Taylor & Francis
Taylor & Francis Group

International Journal of Sustainable Energy

ISSN: 1478-6451 (Print) 1478-646X (Online) Journal homepage: http://www.tandfonline.com/loi/gsol20

Sustainable energy planning decision using the intuitionistic fuzzy analytic hierarchy process: choosing energy technology in Malaysia

Lazim Abdullah & Liana Najib

To cite this article: Lazim Abdullah & Liana Najib (2016) Sustainable energy planning decision using the intuitionistic fuzzy analytic hierarchy process: choosing energy technology in Malaysia, International Journal of Sustainable Energy, 35:4, 360-377, DOI: 10.1080/14786451.2014.907292

To link to this article: http://dx.doi.org/10.1080/14786451.2014.907292

Published online: 23 Apr 2014.

International Journal of Sustainable Energy, 2016
Vol. 35, No. 4, 360–377, http://dx.doi.org/10.1080/14786451.2014.907292

Taylor & Francis
Taylor & Francis Group

Sustainable energy planning decision using the intuitionistic fuzzy analytic hierarchy process: choosing energy technology in Malaysia

Lazim Abdullah* and Liana Najib

School of Informatics and Applied Mathematics, University Malaysia Terengganu, 21030 Kuala Terengganu, Terengganu, Malaysia

(*Received 1 October 2013; accepted 13 March 2014*)

Energy consumption for developing countries is sharply increasing due to the higher economic growth due to industrialisation along with population growth and urbanisation. The increasing demand of energy leads to global energy crisis. Selecting the best energy technology and conservation requires both quantitative and qualitative evaluation criteria. The fuzzy set-based approach is one of the well-known theories to handle fuzziness, uncertainty in decision-making and vagueness of information. This paper proposes a new method of intuitionistic fuzzy analytic hierarchy process (IF-AHP) to deal with the uncertainty in decision-making. The new IF-AHP is applied to establish a preference in the sustainable energy planning decision-making problem. Three decision-makers attached with Malaysian government agencies were interviewed to provide linguistic judgement prior to analysing with the new IF-AHP. Nuclear energy has been decided as the best alternative in energy planning which provides the highest weight among all the seven alternatives.

Keywords: energy technology; energy planning; intuitionistic fuzzy sets; analytic hierarchy process; multi-criteria decision-making

1. Introduction

Sustainable energy planning refers to man-made long-range policies which use resources to meet mankind needs while preserving the environment to help the foreseeable future of a local, national, regional and global energy system. The main points of sustainable energy planning are to optimise energy efficiency, low-or-no carbon energy emissions, and equitable energy services provision to users. The worldwide energy crisis simultaneously moves beyond the threats of climate change, greenhouse effects, toxic pollutants and air pollutants especially for developing countries (Wang et al. 2009). Usually, developing countries need to overcome the increasing demand of growth mainly due to industrialisation, population growth and urbanisation which leads to increase in demand for energy (UNDP 2006). Globally, energy demand seems to increase every annum due to the anticipated higher gross domestic product growth. Besides, the transportation and industrial sectors will persist to be the major energy consumers by 41.1% and 38.8% of the total energy demand by 2010 in Malaysia (UNDP 2006). The primary energy sources such as crude oil, natural gas and conventional fuels are extremely limited resources formed by the process

*Corresponding author. Email: lazim_m@umt.edu.my

through solar energy accumulation over millions of years because of energy fluctuations in reserves and prices due to the increased costs of power station (Al-Mofleh et al. 2009). The increase in energy costs has made the energy planning and efficiency as a prime option to prevent the energy demands and costs. Thus, it is compulsory to highly maintain sustainable energy planning to ensure efficient utilisation of energy sources, diversification of sources and minimisation of wastages.

However, due to the complexity in choosing among various alternative energy sources and technologies of energy planning decision problems, multi-criteria decision-making (MCDM) is used as solvable tools. Furthermore, MCDM has been attracting increasing attention since a long time. MCDM includes decision support and evaluation for addressing complex problems featuring high uncertainty, conflicting objectives, multi interests and perspectives (Kaya and Kahraman 2011). Various applications of sustainable energy planning are adapted in MCDM (Buchholz et al. 2009; Doukas, Andreas, and Psarras 2007; Jing, Bai, and Wang 2012) approaches such as technique for order performance by similarity to ideal solution, weighted sum method, weighted product method, preference ranking organisation method for enrichment evaluation (PROMETHEE), the elimination and choice translating reality (ELECTRE), multi-attribute utility theory and analytic hierarchy process (AHP). The most appropriate MCDM technique that is frequently used in energy planning area is AHP followed by PROMETHEE and ELECTRE (Pohekar and Ramachandran 2004). The main advantage of the AHP is its inherent ability to handle intangibles, less-cumbersome mathematical calculations and it is more easily comprehended in comparison with other methods. However, in most cases of AHP procedures, the decision-makers are usually unable to explicitly explain the uncertainty due to the fuzzy nature of the decision-making process. This point motivates the notion that AHP helps them to provide an ability of giving interval or fuzzy judgments instead of crisp numbers (Bozbura and Beskese 2007).

The theory of intuitionistic fuzzy set (IFS) was developed by Atanassov in 1986 to represent vague and incomplete information. It considers degree of an element belongs to membership function and non-membership function. The notation of IFS is a sequel of fuzzy sets theory by Zadeh (1965) to handle uncertainty and fuzziness more effectively than fuzzy sets. Similar to the fuzzy set, the IFS was also applied to stimulate the human decision-making process (Szmidt and Kacprzyk 1996) in various fields such as in medical (De, Biswas, and Roy 2001), topology (Turanli and Coker 2000), economic (Chen and Li 2011), environmental (Xu 2007a) and social sciences (Wang 2009). The concept of IFS can be viewed as an alternative approach to define a fuzzy set in cases where available information is not sufficient for the definition of an imprecise concept by means of a conventional fuzzy set (Li 2005). An algorithm for solving MCDM problems has been provided by Atanassov (1986) in which the weights' criteria are given by the crisp number and the values are interpreted in intuitionistic fuzzy numbers.

Advances research of the AHP method using the IFS theory has been explored by several researchers. Many attempts have been suggested in the literature to incorporate different types of IFS in the formal AHP framework. For example, Rehan and Solomon (2009) introduced intuitionistic fuzzy AHP (IF-AHP) in environmental decision-making which expressed the vagueness using the fuzzification factor to generalise the fuzzy pair-wise comparison matrix of three vertices of the crisp number of Saaty's AHP preference scale measurement as the IFS notation. Thus, the pair-wise comparison can be generalised as the minimum and maximum values of a membership value of zero and the most likely value has a membership of one. Abdullah, Sunadia, and Imran (2009) proposed a new AHP using two notations of the IFS membership function and non-membership function without considering values of the hesitation degree as one component in the IFS preference measurement notation. Very recently, Hai, Gang, and Xiangqian (2011) proposed IF-AHP that synthesise eigenvectors of the intuitionistic fuzzy comparison matrix which all the decision information are represented by intuitionistic fuzzy values.

In this study, a new IF-AHP with a new preference scale of pair-wise comparison matrix judgment is proposed by considering the values of the membership function, non-membership function and the degree of hesitation index concurrently to test the alternatives selection for sustainable energy planning. With an attempt to consider the values of the hesitation degree, it could be anticipated that the preference scale of matrix judgment makes a more comprehensive look. This new preference scale also leads us to propose a new consistency test for matrix judgment by using the values of the hesitation degree. The new preference scale with hesitation degree could avoid the DMs from repeating the overall process of IF-AHP and the outcome of the decision process would fit to the problems. In order to demonstrate the potential of this methodology, an application in the energy planning area is presented.

2. Sustainable energy planning in Malaysia

The Malaysian government has managed to implement the policies and strategies to maintain the issues of security, energy efficiency and environmental effects to meet the increasing demand of energy for development sectors. Currently, Malaysia is extremely focusing on developing sustainable energy planning policies in order to reduce the dependency on fossil fuel and contribute towards climate change effects (Hashim and Ho 2011). The policies that have been recently implemented for energy planning are National Energy Planning and National Green Technology Policy 2009 (Ministry of Energy 2010), National Biofuel Policy 2006 (Chua and Oh 2010) and National Renewable Energy Policy 2010 (Ministry of Energy 2010). These formulated numerous energy-related policies ensure long-term policies for sustainable energy planning to minimise the energy usage but at the same time increasing the economic growth towards as in a developing country, respectively.

Energy system plays a very important role in the economic growth and social development of a country and the living quality of people. For the rapid growth of economy, Malaysia needs plenty of energy resources to support the industrial sector and to enhance the productivity. MCDM procedures have been applied in many energy related research. Energy optimisation modelling (Dong et al. 2012), energy planning and selection (Buchholz et al. 2009; Kaya and Kahraman 2011; Tsoutsos et al. 2009; Wang, Xu, and Song 2011), energy review and analysis (Al-Mofleh et al. 2009; Rahman Mohamed and Lee 2006; Shafie et al. 2011; Wang et al. 2009) and energy alternatives (Jing, Bai, and Wang 2012; Scott et al. 2012; Solangi et al. 2011), just to name a few. In the decision-making process, the most common energy alternatives involved are solar energy (also known as the photovoltaic system), wind energy, hydraulic energy, biomass, combine heat and power (CHP) and wave or ocean energy (Tsoutsos et al. 2009). Besides, nuclear energy and conventional energy resources such as coal, oil and natural gas may be included in the list of alternative energy technologies (Tan and Foo 2007). The selection of criteria requires parameters related to reliability, appropriateness, practically and limitations of measurement.

Amongst the listed energy sources, Malaysia is well-known as a good dependent on energy mix resources such as conventional energy (oil, natural gas and coal), biomass, solar and hydro. In the electricity sector, almost 94.5% electricity is generated by natural gas, coal and oil, while the other percentage is generated by hydroelectric power (Shafie et al. 2011). Figure 1 shows the increasing usage of conventional energy despite hydroelectric power. This is due to huge and redundant amount of energy resources. According to Rahman Mohamed and Lee (2006), natural gas reserves in Malaysia is the largest in South East Asia and 12th largest in the world while coal reserve currently stands out about 1712 million tons of coal ranging from lignite to anthracite. However, the contribution of oil sources has declined from 46.8% in the year of 2005 to 44.7% by 2010 (UNDP 2006). Moreover, the climate and geographic conditions in Malaysia play an

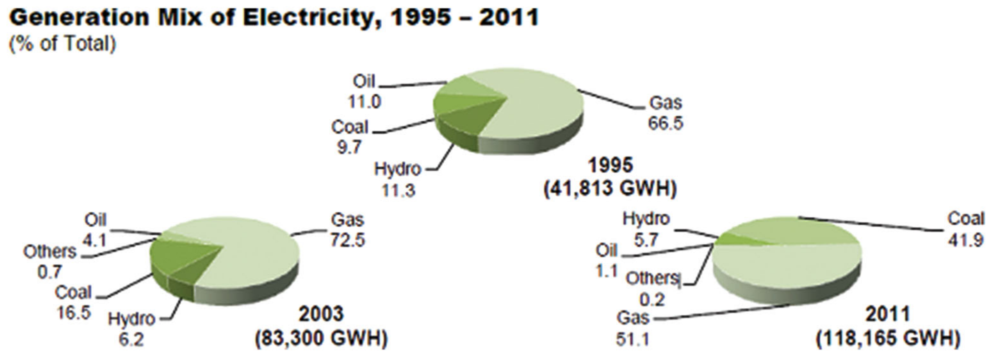

Figure 1. Malaysian Generation Mix of Electricity, 1995–2011 (Ministry of Energy 2010).

important role for the development of solar energy (also known as the photovoltaic system) due to abundant sunlight power throughout the year. Currently, solar energy is the easiest and has the fastest production without considering the maintenance and environmental impacts since the sources can be directly used. The largest solar installations are solar water heating systems in hotels, small food and beverage industries and upper middle class urban homes. Next, biomass energy is an organic non-fossil material of biological origin that may be used as fuel for heat production or electricity generation. Electricity generated from biomass is based on the steam turbine technology. Many regions of the world still have large unexploited supplies of biomass residues that can be converted into competitively valued electricity. One of the problems of biomass is that the material that is directly combusted in cooking stoves produces pollutants, leading to severe health and environmental consequences (UNDP 2007).

Malaysia has no nuclear power generation and has no plan to initiate a nuclear power programme in the future. Recently, Malaysia and several Southeast Asian regions such as Thailand, Vietnam and Indonesia announced to implement nuclear energy plans. However, there are some anxiety that have always been discussed by many scholars about how to remove the waste disposal and the high maintenance of decommissioning the nuclear power plant operation (Oh, Pang, and Chua 2010). For developed countries such as France and South Korea, almost 75% of the electricity needs are supported from 59 nuclear reactors and 40% of electricity needs by 20 nuclear power plant, respectively (Oh, Pang, and Chua 2010). Another potential energy identified in Malaysia is hydropower, wind energy and CHP. Hydropower is generally pointed as a potential and kinetic energy of water converted into electricity in hydroelectric plants ranging in size from very small to huge operations, while wind energy is a kinetic energy of wind exploited for electricity generation by wind turbines. Both of these energy supplies also highly support the electricity needs in our country. Lastly, CHP is also particularly useful for installations that incur high heating or cooling loads, such as factories, hotels, hospitals and commercial buildings since the CHP system can be used for heating or cooling tools in the industrial sector. CHP has high thermal efficiency ratios as compared with conventional thermal generation techniques. Efficiencies of up to 90% are possible unlike conventional thermal generation (40%) and combined cycle generation plants (55%).

As a conclusion, energy alternatives have their own advantages and disadvantage towards Malaysia's industrialisation sectors, which lead to increased economic growth. There are exactly useful and beneficial energy provided by our country. However, due to increasing global energy alternatives, many researchers seldom work on identified most appropriate energy sources that can be of more advantageous to our country. Hence, it is important to seek and recognise the greatest energy resources for the future generation and maintain the sustainable energy planning and environmental impacts in Malaysia. Towards searching and finding the best alternatives, the common aspects and criteria to evaluate the energy resources are technical, economic, environmental and

Table 1. Typical evaluation of energy supply systems.

Aspects	Criteria
Technical	Efficiency
	Exergy efficiency
Economic	Investment costs
	Operation and maintenance cost
Environmental	NO_x emission
	CO_2 emission
	Land use
Social criteria	Social acceptability
	Job creation

social criteria. Table 1 summarises the typical evaluation of energy supply systems from Wang et al. (2009), which will be used in this framework procedures.

3. Preliminaries

This section introduces the basic definitions relating to fuzzy sets, IFS, triangular fuzzy number (TFN) and triangular intuitionistic fuzzy numbers (TIFNs) which are needed to clarify the proposed method.

3.1. *Definition of fuzzy sets and IFS*

To deal with the uncertainty of human thought due to imprecision and vagueness, Zadeh (1965) introduces fuzzy sets and fuzzy logic theory which are most potent as mathematical tools for modelling uncertainty measurements in the system.

Definition 1 *A fuzzy set A in the universe of discourse* $X = \{x_1, x_2, \ldots, x_n\}$ *is defined as*

$$A = \{\langle x, \mu_x(x)\rangle | x \in X\}, \tag{1}$$

which is characterised by the membership function $\mu_x(x) : X \to [0, 1]$, *where* $\mu_x(x)$ *indicates the membership degree of the element x to the set A.*

The extension of fuzzy set to IFS is defined by Atanassov (1986). The IFS concept is defined as follows:

Definition 2 *Let X be an ordinary finite non-empty set. An IFS in A is an expression A given by*

$$A = \{\langle x, \mu_x(x), v_x(x)\rangle | x \in X\}, \tag{2}$$

where $\mu_x : X \to [0, 1]$; $v_x : X \to [0, 1]$ *with the condition:* $0 \leq \mu_x(x) + v_x(x) \leq 1$, *for all x in X. The numbers* $\mu_x(x)$ *and* $v_x(x)$ *denote, respectively, the degree of the membership and the degree of the non-membership of the element x in the set A. The notation of IFS 'A' is defined as follows:*

$$\pi_x(x) = 1 - \mu_x(x) - v_x(x); \pi_x : X \to [0, 1], \tag{3}$$

represents the degree of hesitation or intuitionistic index or non-determinacy of x to A. Therefore, for ordinary fuzzy sets the degree of hesitation $\pi_x(x) = 0$.

For convenience of computation, an intuitionistic fuzzy number (IFN) is viewed as $\alpha = (\mu_\alpha, v_\alpha, \pi_\alpha)$, *where* $\mu_\alpha \in [0, 1], v_\alpha \in [0, 1]; \mu_\alpha + v_\alpha \leq 1, \pi_\alpha = 1 - \mu_\alpha - v_\alpha$.

3.2. *Definition of TFN and TIFNs*

The fuzzy set theory [11] is designed to deal with the extraction of the primary possible outcome from a multiplicity of information vaguely and imprecisely. Fuzzy set theory treats vague data as possibility distributions in terms of set memberships. TFN is one of the fuzzy numbers with membership functions. According to the definition of Laarhoven and Pedrycz (1983), TFN should possess the following basic features.

Definition 3 *A fuzzy number A on* $\Re$ *to be a TFN if its membership functions* $\mu_{\tilde{A}}(x) : \Re \rightarrow [0, 1]$ *are equal to*

$$\mu_{\tilde{A}}(x) = \begin{bmatrix} \dfrac{x-l}{m-l}, & l \leq x \leq m, \\ \dfrac{u-x}{u-m}, & m \leq x \leq u, \\ 0 & \text{otherwise}, \end{bmatrix} \tag{4}$$

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* $\tilde{A} = (l, m, u)$

In a similar way the concept of a TFN was introduced by Dubois and Prade (1980), the concept of TIFNs is defined as follows:

Definition 4 *A TIFN* $\tilde{a} = \langle(\underline{a}, a, \bar{a}); w_{\tilde{a}}, u_{\tilde{a}}\rangle$ *is a special intuitionistic fuzzy (IF) set on a real number set R whose membership function and non-membership function are defined as follows:*

$$\mu_{\tilde{a}}(x) = \begin{cases} \dfrac{(x-a)w_{\tilde{a}}}{(a-\underline{a})} & \text{if } \underline{a} \leq x < a, \\ w_{\tilde{a}} & \text{if } x = a, \\ \dfrac{(a-x)w_{\tilde{a}}}{(\bar{a}-a)} & \text{if } a < x \leq \bar{a}, \\ 0 & \text{if } x < \underline{a} \text{ or } x > \bar{a}, \end{cases} \tag{5}$$

and

$$v_{\tilde{a}}(x) = \begin{cases} \frac{[a-x+u_{\tilde{a}}(x-\underline{a})]}{(a-\underline{a})} & \text{if } \underline{a} \leq x < a, \\ u_{\tilde{a}} & \text{if } x = a, \\ \frac{[x-a+u_{\tilde{a}}(\bar{a}-x)]}{(\bar{a}-a)} & \text{if } a < x \leq \bar{a}, \\ 0 & \text{if } x < \underline{a} \text{ or } x > \bar{a}. \end{cases} \tag{6}$$

The values of $w_{\tilde{a}}$ *and* $u_{\tilde{a}}$ *represent the maximum degree of membership and the minimum degree of non-membership, respectively, such that the notation satisfies the conditions* $0 \leq w_{\tilde{a}} \leq 1$, $0 \leq u_{\tilde{a}} \leq 1$ *and* $0 \leq w_{\tilde{a}} + u_{\tilde{a}} \leq 1$.

If $\underline{a} \geq 0$ *and one of the three values* $\underline{a}$*, a and* $\bar{a}$ *is not equal to 0, then the TIFN* $\tilde{a} = \langle(\underline{a}, a, \bar{a}); w_{\tilde{a}}, u_{\tilde{a}}\rangle$ *is called a positive TIFN, denoted by* $\tilde{a} > 0$*. Likewise, if* $\bar{a} \leq 0$ *and one of the three values* $\underline{a}$*, a and* $\bar{a}$ *is not equal to 0, then the* $\tilde{a} = \langle(\underline{a}, a, \bar{a}); w_{\tilde{a}}, u_{\tilde{a}}\rangle$ *is called a negative TIFN, and denoted by* $\tilde{a} < 0$.

3.3. *A new preference scale of IF-AHP*

A linguistic data is a variable whose value is a natural language. It deals with complex or undefined situations where conventional quantitative expressions fail to describe (Zhang and Liu 2011). The

Table 2. Conversion of consistency expressions to membership grades.

Consistency	$\pi(x)$	$\mu''(x)$
No/very low consistency	0.8–1	0.1111–0.0
Low consistency	0.6–0.8	0.3333–0.1111
Moderate consistency	0.4–0.6	0.5555–0.3333
High consistency	0.2–0.4	0.7777–0.5555
Very high/total consistency	0–0.2	1.0000–0.7777

rating of each criterion and alternative in this case can be expressed by the AHP measurement scale. This assessment can be converted into TIFNs. This new preference scale is norm-based of hesitation degree of TIFNs. The conversion of the AHP number into TIFNs is explained by averaging each AHP preference scale with respect to the total of the AHP measurement scale. A conversion table of consistency expressions to membership grade is used to define the new preference scale of TIFNs. Below are the conversion steps of AHP preference numbers into TIFNs.

The AHP preference scale will convert to TIFNs, $x = (\mu_x, v_x, \pi_x)$, by averaging data scaling, $\mu''(x)$ with respect to consistency expression of membership grades. Based on the table from Hersh (2006), the conversion is proposed in Table 2.

Then, the TIFNs can be calculated by the following equations:

$$\mu''(x) = \frac{x_{ij}}{m}, \tag{7}$$

where x_{ij} is scale of AHP crisp number and m is total of scale measurement of preference.

Membership degree, non-membership degree and degree of hesitation are calculated using the Equations (8)–(10)

$$\mu(x) = \mu''(x)[1 - \pi(x)], \tag{8}$$

$$v(x) = [1 - \mu''(x)][1 - \pi(x)], \tag{9}$$

$$\pi(x) = 1 - v(x) - \mu(x). \tag{10}$$

The following example is given to illustrate the conversion:

Let $x_{ij} = 1$, and $m = 9$, then

$$\mu''(x) = \frac{x_{ij}}{m} = \frac{1}{9} = 0.1111.$$

According to Table 1, if the value of $\mu''(x)$ is 0.1111, then the hesitation degree $\pi(x)$ is 0.8. The value of membership, $\mu(x)$, and the non-membership, $v(x)$, function can be obtained using Equations (8) and (9);

$$\begin{aligned} \mu(x) &= \mu''(x)[1 - \pi(x)], \\ &= 0.1111(1 - 0.8), \\ &= 0.02, \\ v(x) &= [1 - \mu''(x)][1 - \pi(x)], \\ &= (1 - 0.1111)(1 - 0.8), \\ &= 0.18. \end{aligned}$$

From the above calculation, the TFINs for the pair-wise matrix of AHP are 0.02, 0.18, 0.80 for equally importance scale of pair-wise comparison. Thus, the three vertices that are obtained are

Table 3. Conversion of the AHP preference number to TIFNs.

Preference on pair wise comparison	AHP preference number	Reciprocal AHP number	TIFNs	Reciprocal TIFNs
Equally important (E)	1	1	(0.02, 0.18, 0.80)	(0.02, 0.18, 0.80)
Intermediate value (IV)	2	1/2	(0.06, 0.23, 0.70)	(0.23, 0.06, 0.70)
Moderately/weakly more important (WMI)	3	1/3	(0.13, 0.27, 0.60)	(0.27, 0.13, 0.60)
Intermediate value (IV)	4	1/4	(0.22, 0.28, 0.50)	(0.28, 0.22, 0.50)
Strongly more important (SMI)	5	1/5	(0.33, 0.27, 0.40)	(0.27, 0.33, 0.40)
Intermediate value (IV)	6	1/6	(0.47, 0.23, 0.30)	(0.23, 0.47, 0.30)
Very strong more important (VSMI)	7	1/7	(0.62, 0.18, 0.20)	(0.18, 0.62, 0.20)
Intermediate value (IV)	8	1/8	(0.80, 0.10, 0.10)	(0.10, 0.80, 0.10)
Extremely/absolutely more important (AMI)	9	1/9	(1.0, 0, 0)	(0, 1.0, 0)

known as TIFN, which include the values of hesitation degree. Other AHP preference numbers are calculated in a similar manner.

AHP linguistic measures of importance used for pair-wise comparison (Saaty 1980) and the new conversion of AHP linguistic preference into TIFNs are proposed in Table 3.

4. The proposed IF-AHP procedure with the new preference scale

The IFS framework extends Saaty's AHP method with the IFS theory. Similar to fuzzy AHP and AHP methods, the proposed IF-AHP can also deal with the relative strength between criterion and alternatives of MCDM problems. The new preference scale of the AHP crisp data to TIFNs is used as measurement in the pair-wise comparison judgement matrix. The proposed IF-AHP method is described as below

Step 1 Construct hierarchy structure of MCDM problems.

Data for criterion and alternatives must be identified as part of an MCDM problem.

Step 2 Scale the pair-wise comparison scale of IF-AHP with the new preference scale of the TIFNs judgement matrix.

In MCDM problems, responses from DMs are mainly focused on the opinion of the DMs regarding rating of the criterion of the problems based on the identified criteria. The DMs were asked to specify rating using nine AHP linguistic scales varying from 'just equal' to 'absolutely more important' over the factors associated with MCDM problems. The new preference scale of IF-AHP is used to define the DMs measurement of each criterion and alternatives of the MCDM problems. The new conversion of AHP linguistic preference into TIFNs proposed in Table 3.

Step 3 Determine the weights of DMs.

The importance of the DMs is considered as linguistic variables. The defined TIFNS for linguistic variables are given in Table 4.

Let $D_k = (\mu_k, v_k, \pi_k)$ be an intuitionistic fuzzy number for rating of the kth decision-maker. Based on Boran et al. (2009), the weights of the kth decision-maker can be obtained using Equation (11).

$$\lambda_k = \frac{(\mu_k + \pi_k(\mu_k/(\mu_k + v_k)))}{\sum_{k=1}^{t}(\mu_k + \pi_k(\mu_k/(\mu_k + v_k)))}. \tag{11}$$

Step 4 Construct the aggregated intuitionistic fuzzy judgement matrix based on DMs.

Table 4. Linguistic variables for the importance of DMs (Boran et al. 2009).

Linguistic variables	TFINs
Very important	(0.90, 0.05, 0.05)
Important	(0.75, 0.20, 0.05
Medium	(0.50, 0.40, 0.10)
Unimportance	(0.25, 0.60, 0.15)
Very unimportance	(0.10, 0.80, 0.10)

Let $R^{(k)} = (r_{ij}^{(k)})_{m\times n}$ be an intuitionistic fuzzy decision matrix of the kth decision-maker. Let $\lambda = \{\lambda_1, \lambda_2, \ldots, \lambda_n\}$ be the weight of the all decision-maker and $\sum_{k=1}^{t} \lambda = 1 \in [0,1]$. In the group decision-making process, all the individual decision opinions need to be fused into group opinion to construct an aggregated intuitionistic fuzzy decision matrix (Zhang and Liu 2011) by applying the intuitionistic fuzzy weighted averaging operator proposed by Xu (2007b)

$$\begin{aligned} r_{ij} &= IFWA_\lambda(r_{ij}^{(1)}, r_{ij}^{(2)}, \ldots, r_{ij}^{(t)}) = \lambda_1 r_{ij}^{(1)} \oplus \lambda_2 r_{ij}^{(2)} \oplus \cdots \oplus \lambda_t r_{ij}^{(t)}, \\ &= \left(1 - \prod_{k=1}^{t} (1-\mu_{ij}^{(k)})^{\lambda_k}, \prod_{k=1}^{t} ((v_{ij}^{(k)})^{\lambda_k}), \prod_{k=1}^{t} (1-\mu_{ij}^{(k)}) - \prod_{k=1}^{t} ((v_{ij}^{(k)})^{\lambda_k})\right), \end{aligned} \tag{12}$$

where

$$r_{ij} = (\mu_{ij}, v_{ij}, \pi_{ij}), \quad \mu_{ij} = 1 - \prod_{k=1}^{t} (1-\mu_{ij}^{(k)})^{\lambda_k}, \quad v_{ij} = \prod_{k=1}^{t} ((v_{ij}^{(k)})^{\lambda_k}),$$

$$\pi_{ij} = \prod_{k=1}^{t} (1-\mu_{ij}^{(k)}) - \prod_{k=1}^{t} ((v_{ij}^{(k)})^{\lambda_k}) \quad i \in M, j \in N.$$

Step 5 Calculate the consistency ratio (CR) of the aggregated intuitionistic fuzzy judgement matrix.

Since the aggregated IF matrix consists the value of $\pi(x)$, which is the hesitation value, to express in consistency grades of TIFNs, thus we introduce a new method to calculate the overall consistency value. The value of random indices (RI) is retrieved from Saaty (1980). It is shown in Table 5.

Then the new CR is given in Equation. (13).

$$\text{Consistency ratio, CR} = \frac{((\lambda_{\max} - n)/(n-1))}{R \cdot I}, \tag{13}$$

where assume $(\lambda_{\max} - n)$ is the average value of the hesitation value, $\pi(x)$ of the aggregated IF matrix of criterion and each alternatives and n is the size of the matrix.

CR is acceptable if it does not exceed 0.10 (Saaty 1980). If the CR is greater than 0.10, then the judgment matrix should be considered as inconsistent. In order to ensure that consistency is met, the judgement matrix should be redone.

Step 6 Calculate the intuitionistic fuzzy weight of the aggregated intuitionistic fuzzy judgement matrix.

The weights of criteria are obtained by using the most important of DMs preference weights index, while the IF matrix of alternatives are using the sequence of decision-maker

Table 5. 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

weights index judgement. In order to obtain the weights, we modify the intuitionistic fuzzy entropy introduced by Vlashos and Sergiadis (2007). The summation in Vlashos and Sergiadis (2007) is removed to obtain the aggregated value of each IFS matrix row. The intuitionistic fuzzy entropy of each aggregate of each row of the IF matrix is defined as Equation (14).

$$\bar{\bar{w}}_i = -\frac{1}{n \ln 2}[\mu_i \ln \mu_i + v_i \ln v_i - (1-\pi_i) \ln(1-\pi_i) - \pi_i \ln 2]. \tag{14}$$

Here if $\mu_i = 0, v_i = 0, \pi_i = 1$, then $\mu_i \ln \mu_i = 0$, $v_i \ln v_i = 0$, $(1-\pi_i)\ln(1-\pi_i) = 0$ and if $\mu_i = 1$, $v_i = 0$, $\pi_i = 0$, then $\mu_i \ln \mu_i = 0$, $v_i \ln v_i = 0$, $(1-\pi_i)\ln(1-\pi_i) = 0$, respectively.

Thus, the final entropy weights of each IF matrix are redefined as Equation (15).

$$w_i = \frac{1-\bar{\bar{w}}_i}{n - \sum_{j=1}^{n} \bar{\bar{w}}_i}, \tag{15}$$

where $\sum_{j=1}^{n} w_i = 1$.

Step 7 Rank all the alternatives.

Compute the relative weight and rank the alternatives.

$$W_i = \sum w_i A_{ij}, \tag{16}$$

where w_i is the overall relative rating for alternatives i, w_i is the average normalised weight for criteria $j$and A_{ij} the average normalised weights aggregated matrix for criteria j with respect to alternatives i.

In this IF-AHP framework, we introduced a new equation to calculate the CR of each matrix pair-wise comparison by applying the values of the hesitation degree in the TIFNs notation. One of the benefits of considering hesitation degree is to strengthen the TIFNs notations with respect to the intuitionistic fuzzy matrix. Besides, we also modified intuitionistic fuzzy entropy by removing the summation element in order to obtain intuitionistic fuzzy entropy of each aggregated row of the IF matrix. Since, the matrix is proposed by aggregating each row of the intuitionistic fuzzy matrix, it is feasible to calculate the intuitionistic fuzzy entropy of each row instead of summation of the intuitionistic fuzzy matrix.

5. Implementation

The AHP question was designed to evaluate the sustainable energy planning decision problems. The questionnaire was used as a guideline in personal interview with the experts in sustainable energy. Based on the MCDM framework, this group of experts are called as decision-makers. Three decision-makers were sought to provide linguistic judgement data based on the IF-AHP questionnaire. Three of the experts comprise two academicians from Department of Electrical Engineering, Department of Environmental Sciences at a public university and an engineer from

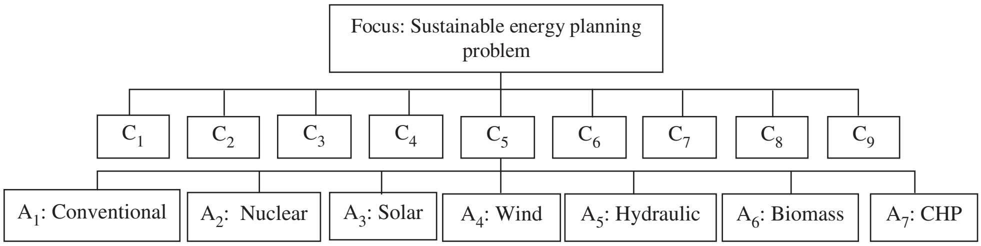

Figure 2. The hierarchical structure for energy planning selection.

Department of Environment at a government ministry in Malaysia. The experts need to judge the relative measurement between the criterion and the alternatives using pair-wise comparison proposed by Saaty (1980). The selected criteria to evaluate each alternative include '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 sustainable energy planning are 'conventional energy'(A_1), 'nuclear energy'(A_2), 'solar energy' (A_3), 'wind energy' (A_4), 'hydraulic energy' (A_5), 'biomass energy' (A_6) and 'CHP energy' (A_7). The scale and the relative importance are presented in Table 3.

Step 1 Construct a hierarchical diagram of the MCDM problem

The hierarchical structure of energy planning problem is illustrated in Figure 2.

Step 2 Scaling of the pair-wise comparison scale of fuzzy analytic hierarchy process with the preference scale of TFN.

The compilations of three experts' $(\lambda_1, \lambda_2, \lambda_3)$ linguistics variables for the criteria are constructed in Table 6. The alphabet 'R' represents the reciprocal scale of pair-wise comparisons. Usually, the shaded boxes can be defined by the author by a pair-wise comparison of the preference scale since the decision-maker only has to fill the other boxes of the AHP questionnaire. As example, λ_1 states that C_1 is 'very strong more important (VSMI)' than C_2 which is represented by '(0.62, 0.18, 0.20)'. Then, the reciprocal for 'very strong more important (RVSMI)' of C_2–C_1 is (0.18, 0.62, 0.20). The abbreviations and preference scale of IF-AHP are shown in Table 3.

Step 3 Determine the weights of DMs.

The importance of the decision-makers in the group decision-making process is shown in Table 3. In order to obtain the weights $\lambda_k(1, 2, 3)$ of the decision-makers, Equation (11) is used. The importance of linguistic variables of the three experts is $\lambda_1 = (0.5, 0.4, 0.1)$, $\lambda_2 = (0.9, 0.05, 0.05)$ and $\lambda_1 = (0.9, 0.05, 0.05)$.

$$\lambda_1 = \frac{(0.5 + 0.1(0.5/(0.5 + 0.4)))}{\begin{array}{c}(0.5 + 0.1(0.5/(0.5 + 0.4))) + (0.9 + 0.05(0.9/(0.9 + 0.05))) \\ + (0.9 + 0.05(0.9/(0.9 + 0.05)))\end{array}} = 0.2267.$$

By applying the same equation, the weights of $\lambda_2 = 0.3866$ and $\lambda_3 = 0.3866$.

Step 4 Construct the aggregated intuitionistic fuzzy judgement matrix based on DMs.

Equation (12) is used to aggregate all the conversion of the intuitionistic fuzzy decision matrix of criterion and alternatives. Table 7 shows the example of aggregated matrix judgment by λ_1.

$$r_{C_1} = \left(1 - \prod_{k=1}^{t}(1 - \mu_{ij}^{(k)})^{\lambda_1}, \prod_{k=1}^{t}((v_{ij}^{(k)})^{\lambda_1}), \prod_{k=1}^{t}(1 - \mu_{ij}^{(k)}) - \prod_{k=1}^{t}((v_{ij}^{(k)})^{\lambda_1})\right),$$

Table 6. Pair-wise comparison of criterion.

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	(1,1,1)	E1:RVSMI E2:WMI E3:WMI	E1:RVSMI E2:VSMI E3:WMI	E1:RVSMI E2:RSMI E3:RWMI	E1:SMI E2:RVSMI E3:AMI	E1:SMI E2:RVSMI E3:AMI	E1:RWMI E2:RWMI E3:RWMI	E1:RWMI E2:WMI E3:RWMI	E1:RSMI E2:WMI E3:WMI
C_2	E1:VSMI E2:RWMI E3:RWMI	(1,1,1)	E1:RVSMI E2:RVSMI E3:RWMI	E1:RVSMI E2:SMI E3:RWMI	E1:SMI E2:RVSMI E3:WMI	E1:SMI E2:RVSMI E3:WMI	E1:RWMI E2:VSMI E3:RWMI	E1:RWMI E2:RVSMI E3:RWMI	E1:RWMI E2:RVSMI E3:WMI
C_3	E1:VSMI E2:RVSMI E2:RWMI	E1:VSMI E2:VSMI E3:WMI	(1,1,1)	E1:RAMI E2:RVSMI E3:WMI	E1:WMI E2:WMI E3:SMI	E1:WMI E2:WMI E3:SMI	E1:RAMI E2:RVSMI E3:E	E1:WMI E2:AMI E3:RWMI	E1:RSMI E2:RVSMI E3:SMI
C_4	E1:VSMI E2:SMI E3:WMI	E1:VSMI E2:RSMI E3:WMI	E1:AMI E2:VSMI E3:RWMI	(1,1,1)	E1: SMI E2:RAMI E3:SMI	E1:SMI E2:RAMI E3:SMI	E1:RVSMI E2:RVSMI E3:E	E1:RWMI E2:SMI E3:RWMI	E1:RSMI E2:RAMI E3:SMI
C_5	E1:RSMI E2:VSMI E3:RAMI	E1:RSMI E2:VSMI E3:RWMI	E1:RWMI E2:WMI E3:RSMI	E1:RSMI E2:AMI E3:RSMI	(1,1,1)	E1:SMI E2:RVSMI E3:E	E1:VSMI E2:RVSMI EI3:RWMI	E1:VSMI E2:RVSMI E3:RWMI	E1:RWMI E2:RSMI E3:WMI
C_6	E1:RSMI E2:VSMI E3:RAMI	E1:RSMI E2:VSMI E3:RWMI	E1:RWMI E2:WMI E3:RSMI	E1:RSMI E2:AMI E3:RSMI	E1:RSMI E2:VSMI E3:E	(1,1,1)	E1:VSMI E2:RWMI E3:RWM	E1:VSMI E2:RVSMI E3:RWMI	E1:RWMI E2:RSMI E3:WMI
C_7	E1:WMI E2:WMI E3:WMI	E1:WMI E2:RVSMI E3:WMI	E1:AMI E2:VSMI E3:E	E1:VSMI E2:VSMI E3:E	E1:RVSMI E2:VSMI E3:WMI	E1:RVSMI E2:WMI E3:WMI	(1,1,1)	E1:RSMI E2:RVSMI E3:WMI	E1:RSMI E2:RSMI E3:SMI
C_8	E1:WMI E2:RWMI E3:WMI	E1:WMI E2:VSMI E3:WMI	E1:RWMI E2:RAMI E3:WMI	E1:WMI E2:RSMI E3:WMI	E1:RVSMI E2:VSMI E3:WMI	E1:RVSMI E2:VSMI E3:WMI	E1:SMI E2:VSMI E3:RWMI	(1,1,1)	E1:RSMI E2:RSMI E3:E
C_9	E1:SMI E2:RWMI E3:RWMI	E1:SMI E2:VSMI E3:RWMI	E1:SMI E2:VSMI E3:RSMI	E1:SMI E2:AMI E3:RSMI	E1:WMI E2:SMI E3:RWMI	E1:WMI E2:SMI E3:RWMI	E1:SMI E2:SMI E3:RSMI	E1:SMI E2:WMI E3:E	(1,1,1)

$$
= \begin{pmatrix} 1 - \prod_{k=1}^{t} ((1-0.02)^{0.2267} + (1-0.18)^{0.2267} + \cdots + (1-0.27)^{0.2267}), \\ \times \prod_{k=1}^{t} ((0.18)^{0.2267} + (0.62)^{0.2267} + \cdots + (0.33)^{0.2267}), \\ \prod_{k=1}^{t} ((1-0.02)^{0.2267} + (1-0.18)^{0.2267} + \cdots + (1-0.27)^{0.2267}) \\ - \prod_{k=1}^{t} ((0.18)^{0.2267} + (0.62)^{0.2267} + \cdots + (0.33)^{0.2267}) \end{pmatrix}
$$
$$
= (0.41, 0.07, 0.52).
$$

Then, the similar fashion of calculation is applied to determine the aggregated matrix for $C_2, C_3, \ldots, C_9$. Then, Equation (12) is also used to execute the aggregated matrix of each criterion with respect to alternatives. Table 8 shows the aggregated matrix of each criterion with respect to alternatives.

Step 5 Calculate the CR of the aggregated intuitionistic fuzzy judgment matrix of the criterion and alternatives. The calculation of CR is based on Equation (13) to test the consistency of the pair-wise comparison of TIFNs. Calculation of CR of aggregated matrix judgment

Table 7. Aggregated matrix of criterion.

C_n	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	Aggregated matrix
C_1	(0.02, 0.18, 0.80)	(0.18, 0.62, 0.20)	(0.18, 0.62, 0.20)	(0.18, 0.62, 0.20)	(0.33, 0.27, 0.40)	(0.33, 0.27, 0.40)	(0.27, 0.13, 0.60)	(0.27, 0.13, 0.60)	(0.27, 0.33, 0.40)	(0.41, 0.07, 0.52)
C_2	(0.62, 0.18, 0.20)	(0.02, 0.18, 0.80)	(0.18, 0.62, 0.20)	(0.18, 0.62, 0.20)	(0.33, 0.27, 0.40)	(0.33, 0.27, 0.40)	(0.27, 0.13, 0.60)	(0.27, 0.13, 0.60)	(0.27, 0.33, 0.40)	(0.51, 0.05, 0.44)
C_3	(0.62, 0.18, 0.20)	(0.62, 0.18, 0.20)	(0.02, 0.18, 0.80)	(0, 1.0, 0)	(0.13, 0.27, 0.60)	(0.13, 0.27, 0.60)	(0, 1.0, 0)	(0.27, 0.13, 0.60)	(0.27, 0.33, 0.40)	(0.48, 0.08, 0.44)
C_4	(0.62, 0.18, 0.20)	(0.62, 0.18, 0.20)	(1.0, 0, 0)	(0.02, 0.18, 0.80)	(0.33, 0.27, 0.40)	(0.33, 0.27, 0.40)	(0.18, 0.62, 0.20)	(0.27, 0.13, 0.60)	(0.27, 0.33, 0.40)	(1, 0, 0)
C_5	(0.27, 0.33, 0.40)	(0.27, 0.33, 0.40)	(0.27, 0.13, 0.60)	(0.27, 0.33, 0.40)	(0.02, 0.18, 0.80)	(0.33, 0.27, 0.40)	(0.62, 0.18, 0.20)	(0.62, 0.18, 0.20)	(0.27, 0.13, 0.60)	(0.59, 0.04, 0.37)
C_6	(0.27, 0.33, 0.40)	(0.27, 0.33, 0.40)	(0.27, 0.13, 0.60)	(0.27, 0.33, 0.40)	(0.27, 0.33, 0.40)	(0.02, 0.18, 0.80)	(0.62, 0.18, 0.20)	(0.62, 0.18, 0.20)	(0.27, 0.13, 0.60)	(0.58, 0.04, 0.37)
C_7	(0.13, 0.27, 0.60)	(0.13, 0.27, 0.60)	(1.0, 0, 0)	(0.62, 0.18, 0.20)	(0.18, 0.62, 0.20)	(0.18, 0.62, 0.20)	(0.02, 0.18, 0.80)	(0.27, 0.33, 0.40)	(0.27, 0.33, 0.40)	(1, 0, 0)
C_8	(0.13, 0.27, 0.60)	(0.13, 0.27, 0.60)	(0.13, 0.27, 0.60)	(0.13, 0.27, 0.60)	(0.18, 0.62, 0.20)	(0.18, 0.62, 0.20)	(0.33, 0.27, 0.40)	(0.02, 0.18, 0.80)	(0.27, 0.33, 0.40)	(0.32, 0.10, 0.58)
C_9	(0.33, 0.27, 0.40)	(0.33, 0.27, 0.40)	(0.33, 0.27, 0.40)	(0.33, 0.27, 0.40)	(0.13, 0.27, 0.60)	(0.13, 0.27, 0.60)	(0.33, 0.27, 0.40)	(0.33, 0.27, 0.40)	(0.02, 0.18, 0.80)	(0.46, 0.06, 0.48)

Table 8. Aggregated matrix of criterion with respect to alternatives.

C_n	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	(0.42, 0.10, 0.48)	(0.34, 0.06, 0.60)	(0.28, 0.22, 0.49)	(0.23, 0.29, 0.48)	(0.25, 0.10, 0.65)	(0.25, 0.10, 0.65)	(0.33, 0.14, 0.53)	(0.30, 0.08, 0.61)	(0.24, 0.35, 0.41)
A_2	(0.68, 0.09, 0.23)	(0.41, 0.12, 0.47)	(1, 0, 0)	(1, 0, 0)	(0.32, 0.05, 0.63)	(0.32, 0.05, 0.63)	(0.36, 0.27, 0.37)	(1, 0, 0)	(0.36, 0.27, 0.37)
A_3	(0.31, 0.09, 0.60)	(0.24, 0.10, 0.66)	(1, 0, 0)	(1, 0, 0)	(0.37, 0.12, 0.51)	(0.37, 0.12, 0.51)	(0.42, 0.05, 0.53)	(1, 0, 0)	(0.46, 0.20, 0.33)
A_4	(0.26, 0.26, 0.48)	(0.32, 0.06, 0.61)	(1, 0, 0)	(1, 0, 0)	(0.24, 0.10, 0.66)	(0.24, 0.10, 0.66)	(0.43, 0.12, 0.45)	(1, 0, 0)	(0.57, 0.10, 0.33)
A_5	(0.48, 0.13, 0.39)	(0.3, 0.07, 0.63)	(1, 0, 0)	(1, 0, 0)	(0.27, 0.08, 0.65)	(0.27, 0.08, 0.65)	(0.44, 0.11, 0.45)	(1, 0, 0)	(0.62, 0.12, 0.26)
A_6	(0.35, 0.14, 0.51)	(0.27, 0.43, 0.30)	(1, 0, 0)	(1, 0, 0)	(0.3, 0.07, 0.63)	(0.3, 0.07, 0.63)	(0.45, 0.11, 0.44)	(1, 0, 0)	(0.68, 0.09, 0.23)
A_7	(0.40, 0.23, 0.37)	(0.24, 0.10, 0.66)	(1, 0, 0)	(1, 0, 0)	(0.32, 0.06, 0.61)	(0.32, 0.06, 0.61)	(0.46, 0.10, 0.43)	(1, 0, 0)	(0.73, 0.07, 0.20)

Table 9. Final entropy weights of criterion.

C_n	Aggregated matrix	Entropy weights, $\bar{\bar{w}}_i$	Final entropy weights, w_i
C_1	(0.41, 0.07, 0.52)	0.088714021	0.108102
C_2	(0.51, 0.05, 0.44)	0.076000338	0.10961
C_3	(0.48, 0.08, 0.44)	0.086750383	0.108334
C_4	(1, 0, 0)	0	0.111111
C_5	(0.59, 0.04, 0.37)	0.066051439	0.11079
C_6	(0.58, 0.04, 0.37)	0.067485449	0.11062
C_7	(1, 0, 0)	0	0.118625
C_8	(0.32, 0.10, 0.58)	0.101061378	0.106637
C_9	(0.46, 0.06, 0.48)	0.084030064	0.108657

of criterion (Table 6) is shown in the following example:

$$C \cdot R = \frac{((0.52 + 0.44 + \cdots + 0.48)/8)}{1.45}.$$
$$= 0.03$$

From the calculation, the consistency test of aggregated intuitionistic fuzzy judgment for criterion is 0.03. The matrix is consistent.

Step 6 Calculate the intuitionistic fuzzy weight of the aggregated intuitionistic fuzzy judgment matrix.

Obtain the entropy weights and final entropy weights of each criterion and alter natives by using Equations (14) and (15).

For example, entropy weights and final entropy weights of criterion are,

$$\bar{\bar{w}}_{C_1} = -\frac{1}{n \ln 2}[\mu_i \ln \mu_i + v_i \ln v_i - (1-\pi_i)\ln(1-\pi_i) - \pi_i \ln 2],$$
$$= \frac{1}{9 \ln 2}[0.41 \ln 0.41 + 0.07 \ln 0.07 - (1-0.52)\ln(1-0.52_i) - 0.52 \ln 2],$$
$$= 0.0.0897.$$
$$w_{C_1} = \frac{1-\bar{\bar{w}}_i}{n - \sum_{j=1}^{n}\bar{\bar{w}}_i},$$
$$= \frac{1-0.0897}{9-(0.0897+0.076+\cdots+0.0840)} = 0.1081.$$

The entropy weights and final entropy weight for all criteria are shown in Table 9.

Step 7 Rank all the alternatives.

Compute the relative weight and rank the alternatives using Equation (16):

$$W_{A_1} = \sum w_i A_{ij},$$
$$= \sum (0.1081 \times 0.0.1436) + (0.1096 \times 0.1382) + \cdots + (0.2489 \times 0.3394),$$
$$= 0.1313.$$

The other alternatives relatives' weights are calculated in a similar manner. The final priority weights are shown in Table 10.

Table 10. 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	Final priority
Weight	0.1081	0.1096	0.1083	0.1111	0.1106	0.0814	0.1186	0.1066	0.1087	weight
Alternatives										
A_1	0.1436	0.1444	0.1251	0.1251	0.1418	0.1418	0.1412	0.1268	0.1384	0.1313
A_2	0.1487	0.1436	0.1458	0.1458	0.1444	0.1444	0.1400	0.1455	0.1382	0.1387
A_3	0.1421	0.1417	0.1458	0.1458	0.1429	0.1429	0.1452	0.1455	0.1398	0.1383
A_4	0.1399	0.1441	0.1458	0.1458	0.1416	0.1416	0.1429	0.1455	0.1437	0.1382
A_5	0.1437	0.1432	0.1458	0.1458	0.1423	0.1423	0.1432	0.1455	0.1444	0.1387
A_6	0.1414	0.1414	0.1458	0.1458	0.1431	0.1431	0.1436	0.1455	0.1467	0.1387
A_7	0.1406	0.1417	0.1458	0.1458	0.1439	0.1439	0.1439	0.1455	0.1488	0.1391

Table 11. Weight of sustainable energy planning problem.

	Priority weight of Expert 1	Priority weight of Expert 2	Priority weight of Expert 3	Weights	Rank
A_1	0.1313	0.1371	0.1441	0.1375	7
A_2	0.1387	0.1402	0.1489	0.1426	1
A_3	0.1383	0.1440	0.1448	0.1424	2
A_4	0.1382	0.1441	0.1390	0.1405	4
A_5	0.1387	0.1451	0.1391	0.1410	3
A_6	0.1387	0.1402	0.1391	0.1394	5
A_7	0.1391	0.1396	0.1391	0.1393	6

The overall weight and rank of sustainable energy planning are obtained by the arithmetic mean of the experts' final weight of alternatives with respect to each criterion. Table 11 summarises the experts' final weight and rank on alternatives problems.

Based on Table 11, the ranking of alternatives in descending order are $A_2 \succ A_3 \succ A_5 \succ A_4 \succ A_6 \succ A_7 \succ A_1$ According to the framework of IF-AHP, the best alternative is A_2 (nuclear energy). The order of the rest alternatives are solar, hydraulic, wind, biomass, CHP power and conventional.

6. Results and discussion

A rank and weight of sustainable energy planning in selecting energy alternatives were obtained by applying a new preference scale of IF-AHP procedures. The new preference scale of IF-AHP as a decision tool was successfully implemented. The proposed procedure was considering the hesitation degree as the third parameter in the IFS notation. It seems that the MCDM method managed to cope with the pair-wise comparison in AHP despite the introduction of the third parameter and dual memberships in IFS. The weight obtained was then used to rank the best alternatives in energy planning. The best alternative, A_2 (nuclear energy), gives the highest value of weight among the alternatives. The decision was made by recognising that nuclear energy leads in the first place followed by solar, hydraulic, wind, biomass, CHP power and conventional. The pattern of preferences among the three experts is illustrated in Figure 3.

Expert 1 (E1) and Expert 3 (E3) decide that nuclear energy is the preferred choice in energy planning despite a substantial difference in weight. It is good not to mention that all the three experts are consistent in deciding the rank of five alternatives out of seven.

Although Malaysia has established the Nuclear Agency and has periodically reviewed the nuclear option, however there is no nuclear power generation plant nor is there a plan to embark

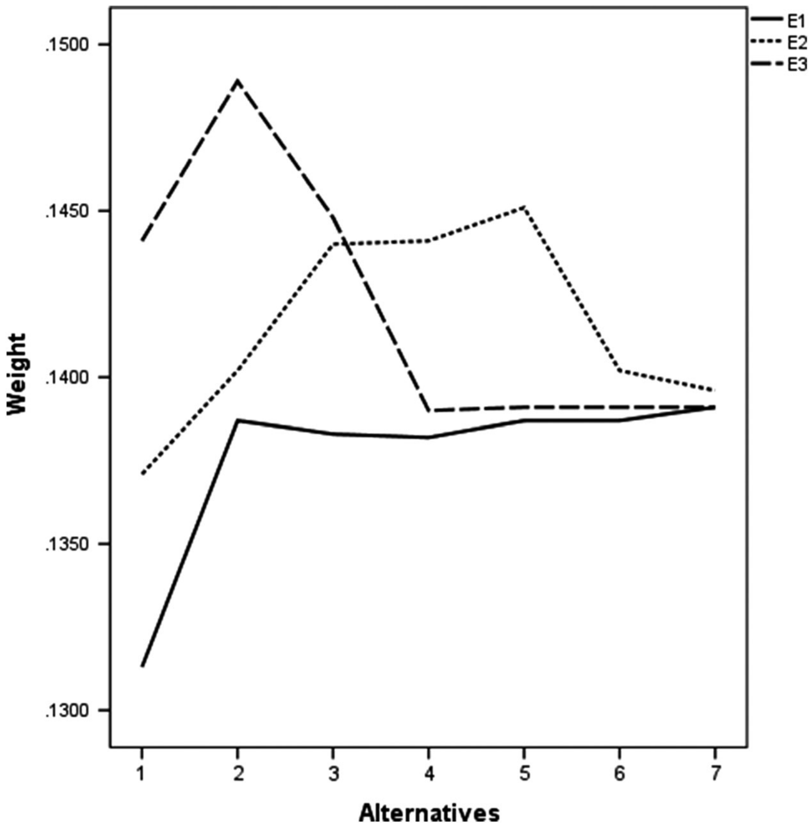

Figure 3. Priority weight of energy alternatives.

on a nuclear power programme in the foreseeable future. Generally, it will take years to prepare the nuclear workforce for this technology in all aspects, ranging from the planning until to the decommissioning including the final waste disposal of the nuclear power plant. This study reveals the importance of nuclear energy to be implemented in Malaysia. Nuclear energy has managed to support almost 70% electricity in developed country such as France and South Korea (Oh, Pang, and Chua 2010). As an alternative to energy consumption, nuclear energy is one of the potent energy sources for the future sustainable energy planning. Moreover, supporters of nuclear plants advocate that nuclear energy is a stable and reliable source of energy. The power generated is cleaner because it emits significantly less carbon waste into the environment as compared with coal- and gas-driven generators (Khor and Lalchand 2014).

7. Conclusions

The aim of this paper was to propose a new preference scale in IF-AHP procedures and test its feasibility in the real case experiment of solving the sustainable energy planning decision problem. Energy planning is a complicated issue in which both qualitative and quantitative criteria must be considered. Thus, IF-AHP with the new preference scale was used to investigate the decision problems and find suitable ways to deal with uncertainty. This new preference scale of measurement has included the degree of hesitation for every single triangular intuitionistic fuzzy number. CR of matrix judgment was calculated using the hesitation degree. Besides the inclusion of the hesitation degree, this proposed IF-AHP also took into consideration the modified intuitionistic fuzzy entropy. The modification was carried out by removing the summation of the column matrix. The aggregated intuitionistic fuzzy matrix was utilised to obtain the final relative weights and ranks. To investigate the feasibility of the proposed method, the energy planning problem was used as a platform to deal with this new preference scale of matrix comparison. The alternative nuclear energy with a weight of 0.1426 was the most preferred choice among all the alternatives. The second preferred choice in sustainable energy planning was solar with a weight of 0. 1424 followed by hydraulic with a weight of 0.1410. The alternatives, wind, biomass, CHP power and conventional, were ranked as the last four in this preference scale. The proposed IF-AHP was successfully tested in energy sources selection. However, this proposed framework warrants further investigations especially in validity and reliability. Further research in some other real case experiments would further enhance robustness of the method. Comparison study and sensitivity analysis are some of the possible validation tools that can be explored to strengthen the proposed IF-AHP framework.

References

Abdullah, L., J. Sunadia, and T. Imran. 2009. "A New Analytic Hierarchy Process in Multi-attribute Group Decision Making." *International Journal of Soft Computing* 4 (5): 208–214.

Al-Mofleh, A., S. Taib, M. A. Mujeebu, and W. Salah. 2009. "Analysis of Sectoral Energy Conservation in Malaysia." *Energy* 34 (6): 733–739.

Atanassov, K. T. 1986. "Intuitionistic Fuzzy Sets." *Fuzzy Sets and Systems* 20 (1): 87–96.

Boran, F. E., S. Genç, M. Kurt, and D. Akay. 2009. "A Multi-criteria Intuitionistic Fuzzy Group Decision Making for Supplier Selection with TOPSIS Method." *Expert Systems with Applications* 36 (8): 11363–11368.

Bozbura, F. T., and A. Beskese. 2007. "Prioritization of Organizational Capital Measurement Indicators using Fuzzy AHP." *International Journal of Approximate Reasoning* 44 (2): 124–147.

Buchholz, T., E. Rametsteiner, T. A. Volk, and V. A. Luzadis. 2009. "Multi Criteria Analysis for Bioenergy Systems Assessments." *Energy Policy* 37 (2): 484–495.

Chen, Y., and B. Li. 2011. "Dynamic Multi-attribute Decision Making Model based on Triangular Intuitionistic Fuzzy Numbers." *Science Iranica* 18 (2): 268–274.

Chua, S. C., and T. H. Oh. 2010. "Review on Malaysia's National Energy Developments: Key Policies, Agencies, Programmes and International Involvements." *Renewable and Sustainable Energy Reviews* 14 (9): 2916–2925.

De, S. K., R. Biswas, and A. R. Roy. 2001. "An Application of Intuitionistic Fuzzy Sets in Medical Diagnosis." *Fuzzy Sets and Systems* 117 (2): 209–213.

Dong, C., G. H. Huang, Y. P. Cai, and Y. Liu. 2012. "An Inexact Optimization Modeling Approach for Supporting Energy Systems Planning and Air Pollution Mitigation in Beijing City." *Energy* 37 (1): 673–688.

Doukas, H. C., B. M. Andreas, and J. E. Psarras. 2007. "Multi-criteria Decision Aid for the Formulation of Sustainable Technological Energy Priorities using Linguistic Variables." *European Journal of Operational Research* 182 (2): 844–855.

Dubois, D., and H. Prade. 1980. *Fuzzy Sets and Systems: Theory and Applications*. New York: Academic Press.

Hai, W., Q. Gang, and F. Xiangqian. 2011. "An Intuitionistic Fuzzy AHP based on Synthesis of Eigenvectors and its Application." *Information Technology Journal* 10 (10): 1850–1866.

Hashim, H., and W. S. Ho. 2011. "Renewable Energy Policies and Initiatives for a Sustainable Energy Future in Malaysia." *Renewable and Sustainable Energy Reviews* 15 (9): 4780–4787.

Hersh, M. A. 2006. *Mathematical Modeling for Sustainable Development*. Berlin: Springer-Verlag.

Jing, Y.-Y., H. Bai, and J.-J. Wang. 2012. "A Fuzzy Multi-criteria Decision-making Model for CCHP Systems Driven by Different Energy Sources." *Energy Policy* 42 (3): 286–296.

Kaya, T., and C. Kahraman. 2011. "Multicriteria Decision Making in Energy Planning using a Modified Fuzzy TOPSIS Methodology." *Expert Systems with Applications* 38 (6): 6577–6585.

Khor, C. S., and G. Lalchand. 2014. "A Review on Sustainable Power Generation in Malaysia to 2030: Historical Perspective, Current Assessment, and Future Strategies." *Renewable and Sustainable Energy Reviews* 29: 952–960.

Laarhoven, P. J. M., and W. Pedrycz. 1983. "A Fuzzy Extension of Saaty's Priority Theory." *Fuzzy Sets and Systems* 11 (1–3): 229–241.

Li, D. F. 2005. "Multi-attribute Decision Making Models and Method using Intuitionistic Fuzzy Sets." *Journal of Computer System and Science* 70 (1): 73–85.

Ministry of Energy, Water and Communication. 2010. National Energy Policy. http://www.kettha.gov.my/en

Oh, T. H., S. Y. Pang, and S. C. Chua. 2010. "Energy Policy and Alternative Energy in Malaysia: Issues and Challenges for Sustainable Growth." *Renewable and Sustainable Energy Reviews* 14 (4): 1241–1252.

Pohekar, S. D., and M. Ramachandran. 2004. "Application of Multi-criteria Decision Making to Sustainable Energy Planning – A Review." *Renewable and Sustainable Energy Reviews* 8 (4): 365–381.

Rahman Mohamed, A., and K. T. Lee. 2006. "Energy for Sustainable Development in Malaysia: Energy Policy and Alternative Energy." *Energy Policy* 34 (14): 2388–2397.

Rehan, S., and T. Solomon. 2009. "Environmental Decision Making under Uncertainty using Intuitionistic Fuzzy Analytic Hierarchy Process (IF-AHP)." *Stochastic Environment Research Risk Assessment* 23 (1): 75–91.

Saaty, T. L. 1980. *The Analytical Hierarchy Process*. New York: McGraw-Hill.

Scott, J. A., W. Ho, and P. K. Dey. 2012. "A Review of Multi-criteria Decision-making Methods for Bioenergy Systems." *Energy* 42 (1): 146–156.

Shafie, S. M., T. M. I. Mahlia, H. H. Masjuki, and A. Andriyana. 2011. "Current Energy Usage and Sustainable Energy in Malaysia: A Review." *Renewable and Sustainable Energy Reviews* 15 (9): 4370–4377.

Solangi, K. H., M. R. Islam, R. Saidur, N. A. Rahim, and H. Fayaz. 2011. "A Review on Global Solar Energy Policy." *Renewable and Sustainable Energy Reviews* 15 (4): 2149–2163.

Szmidt, E., and J. Kacprzyk. 1996. "Intuitionistic Fuzzy Sets in Group Decision Making." *NIFS* 2 (1): 15–32.

Tan, R. R., and D. C. Y. Foo. 2007. "Pinch Analysis Approach to Carbon-constrained Energy Sector Planning." *Energy* 32 (8): 1422–1429.

Tsoutsos, T., M. Drandaki, N. Frantzeskaki, E. Iosifidis, and I. Kiosses. 2009. "Sustainable Energy Planning by using Multi-criteria Analysis Application in the Island of Crete." *Energy Policy* 37 (5): 1587–1600.

Turanli, N., and D. Coker. 2000. "Fuzzy Connectedness in Intuitionistic Fuzzy Topological Spaces." *Fuzzy Sets and Systems* 116 (3): 369–375.

UNDP (United Nations Development Programme) 2006. "Achieving Industrial Energy Efficiency in Malaysia." ISBN 983-40995-7-6.

UNDP (United Nations Development Programme) 2007. "Malaysia Generating Renewable Energy from Palm Oil Wastes." ISBN 983-3904-01-3.

Vlashos, I. K., and G. D. Sergiadis. 2007. "Intuitionistic Fuzzy Information-Applications to Pattern Recognition." *Pattern Recognition Letters* 28 (2): 197–206.

Wang, J.-J., Y.-Y. Jing, C.-F. Zhang, and J.-H. Zhao. 2009. "Review on Multi-criteria Decision Analysis Aid in Sustainable Energy Decision-making." *Renewable and Sustainable Energy Reviews* 13 (9): 2263–2278.

Wang, L., L. Xu, and H. Song. 2011. "Environmental Performance Evaluation of Beijing's Energy use Planning." *Energy Policy* 39 (6): 3483–3495.

Wang, P. 2009. "QoS-aware Web Services Selection with Intuitionistic Fuzzy Set under Consumer's Vague Perception." *Expert Systems with Applications* 36 (3): 4460–4466.

Xu, Z. S. 2007a. "Multi-person Multi-attribute Decision Making Models under Intuitionistic Fuzzy Environment." *Fuzzy Optimization and Decision Making* 6 (3): 221–236.

Xu, Z. S. 2007b. "Intuitionistic Fuzzy Aggregation Operators." *IEEE Transactions on Fuzzy Systems* 15 (6): 1179–1187.

Zadeh, L. A. 1965. "Fuzzy Sets." *Information and Control* 8 (3): 338–353.

Zhang, S., and S. Liu. 2011. "A GRA-based Intuitionistic Fuzzy Multi-criteria Group Decision Making Method for Personnel Selection." *Expert Systems with Applications* 38 (9): 11401–11405.