right] \tag{1}$$

where l and u represent the lower and upper bounds of the fuzzy numbers $\tilde{A}$, respectively, and m is the median value. The TFN is denoted as $\tilde{A} = (l, m, u)$.

Saaty (1990) suggests the pair-wise comparison matrix can pass the consistency test, if the consistency ratio $C.R.=\frac{C.I.}{RI}<0.1$, where the consistency index, $C.I=\frac{\lambda_{max}-n}{n-1}$, RI is the average random index based on matrix size, λ_{max} is the maximum eigenvalues of a matrix comparison of judgment and n is the order of the matrix comparison. Matrix comparison is an acceptable if the ratio of $C.R.<0.1$. Random index (RI) represents the average consistency index over numerous random entries of the same order reciprocal matrices. This relationship is shown in Table 2.

Table 2: Random indices (RI) of sizes of matrices

n	1-2	3	4	5	6	7	8	9
RI	0.0	.58	.90	1.12	1.24	1.32	1.41	1.45

Step 4: The value of fuzzy synthetic extent with respect to the ith object is defined as

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

To obtain $\sum_{j=1}^{m}M_{g_i}^{j},\ \forall i=(1,2,...,n)$, the fuzzy addition operation of m extent analysis values for a particular matrix is performed such that

$$\sum_{j=1}^{m}M_{g_i}^{j}=\left(\sum_{j=1}^{m}l_j,\sum_{j=1}^{m}m_j,\sum_{j=1}^{m}u_j\right) \tag{3}$$

And to obtain $\left[\sum_{i=1}^{n}\sum_{j=1}^{m}M_{g_i}^{j}\right]^{-1}$, perform the fuzzy addition operation of $M_{g_i}^{i}\ (j=1,2,...,n)$ values such that

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m}M_{g_i}^{j}\right]^{-1}=\left(\frac{1}{\sum_{i=1}^{n}u_i},\frac{1}{\sum_{i=1}^{n}m_i},\frac{1}{\sum_{i=1}^{n}l_i}\right) \tag{4}$$

Step 5: The degree of possibility of $M_2=(l_2,m_2,u_2)\geq M_1=(l_1,m_1,u_1)$ is defined as

$$V(M_2\geq M_1)=\sup_{y\geq x}\left[\min\left(\mu_{M_1}(x),\mu_{M_2}(y)\right)\right] \tag{5}$$

Can be equivalently expressed as $V(M_2\geq M_1)=hgt(M_1\cap M_2)=\mu_{M_2}(d)$

$$=\begin{cases}1, & \text{if } m_2\geq m_1\\ 0, & \text{if } l_1\geq u_2\\ \frac{l_1-u_2}{(m_2-u_2)-(m_1-_{l1})}, & \text{otherwise}\end{cases} \tag{6}$$

To compare M_1 and M_2, we need both the values of $V(M_1\geq M_2)$ and $V(M_2\geq M_1)$.

Step 6: The degree possibility for a convex fuzzy number to be greater than k convex fuzzy $M_i\ (i=1,2,...,k)$ can be defined by $V(M\geq M_1,M_2,...,M_k)=V\left[(M\geq M_1)\text{ and }(M\geq M_2)\text{ and ... and }(M\geq M_k)\right]$

$$=\min V(M\geq M_i),\ i=1,2,3,...,k \tag{7}$$

Assume that $d'(A_i) = \min V(S_i \geq S_k)$ (8)

For $k = 1, 2, ..., n; k \neq i$. The weight vector is given by

$$W' = \left(d'(A_1), d'(A_2), ..., d'(A_n)\right)^T \quad (9)$$

Where $A_i\ (i = 1, 2, ..., n)$ are n elements.

Step 7: Via normalization, the normalized weight vectors are

$$W = \left(d'(A_1), d'(A_2), ..., d'(A_n)\right)^T \quad (10)$$

Decision matrix is normalized via the following TOPSIS equation:

$$r_{ij} = \frac{w_{ij}}{\sqrt{\sum_{j=1}^{j} w_{ij}^2}},\ j = 1, 2, 3, ..., j\ i = 1, 2, 3, ..., n \quad (11)$$

Step 8: Rank all the alternatives.
Computing the relative weight and ranking the alternatives.

$$W_i = \sum w_i A_{ij} \quad (12)$$

where

$w_i =$ Overall relative rating for alternatives *i*

$w_i =$ Average normalized weight for criteria *j*

$A_{ij} =$ Average normalized weights aggregated matrix for criteria *j* with respects to alternatives *i*.

3. Implementation of FAHP to Sustainable Energy Planning

The evaluation of the energy planning system from Wang et al., (2009) will be used in this framework procedures. For the selection purpose, a set of alternatives, attributes/criterion and DMs under consideration, and also their abbreviations are given. The set of alternatives can be given as $A = \{A_i\}, (i = 1, 2, 3, 4, 5, 6, 7)$ where A_1 is Conventional energy, A_2 is Nuclear energy, A_3 is Solar energy, A_4 is Wind energy, A_5 is Hydraulic systems, A_6 is Biomass energy and A_7 is CHP system. The selected criterion is made on the basis of nine attributes covered by four aspects which are 'Efficiency' (C_1), 'Exergy efficiency' (C_2), 'Investment cost' (C_3), 'Operation and maintenance cost' (C_4), 'NO_x emission' (C_5), 'CO_2 emission' (C_6), 'Land use' (C_7), 'Social acceptability' (C_8) and 'Job creation' (C_9). The alternatives of the case study then are evaluated by three DMs whose are expert in sustainable and renewable energy planning. The background information of the DMs that are used in this study are given in Table 3.

Table 3: The background information of the DMs

Organization	Expertise	Experiences (in years)
Government instituition (DM1)	Energy/Wave renewable	>10
Government instituition (DM2)	Renewable Energy Research (Solar, Wind & Wave energy)	>10
Government instituition (DM3)	Energy renewable/planning	>10

Step 1: Figure 1 illustrates the sustainable energy planning hierachical diagram.

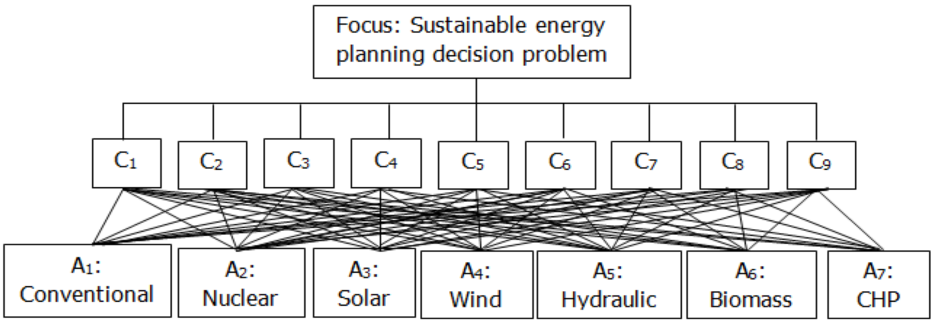


Figure 1: Sustainable Energy Planning Hierachical Diagram

Step 2: The DMs' linguistics variables for the criteria and alternatives are constructed. Table 4 shows the DM1's TFN scale. Noted that, every DMs has their own preference scale. The shaded boxes represent the pair-wise comparisons of the DMs' evaluation using TFN reciprocal scale.

Table 4: DM1 Pair-wise comparison of criterion

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	(1,1,1)				SMI	SMI			
C_2	VSMI	(1,1,1)			SMI	SMI			
C_3	VSMI	VSMI	(1,1,1)		WMI	WMI		WMI	
C_4	VSMI	VSMI	AMI	(1,1,1)	SMI	SMI			
C_5					(1,1,1)	SMI	VSMI	VSMI	
C_6						(1,1,1)	VSMI	VSMI	
C_7	WMI	WMI	AMI	VSMI			(1,1,1)		
C_8	WMI	WMI		WMI			SMI	(1,1,1)	
C_9	SMI	SMI	SMI	SMI	WMI	WMI	SMI	SMI	(1,1,1)

Step 3: Consistency test of the pair-wise comparison matrices. The aggregated judgment matrices are shown in Table 5.

Table 5: DM1 Aggregated Fuzzy Judgment Matrix of Criterion

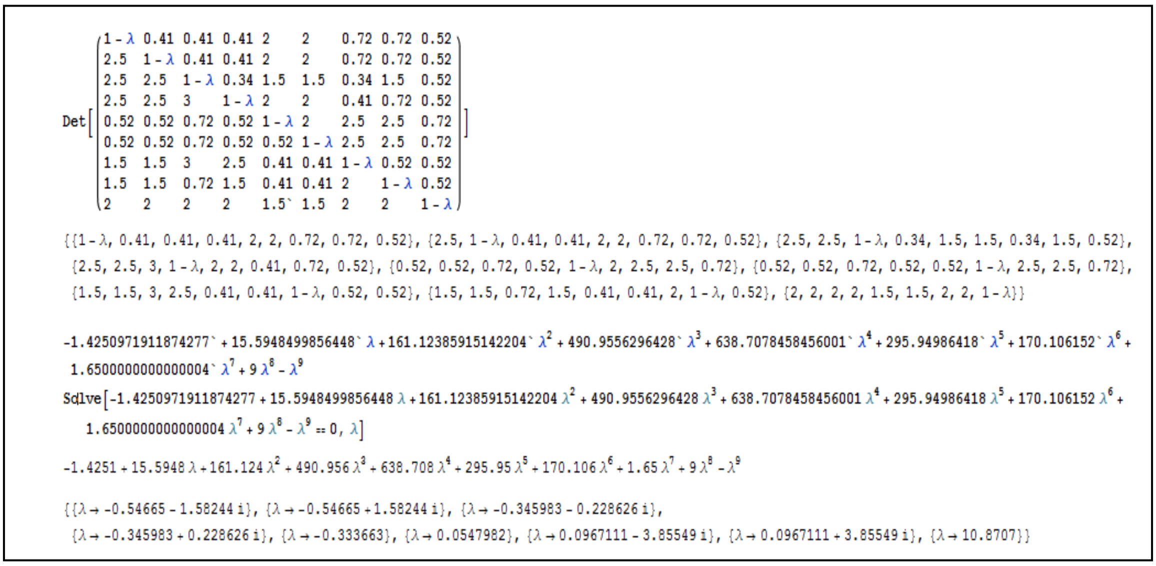
Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	**1**	0.41	0.41	0.41	2	2	0.72	0.72	0.52
C_2	2.5	**1**	0.41	0.41	2	2	0.72	0.72	0.52
C_3	2.5	2.5	**1**	0.34	1.5	1.5	0.34	1.5	0.52
C_4	2.5	2.5	3	**1**	2	2	0.41	0.72	0.52
C_5	0.52	0.52	0.72	0.52	**1**	2	2.5	2.5	0.72
C_6	0.52	0.52	0.72	0.52	0.52	**1**	2.5	2.5	0.72
C_7	1.5	1.5	3	2.5	0.41	0.41	**1**	0.52	0.52
C_8	1.5	1.5	0.72	1.5	0.41	0.41	2	**1**	0.52
C_9	2	2	2	2	1.5	1.5	2	2	**1**

The consistency test could be computed (1). Based on the computations (Figure 2), the value of $\lambda_{\max} = 10.8707$. The consistency test for the information from Table 5 is shown below:

$$C.I = \frac{\lambda_{\max} - n}{n - 1} = \frac{10.8707 - 9}{8} = 0.2338$$

$$C.R. = \frac{0.2338}{1.45} = 0.16$$

With the consistency ratio (*C.R*) greater than 0.1, it could be concluded that the matrix judgment was unacceptable and the consistency test failed. Inconsistency during the decision process would lead to this situation. Thus, it is advised that the matrix judgement should be redo to meet the consistency ratio needed which is less than 0.1. Table 6 summarized the consistency test of the DMs.



```
     (1-λ  0.41 0.41 0.41 2    2    0.72 0.72 0.52)
     (2.5  1-λ  0.41 0.41 2    2    0.72 0.72 0.52)
     (2.5  2.5  1-λ  0.34 1.5  1.5  0.34 1.5  0.52)
     (2.5  2.5  3    1-λ  2    2    0.41 0.72 0.52)
Det[ (0.52 0.52 0.72 0.52 1-λ  2    2.5  2.5  0.72) ]
     (0.52 0.52 0.72 0.52 0.52 1-λ  2.5  2.5  0.72)
     (1.5  1.5  3    2.5  0.41 0.41 1-λ  0.52 0.52)
     (1.5  1.5  0.72 1.5  0.41 0.41 2    1-λ  0.52)
     (2    2    2    2    1.5` 1.5  2    2    1-λ )

{{1-λ, 0.41, 0.41, 0.41, 2, 2, 0.72, 0.72, 0.52}, {2.5, 1-λ, 0.41, 0.41, 2, 2, 0.72, 0.72, 0.52}, {2.5, 2.5, 1-λ, 0.34, 1.5, 1.5, 0.34, 1.5, 0.52},
 {2.5, 2.5, 3, 1-λ, 2, 2, 0.41, 0.72, 0.52}, {0.52, 0.52, 0.72, 0.52, 1-λ, 2, 2.5, 2.5, 0.72}, {0.52, 0.52, 0.72, 0.52, 0.52, 1-λ, 2.5, 2.5, 0.72},
 {1.5, 1.5, 3, 2.5, 0.41, 0.41, 1-λ, 0.52, 0.52}, {1.5, 1.5, 0.72, 1.5, 0.41, 0.41, 2, 1-λ, 0.52}, {2, 2, 2, 2, 1.5, 1.5, 2, 2, 1-λ}}

-1.4250971911874277` + 15.5948499856448` λ + 161.12385915142204` λ^2 + 490.9556296428` λ^3 + 638.7078458456001` λ^4 + 295.94986418` λ^5 + 170.106152` λ^6 +
 1.6500000000000004` λ^7 + 9 λ^8 - λ^9
Sdlve[-1.4250971911874277 + 15.5948499856448 λ + 161.12385915142204 λ^2 + 490.9556296428 λ^3 + 638.7078458456001 λ^4 + 295.94986418 λ^5 + 170.106152 λ^6 +
   1.6500000000000004 λ^7 + 9 λ^8 - λ^9 == 0, λ]
-1.4251 + 15.5948 λ + 161.124 λ^2 + 490.956 λ^3 + 638.708 λ^4 + 295.95 λ^5 + 170.106 λ^6 + 1.65 λ^7 + 9 λ^8 - λ^9

{{λ → -0.54665 - 1.58244 i}, {λ → -0.54665 + 1.58244 i}, {λ → -0.345983 - 0.228626 i},
 {λ → -0.345983 + 0.228626 i}, {λ → -0.333663}, {λ → 0.0547982}, {λ → 0.0967111 - 3.85549 i}, {λ → 0.0967111 + 3.85549 i}, {λ → 10.8707}}
```

Figure 2: Computations of Lambda-Max

Table 6: Summary of Consistency Test for FAHP Preference Scale

Linguistic Preference scale of the DMs	Judgment element	λ_{max}	$\lambda_{max} \geq n$	Consistency Ratio, CR	Consistency Test
DM1	C_1 to C_9	10.8707	Yes	0.16	Failed
	C_1 to A_1... A_7	8.1411	Yes	0.14	Failed
	C_2 to A_1... A_7	7.7947	Yes	0.10	Passed
	C_3 to A_1... A_7	7.6507	Yes	0.08	Passed
	C_4 to A_1... A_7	7.8216	Yes	0.10	Passed
	C_5 to A_1... A_7	7.5499	Yes	0.07	Passed
	C_6 to A_1... A_7	7.5499	Yes	0.07	Passed
	C_7 to A_1... A_7	7.5143	Yes	0.06	Passed
	C_8 to A_1... A_7	7.6493	Yes	0.08	Passed
	C_9 to A_1... A_7	7.6822	Yes	0.09	Passed
DM2	C_1 to C_9	9.9379	Yes	0.08	Passed
	C_1 to A_1... A_7	7.9940	Yes	0.12	Failed
	C_2 to A_1... A_7	7.5165	Yes	0.07	Passed
	C_3 to A_1... A_7	7.5297	Yes	0.07	Passed
	C_4 to A_1... A_7	7.3085	Yes	0.05	Passed
	C_5 to A_1... A_7	8.7539	Yes	0.22	Failed
	C_6 to A_1... A_7	8.7539	Yes	0.22	Failed
	C_7 to A_1... A_7	8.7257	Yes	0.21	Failed
	C_8 to A_1... A_7	7.6772	Yes	0.08	Passed
	C_9 to A_1... A_7	7.9502	Yes	0.12	Failed
DM3	C_1 to C_9	9.5269	Yes	0.05	Passed
	C_1 to A_1... A_7	7.2095	Yes	0.03	Passed
	C_2 to A_1... A_7	7.2095	Yes	0.03	Passed
	C_3 to A_1... A_7	7.2357	Yes	0.03	Passed
	C_4 to A_1... A_7	7.2357	Yes	0.03	Passed

	C_5 to A_1... A_7	7.3287	Yes	0.04	Passed
	C_6 to A_1... A_7	7.3287	Yes	0.04	Passed
	C_7 to A_1... A_7	7.2577	Yes	0.03	Passed
	C_8 to A_1... A_7	7.3397	Yes	0.04	Passed
	C_9 to A_1... A_7	7.2061	Yes	0.03	Passed

Step 4: The pair-wise comparisons information are used to determine the value of fuzzy synthetic extent with respect to main goal by (2), (3) and (4). The calculation for TFN scale is shown as below:

$$S_{C_1} = (6.40, 8.03, 10.17) \times (\frac{1}{125.63}, \frac{1}{101.33}, \frac{1}{79.50}) = (0.05, 0.08, 0.13)$$

$$\vdots$$

$$S_{C_9} = (12.0, 16.0, 20.0) \times (\frac{1}{125.63}, \frac{1}{101.33}, \frac{1}{79.50}) = (0.09, 0.16, 0.25)$$

Step 5: The degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ is defined. Next, based on the information in step 4, the degree of possibility and computed using (6):

$$\mathrm{V}(\mathrm{S}_{C_1} \geq \mathrm{S}_{C_2}) = 0.5,\ \mathrm{V}(\mathrm{S}_{C_1} \geq \mathrm{S}_{C_3}) = 0.25,\ \mathrm{V}(\mathrm{S}_{C_1} \geq \mathrm{S}_{C_4}) = 0, \mathrm{V}(\mathrm{S}_{C_1} \geq \mathrm{S}_{C_5}) = 0.34, \mathrm{V}(\mathrm{S}_{C_1} \geq \mathrm{S}_{C_6}) = 0.66$$

$$\mathrm{V}(\mathrm{S}_{C_1} \geq \mathrm{S}_{C_7}) = 0.27,\ \mathrm{V}(\mathrm{S}_{C_1} \geq \mathrm{S}_{C_8}) = 0.68,\ \mathrm{V}(\mathrm{S}_{C_1} \geq \mathrm{S}_{C_9}) = 0.$$

The computation is calculated for vector of each criterion and alternatives.

Step 6: The degree possibility for a convex fuzzy number to be greater than k convex fuzzy $\mathrm{M_i}\ (\mathrm{i} = 1, 2, ..., \mathrm{k})$ is defined. The minimum degree of possibility is found (7):

$$d'(S_{C_1}) = \min(0.50, 0.25, 0, 0.34, 0.66, 0.27, 0.68, 0) = 0$$

$$\vdots$$

$$d'(S_{C_9}) = \min(1,1,1,1,1,1,1,1) = 1.0$$

These values yield the following weights vector $\mathrm{W}' = (0, 0.10, 0.36, 0.79, 0.23, 0.54, 0.28, 0.55, 1.0)^{\mathrm{T}}$.

Step 7: Via normalization with (11), the weights priorities of the main criteria are calculated as follows:

$$\mathrm{r_{ij}} = \frac{\mathrm{w_{ij}}}{\sqrt{\sum_{j=1}^{j} \mathrm{w_{ij}^2}}}$$

$$\mathrm{r}_{C_2} = \frac{0.10}{\sqrt{(0)^2 + (0.10)^2 + (0.36)^2 + (0.79)^2 + (0.23)^2 + (0.54)^2 + (0.28)^2 + (0.55)^2 + (1.0^2)}}$$
$$= 0.0264$$

As the calculation is made, the weight priorities of each criterion is,
$\mathrm{W} = (0, 0.0264, 0.0940, 0.2070, 0.0584, 0.1390, 0.0727, 0.1428, 0.2594)$.

Step 8: The final results of weight are computed by (12). Table 7 summarized the DM1 final weight and rank on alternatives problems.

Table 7: DM1 Final Priority Weight of Sustainable Energy Planning Alternatives

Main criteria of the goal										
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	
Weight	0.0000	0.0265	0.0941	0.2070	0.0584	0.1390	0.0728	0.1428	0.2594	Final priority weight
Alternative										
A_1	0.0000	0.0941	0.0000	0.0000	0.2717	0.2717	0.0000	0.0000	0.0000	0.0561
A_2	0.6309	0.7841	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0207
A_3	0.0000	0.0000	0.0000	0.0000	0.2557	0.2557	0.0000	0.0000	0.0000	0.0505
A_4	0.0000	0.0000	0.0965	0.0843	0.3601	0.3601	0.0440	0.0658	0.0000	0.1102
A_5	0.0000	0.0000	0.1813	0.1844	0.0924	0.0924	0.1925	0.1596	0.1058	0.1377
A_6	0.0435	0.1218	0.3482	0.3099	0.0201	0.0201	0.3235	0.2479	0.3439	0.2523
A_7	0.3256	0.0000	0.3740	0.4215	0.0000	0.0000	0.4400	0.5267	0.5503	0.3724

The overall weight and rank of sustainable energy planning are obtained by arithmetic mean of the experts' final weight of alternatives with respect to each criterion. Table 8 summarized the DMs final weight and rank on alternatives problems.

Table 8: Weight of Sustainable Energy Planning Problem

	Priority weight DM1	Priority weight DM2	Priority weight DM3	Final Weights	Rank
A_1	0.0561	0.0000	0.2073	0.0878	5
A_2	0.0207	0.0000	0.3877	0.1361	3
A_3	0.0505	0.0000	0.3496	0.1333	4
A_4	0.1102	0.0269	0.0555	0.0642	7
A_5	0.1377	0.0863	0.0000	0.0747	6
A_6	0.2523	0.3501	0.0000	0.2008	2
A_7	0.3724	0.5367	0.0000	0.3030	1

Based on Table 8, the ranking of alternatives in descending order are $A_7 \succ A_6 \succ A_2 \succ A_3 \succ A_1 \succ A_5 \succ A_4$. According to the framework FAHP steps, the best alternative is A_7 (CHP system) by 30.30% weight averaging followed by Biomass energy (20.8%), Nuclear energy (13.61%), Solar energy (13.33%), Conventional energy (8.78%), Hydraulic power (7.74%) and Wind energy (6.42%).

3.1 Comparative Analysis

The analysis of the results is including the specification of each AHP based method framework of sustainable energy planning. The three methods are significantly computed with the data information provided by the DMs. Based on the analysis, the ranking order of the three AHP based methods can be seen in Figure 3. The results show that AHP, FAHP and Intuitionistic Fuzzy AHP (IF-AHP) were ranked different alternatives for sustainable energy planning selection. Besides, there were also inconsistent relative weights of each alternative among the three methods especially computation by FAHP. There are highly different percentages among the alternatives weights by using FAHP method. However, compared to AHP and proposed IF-AHP analysis described that the weights averaging were approaching to each other with a slight difference. The relative weights of alternatives using AHP and IF-AHP were seen as almost equivalent although the degrees of weights are different.

Through the AHP based methods are purposely same, but finally the relative weights of alternatives values are different for each other. From the results, it can be seen that different approaches of preferences scale and method itself gives different values for each alternative. Fortunately, based on the analysis of results for IF-AHP procedures managed to cover the huge different of weights between AHP original model. There were small diverse for values of each alternative weight.

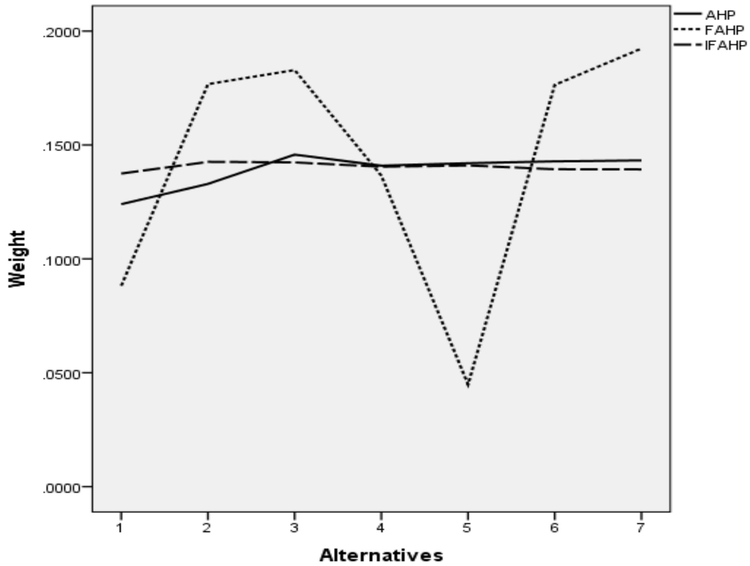


Figure 3: Priority weight of AHP, FAHP and IF-AHP energy alternatives

From the analysis, the best alternative selected by the three methods were A_3 (Solar energy), A_7 (CHP system) and A_2 (Nuclear energy). Thus, among these energy sources can be choose to adapt and develop in Malaysia. For more convenient, averaging weighted out of this three method also can be used to select the best alternative as a recommendation. Figure 4 suggets the final best alternative which is A_7 (CHP system) by 15.82% followed by Solar energy (15.70%), Biomass (15.26%), Nuclear (15.07%), Wind (13.93%), Conventional (11.66%) and Hydraulic (10.93%).

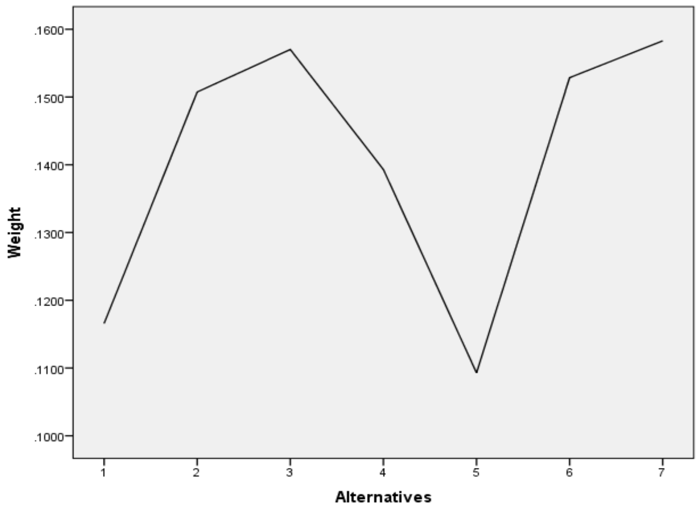


Figure 4: Average alternatives weight by AHP-based methods

4. Conclusions

The extension of FAHP method generously help the current researchers by providing the systematic process for comparing, weighting, and ranking the multiplicity of alternatives for an uncertainty environment. In this study, the result shows that the weight priorities of each energy planning alternative are slightly approximate to each other. There are slightly differ of weight values and seen to be consistent with each other's and it is suggests that CHP system is recommended for the sustainable energy planning decision compared to other alternatives. Furthermore, CHP system system has been widely used to solve building-related energetic problems and environmental issues due to its energy-saving and pollutant emission reduction potentials. CHP system is known to have an ability in generating both electricity and heat in one single process compared to conventional system. In other words, CHP technology can be used to reduce the energy usage and CO_2 emission. Thus, CHP system is generally become the DMs suggestion compared to the others alternatives. In further research, the validity of the comparison using sensitivity analysis can be done to strengthen the framework study.

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