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Selection the optimal technology for electricity generation of 5 MW using a fuzzy multi-criteria decision-making approach

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Abstract. Today's challenges towards a sustainable energy development in most European nations are crucial and highly complicated. We find the need to choose between several technologies generation, whose task is very laborious. Multiple factors that affect the success of a Renewable Energy (RE) project must be analyzed and taken into account. The evaluation and comparison of possible technologies generation is a multi-criteria decision problem because not only economic aspects must be considered but also technical, environmental and social aspects. This paper presents the case for selecting the optimal technology for electricity generation of 5 MW for a region located in the southeast of Spain. As most of the real-world multicriteria decision-making (MCDM) problems contain a mixture of quantitative and qualitative criteria; therefore discrete MCDM methods are inadequate for handling this type of decision problems.

Key words

Fuzzy decision-making process, hierarchical structure, Renewable technology, triangular fuzzy number.

1. Introduction

Access to electricity is essential for economic development of society and progress, determining the level and quality of life of individuals. In short, any approach to energy strategy revolves around three simultaneous satisfactions of requirements: security of supply, environmental sustainability, reducing emissions of greenhouse gases and economic efficiency ensure their generation at the lowest possible cost.

In the case of Spain, these aims are conditioned by the specific circumstances of the energy market. In particular, the electricity generation sector in Spain is faced with the challenge of solving the following problems: high energy intensity, high energy dependence of the generating overcapacity, complexity in the operation of the park, electricity prices, commitments reduction of greenhouse gases.

And forced by the various European directives, Spain has had to adapt their regulations, publishing in particular the: PAE's (Plan de Acción y Eficiencia), and -PER's (Plan Energía Renovables).

Forced by the implementation of the PER, in Spain's electricity production it increased strongly due to the RE. The extended presence of the forms of generation based on RE have caused a change in the way of managing the electricity system, defining a new situation referred to broadly as distribution generation (DG).

In recent years the presence of DG systems in the Spanish energy mix is increasing significantly. However, the selection process of these power generation technologies in a given environment is not a simple and easy resolution process, as it depends on factors of diverse nature among them: power infrastructure, energy supply, maturity technology,... Given the large number of factor involved in their selection, the choice is not so obvious, the use of a MCDM is necessary. The scope of this paper is part of the process of deciding the most appropriate technology. The method proposed will be similar to AHP Fuzzy.

2. Evaluation Criteria

The evaluation criteria represent the indexes, which enable alternatives to be compared from a specific point of view. Therefore, the selection of criteria is of prime importance in the resolution of any selection problem, meaning, that it is vital to identify a coherent family of criteria and not just any set of criteria [1].

The selection of an optimal technology for electricity generation has often been based on a single criterion: economic or technological criterion. However, many more aspects have to be considered such as social and environmental [2]. To be efficiently assessed, the criteria must be decomposed into sub-criteria that contain all the aspects to consider [3] Figure 1 shows a hierarchical structure of a distributed generation technology.

The proposed criteria and sub-criteria are explained in detail in the following sections.

A. Environmental criteria

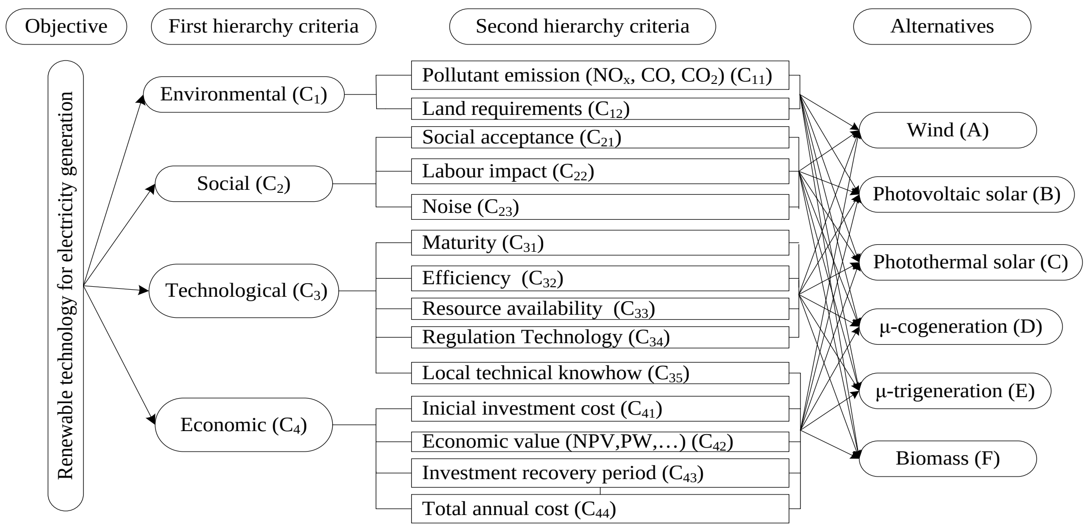

Fig. 1. Hierarchical structure of criteria

The environmental criteria take into account two aspect: air pollution and land requirements. From the standpoint of air pollution the technology have to be assessed with respect to their emissions of the following gases: NO_x, CO and CO_2 emission which is the most prominent greenhouse gas in earth's atmosphere. With respect to land requirements, it represents one of the most critical factors for the intervention site, especially where the human activities are relevant factors of environmental pressure.

B. Social criteria

The construction and operation of a plan affect the general society. The impact on the community is presented in different aspects such as noise, people's perceptions or social acceptance, and labour impact. The different technologies generate more o less noise. The proximity of these plants to people transforms the noise into a potential disadvantage. With respect to the social acceptance, the criterion enhances consensus among social partners.
Finally the labour impact, it takes into account the direct and indirect employment and the possible indirect creation of new professional figures are also assessed [1].

C. Technical criteria

The operational characteristic of the generation technologies used in distributed generation are important aspects to be considered in the selection of a distributed generation technology. From among the technical parameters, two parameters are significantly important: resource availability, this criterion includes primary energy consumption and efficiency. Other criterion, which must be considered, related to the performance characteristics, is the regulation technology which represents the flexibility of control. The maturity of the technology is also an important criterion because mature technologies have a long life and are very reliable. Finally, local technical knowhow of the technology ensures proper maintenance support.

D. Economic criteria

Two aspects in economic matter are important to consider: cost and finance. The investment cost that include both purchase and installation cost is a critical evaluation parameter. Not only investments costs are important but also operation and maintenance costs. Therefore, another criterion must be the total annual cost that includes the operation and maintenance costs. Finance criteria denote the potential to earn or save money. An important criterion to analyse the profitability of an investment is the investment recovery period. Another criterion is the net present value that represents economic return of the project along its life time.

3. Proposed Multi-criteria Decision-Making Model

In this paper, the MCDM problem will be resolved using the following steps:

A. Identify decision criteria.

Almost all of the decision-making problems are MCDM problems. In most cases, the number of criteria is large and then it is necessary to classify them. Following [4] the selected criteria can be structured in a hierarchical manner. More general criteria can be linked with more specific criteria to build the hierarchy. The elements of a given level are mutually independent, but comparable to the elements of the same level and group. The analysis is complete when criteria are specific enough for assessing the alternatives –Figure 1-.

B. Determine the sets of linguistic scales and corresponding fuzzy numbers.

Frequently, it may be extremely difficult to assess the relative importance of criteria pair-wise comparisons or the performance of one alternative on some criteria due to the great uncertainty involved. In these circumstances, DM prefers a linguistic assessment instead of an exact value. One of the key points in fuzzy modelling is to assign the membership functions corresponding to fuzzy numbers that represent vague concepts and imprecise terms expressed often in a natural language. For the sake of simplicity the triangular fuzzy number is used.

Table I. Scales and linguistic term used

LINGÜÍSTIC TERMS	SCALES					
	1	2	3	4	5	6
Absolutely Less important (AL)						✓
Very Strongly Less important (VSL)		✓		✓	✓	✓
Strongly Less important (SL)					✓	✓
Less important (L)	✓	✓	✓	✓	✓	✓
Weakly Less important (WL)			✓	✓	✓	✓
Equally important (E)	✓	✓	✓	✓	✓	✓
Weakly More important (WM)			✓	✓	✓	✓
More important (M)	✓	✓	✓	✓	✓	✓
Strongly More important (SM)					✓	✓
Very Strongly More important (VSM)		✓		✓	✓	✓
Absolutely More important (AM)						✓
GRANULARITY	3	5	5	7	9	11

Based on Chen's [5] research study about a numerical approximation system focused on systematically converted linguistic terms to their corresponding fuzzy numbers, the linguistic terms used in this paper are shown in Table I. Depending on the linguistic terms used by the expert, the expert will be assigned a scale. The lower scale granularity will be assigned to each expert, such that the same linguistic term depending on the scale, will have associate a different membership functions -Table II-.

C. Pair-wise compare decision criteria.

DM is required to provide their opinion of the relative importance for every criteria pair of the same level and group in the hierarchy structure. These linguistic measures are converted into fuzzy members using Table II.

Table II. Memberships functions for scales 1, 3 and 6

LINGUISTIC TÉRMS	ESCALAS		
	1	3	6
AL			(0;0;0,1)
VSL		(0;0;0,2)	(0;0,1;0,2)
SL			(0,1;0,2;0,3)
L	(0;0;0,5)	(0;0,2;0,4)	(0,2;0,3;0,4)
WL		(0,2;0,4;0,6)	(0,3;0,4;0,5)
E	(0;0,5;0)		(0,4;0,5;0,6)
WM		(0,4;0,6;0,8)	(0,5;0,6;0,7)
M	(0,5;0;0)	(0,6:0,8;1)	(0,6;0,7;0,8)
SM			(0,7;0,8;0,9)
VSM		(0,8;1;1)	(0,8;0,9;1)
AM			(0,9;1;1)

It is obvious that a minimum consistency is required, and we have chosen wake transitivity concept as the consistency border that expert opinions have to respect.

D. Estimate weight of the experts.

The quality of the judgments of experts is not equal, and evens the level of criteria and sub-criteria the experts have not a linear behavior in their opinions. So it is necessary to calculate a weight for each expert on the criterion and subcriteria. We used two parameters.

1) *Measure of the vagueness of the scale used for the expert*: There are various parameters that could be used to measure the vagueness of the linguistic terms. The specificity was used for giving a range of values more, and therefore the distinguishability between scales is greater, the equation used would be [6]. k_{esp} defined the vagueness, whose value depending on the chosen scale, is shown in table III.

$$Sp(A) = \int_0^{\alpha_{\max}} F(\mu(A_\alpha)) \cdot d\alpha \qquad (1)$$

Table III. Specifity's Value of each one of the scales

SCALE	1	2	3	4	5	6
SPECIFICITY	0,500	0,750	0,800	0,833	0,875	0,900

2) *Distance between maximum consistency and average value of the sum of the shortlist of expert opinions (k_{inc}):* Initial conditions must comply with the weak transitivity property, to assess the consistency of the opinions of experts. The distance between the shortlists of the opinions of experts and the maximum distance is calculated. So that when this distance is less, will be higher consistency. The expression used as reference is the next [7]:

$$D(m,n) = \sqrt{\frac{1}{3} \cdot \left[(m_1 - c_1)^2 + (m_2 - c_2)^2 + (m_3 - c_3)^2 \right]} \qquad (2)$$

Normalizing the distance values will get the k_{cons}

The weight of the experts will be calculated using the following equation:

$$k_e = \sqrt{k_{esp} \cdot k_{cons}} \qquad (3)$$

The weights of the expert will be obtained normalizing the values k_e, such that, the sum of the weights is unity.

E. Aggregation of the experts' opinions.

The current literature contains several strategies for extending multiattribute decision methods to group settings, in order to obtain solutions that reflect the collective vision of a problem. Three different strategies are [8]. We used Aggregation of individual evaluations (AIE), the experts are supposed to evaluate each alternative by forming fuzzy or linguistic estimates. Afterward, the estimates provided by each expert for each alternative, and taking into account each criterion, are aggregated into some collective estimates.

F. Estimate weight of criteria.

With the hierarchical weighting method, a criterion is associated with a local weight and a global weight. The local weight of a criterion is referred to the weight relative to other criteria at the same group and level, which is to be assessed using the pair-wise comparison process. The global weight of a criterion is referred to the weight relative to all other criteria for the overall objective of the decision problem [9].

1) *Estimate the local weights of criteria*: This problem is solved using classical methods of weighting criteria calculation adapted to operate with triangular fuzzy numbers. By the reciprocal property of preference relation matrix, the following equation has to be satisfied to get of υ'_{ij} with the strongest transitivity restriction between pair-wise comparisons [10]

$$\upsilon'_{ij} = \frac{1}{2} + \frac{\psi(\omega_i) - \psi(\omega_j)}{2} \quad (4)$$

where $\psi(\omega_i)$ can be any nondecreasing function, and $\sum \omega_i = 1$. As the Equation (4) satisfies the additive transitivity property. Then the Equation (4) is rewritten as

$$\upsilon'_{ij} = s_0 \oplus \frac{\omega_i \Theta \omega_j}{2} \quad (5)$$

Where *i* and *j* are criteria of group *g* and level *l*, and $\oplus$ and Θ represent fuzzy addition and subtraction. Due to the fuzziness of the opinions and the wake transitivity restriction considered, we could not find an accurate solution for this problem. ω_i could be calculated by minimization of the distance between υ_{ij} obtained directly from the experts and the value υ'_{ij}, [9]

$$\min \left[\sum_{i=1}^{n} \sum_{j=1}^{n} d^2(\upsilon'_{ij}, \upsilon_{ij}) \right] \quad (6)$$

2) *Estimate the global weights of criteria:* Assume the criterion C_i has *t* upper groups at different levels in the criteria hierarchy and $\omega(j)$ group is the group weight of the *j*th upper group which contains the criterion C_i in the hierarchy. The final value of criterion C_i, W_i, can be derived by

$$W_i = \omega_i \otimes \prod_{j=1}^{t} \omega_{group}^{(j)}, \quad (7)$$

G. Define and normalize the judgment matrix.

The evaluation criteria have their own characteristic and each data of criteria has its own dimension and distribution; it makes comparison difficult. As result, the original data evaluation criteria should be dimensionless and unit-free by normalization method [9].

As G_{ij} is a benefit items,

$$R_{ij} = \frac{G_{ij}}{G_j^+} = \left(\frac{g_{ij}^a}{g_j^{d+}}, \frac{g_{ij}^b}{g_j^{c+}}, \frac{g_{ij}^c}{g_j^{b+}}, \frac{g_{ij}^d}{g_j^{a+}} \wedge 1 \right). \quad (8)$$

As G_{ij} is a cost item,

$$R_{ij} = \frac{G_{ij}}{G_j^+} = \left(\frac{g_j^{a-}}{g_{ij}^d}, \frac{g_j^{b-}}{g_{ij}^c}, \frac{g_j^{c-}}{g_{ij}^b}, \frac{g_j^{d-}}{g_{ij}^a} \wedge 1 \right). \quad (9)$$

H. Calculate value of performance of each alternative.

The more common aggregation operator, generally used to obtain the global performance of each alternative is the weighted sum of criteria values:

$$\omega(A_i) = (W_1 \otimes R_{i1}) \oplus (W_2 \otimes R_{i2}) \oplus \cdots \oplus (W_n \otimes R_{in}), \quad (10)$$

I. Defuzzificate fuzzy utility values

Defuzzification is an important procedure for rating alternatives. Producing a crisp number that represents the membership function $\omega(A_i)$. The method used is centroid

$$R(A_i) = \frac{\int_0^1 x \cdot \omega(A_i)(x) \cdot dx}{\int_0^1 \omega(A_i)(x) \cdot dx}, \quad (11)$$

where *i* is the number of alternatives.

4. Case Study

The proposed problem consists on the selection of the optimal technology for electricity generation of 5 MW in the northwest of the city of Murcia. The total area available for installation is 400000 m^2, near the city

A. Formulation of alternatives

After preliminary screening, the group of experts proposed six alternatives to be evaluated –Figure 1-.

B. Comparison criteria pair-wise

Linguistic rating set defined in Table I is employed to establish the relative importance for every criteria pair. These linguistic measures are converted into fuzzy numbers according to Table II. Table IV summarizes the pair-wise comparison for the first group for three experts.

Table IV. Medium value of the distances

G1	C_1	C_2	C_3	C_4
C_1	-	AL WL WL	AL M SL	AL SM AL
C_2	AM WM WM	-	L SM L	AL VSM
C_3	AM L SM	M SL M	-	AM M L
C_4	AM SL AM	AM VSL VSM	AL L M	-

C. Estimation of expert weights in each one of the five groups

In our case, scales used for the expert is the same, all experts have worked with the sixth scale, as shown in Table III the specificity's value corresponds to 0,9

Table V. – Value of Consistency of the expert (k_{inc})

	EXPERT 1	EXPERT 2	EXPERT 3
G1	0,49072	0,9467	1
G2			
G3	0,93849	0,93849	0,78678
G4	0,62058	0,71642	0,80928
G5	0,84009	0,71322	0,84009

Applying equation (3), and normalization of the values obtained, we have the expert's weights –Table VI-

Table VI. – Experts' weights for each of the sets of criteria (ω_e)

	EXPERT 1	EXPERT 2	EXPERT 3
G1	0,262023	0,363937	0,37404
G2			
G3	0,342981	0,34298	0,314037
G4	0,310905	0,334054	0,355041
G5	0,342302	0,315397	0,342302

D. Aggregation of judgments of the experts

From the opinions obtains the pair-wise comparison for all levels (G1 to G5) for three experts, using the expert's weight for each criterion -Table VI-, we obtain five aggregated matrix, as the following

$$D^1 = \begin{bmatrix} [0,4;0,5;0,6] & [0,60;0,70;0,78] & [0,57;0,67;0,74] & [0,61;0,71;0,75] \\ [0,22;0,30;0,40] & [0,4;0,5;0,6] & [0,42;0,52;0,62] & [0,86;0,96;1] \\ [0,26;0,33;0,43] & [0,38;0,48;0,58] & [0,4;0,5;0,6] & [0,30;0,37;0,47] \\ [0,25;0,29;0,39] & [0,29;0,36;0,46] & [0,53;0,63;0,70] & [0,4;0,5;0,6] \end{bmatrix}$$

E. Estimation of the local weights of criteria and the global weights of criteria

The local (ω_i) and global (W_i). weights are shown in Table VII. The local weight is calculated by difference minimization method, using (5) and (6) and the global weight of each criterion is calculated using (7).

F. Definition of judgment matrix

Each criterion has its own dimension and distribution, in some cases an exact value is possible to define the performance of an alternative on a criterion and in other cases only a linguistic value is adequate. In this last case, the linguistic scale defines in Table VIII and the corresponding fuzzy numbers are used to assess the performance of the alternatives on each criterion. The judgment matrix is shown in Table IX.

Table VIII. Linguistic values of performance of alternatives

LINGÜÍSTIC TERMS	FUZZY NUMBER
Very low (VL)	(0;0;0,25)
Low (L)	(0;0,25;0,5)
Middle (M)	(0,25;0,5;0,75)
High (H)	(0,5;0,75;1)
Very high (VH)	(0,75;1;1)

To operate with these values, the data normalization is necessary -Table IX-.

Tabla VII. Local weight and global weight of criteria

CRITERIA AND SUBCRITERIA	LOCAL WEIGHT (ω_i)	GLOBAL WEIGHT (W_i)
Environmental	ω_1=[0,32 ; 0,39 ; 0,44]	
Pollutant emissions	$\omega_{1,1}$=[0,83 ; 0,93 ; 1]	$W_{1,1}$=[0,2656 ; 0,3627 ; 0,44]
Land requirements	$\omega_{1,2}$=[0 ; 0,07 ; 0,17]	$W_{1,2}$=[0 ; 0,0273 ; 0,0748]
Social	ω_2=[0,28 ; 0,34 ; 0,439]	
Social acceptance	$\omega_{2,1}$=[0,52 ; 0,58 ; 0,63]	$W_{2,1}$=[0,1456 ; 0,1972 ; 0,2766]
Labour impact	$\omega_{2,2}$=[0,17 ; 0,22 ; 0,28]	$W_{2,2}$=[0,0476 ; 0,0748 ; 0,1229]
Noise	$\omega_{2,3}$=[0,14 ; 0,20 ; 0,26]	$W_{2,3}$=[0,0392 ; 0,0680 ; 0,1141]
Technological	ω_3=[0,14 ; 0,20 ; 0,26]	
Maturity	$\omega_{3,1}$=[0,09 ; 0,14 ; 0,2]	$W_{3,1}$=[0,0126 ; 0,0280 ; 0,0520]
Efficiency	$\omega_{3,2}$=[0,35 ; 0,40 ; 0,47]	$W_{3,2}$=[0,0490 ; 0,0800 ; 0,1222]
Resource avaliability	$\omega_{3,3}$=[0,24 ; 0,30 ; 0,35]	$W_{3,3}$=[0,0336 ; 0,0600 ; 0,0910]
Regulation technology	$\omega_{3,4}$=[0,05 ; 0,10 ; 0,16]	$W_{3,4}$=[0,0070 ; 0,0200 ; 0,0416]
Local technical knowhow	$\omega_{3,5}$=[0 ; 0,06 ; 0,1]	$W_{3,5}$=[0 ; 0,0120 ; 0,0260]
Economic	ω_4=[0,02 ; 0,07 ; 0,12]	
Inicial investment	$\omega_{4,1}$=[0,02 ; 0,07; 0,12]	$W_{4,1}$=[0,0004 ; 0,0049 ; 0,0144]
Economic value	$\omega_{4,2}$=[0,43 ; 0,48 ; 0,53]	$W_{4,2}$=[0,0086 ; 0,0336 ; 0,0636]
Investment recovery period	$\omega_{4,3}$=[0,22 ; 0,26 ; 0,32]	$W_{4,3}$=[0,0044 ; 0,0182 ; 0,0384]
Total annual cost	$\omega_{4,4}$=[0,14 ; 0,19 ; 0,24]	$W_{4,4}$=[0,0028 ; 0,0133 ; 0,0288]

G. Results

Once the global weights of criteria have been calculated and the performance of each alternative on each criterion has been assessed and normalized, the fuzzy preference value of each alternative, $\omega(A_i)$, is calculated by using (10). The fuzzy number associated with the global performance of each proposed alternative must be converted into a crisp preference value $R(A_i)$ to ranking the alternatives by using (11). All these values are shown in Table X.

Table X. Local weight and global weight of criteria

ALTERNATIVES	$w(A_i)$	$R(A_i)$	RANK
A	[0,4027; 0,6764; 1,0874]	0,722	1
B	[0,2030; 0,4173; 0,9945]	0,538	5
C	[0,3955; 0,6599; 1,0247]	0,693	3
D	[0,2217; 0,5083; 0,9539]	0,561	4
E	[0,2089; 0,4676; 0,8746]	0,517	6
F	[0,3661; 0,6462; 1,0977]	0,703	2

5. Conclusion

This study develops a scientific framework for selecting the optimal technology for electricity generation of 5 MW in the northwest of the city of Murcia. The characteristics of the proposed decision-making problem are: (a) a finite number of comparable alternatives; (b) multiple criteria for evaluation alternatives; (c) noncommensurable units for measuring the performance rating of the alternatives on some criterion and (d) several expert defined their judge. Therefore, classical MCDM methodologies are inadequate to apply in this type of MCDM problems. To handle with uncertainty of information and vagueness of judgments and large number of criteria, a MCDM methodology based on structure hierarchical and fuzzy sets theory has been proposed.

Compared with other available methods, the advantages of the proposed method can be summarized: (a) a hierarchical structure of criteria is generated to facilitate the process for assessing the weights of criteria, (b) the comparative judgment of pair-wise criteria are expressed in linguistic term, (c) depending on linguistic term used for the expert is defined an expert's scale,

Tabla IX. The features of 6 alternatives of DG technology and the normalization (*in italic*) value of 6 alternatives

		WIND A	PHOTOVOLTAIC SOLAR B	PHOTOTHERMAL SOLAR C	μ-COGENERATION D	μ-TRIGENERATION E	BIOMASS F
$C_{1,1}$: Pollutant emission (g/kWh)	Min.	24 *1*	138,15 *0,173724*	29 *0,827586*	257,41 *0,093236*	257,41 *0,093236*	35,8 *0,670391*
$C_{1,2}$: Land requirements (m^2)	Min	350.000 *0,0000714*	100.000 *0,00025*	137.500 *0,0001818*	25 *1*	51 *0,49019*	14.600 *0,001712*
$C_{2,1}$: Social acceptance	Max	H *(0,5;0,75;1)*	H *(0,5;0,75;1)*	VH *(0,75;1;1)*	M *(0,25;0,5;0,75)*	M *(0,25;0,5;0,75)*	H *(0,5;0,75;1)*
$C_{2,2}$: Labour impact	Max	6 *0,10714*	14 *0,25*	16 *0,285714*	24 *0,42857*	24 *0,42857*	56 *1*
$C_{2,3}$: Noise (dB)	Min	108,1 *0,288621*	31,2 *1*	53 *0,588679*	33,2 *0,939759*	42 *0,712857*	67,5 *0,46222*
$C_{3,1}$: Maturity	Max	VH *(0,75;1;1)*	H *(0,5;0,75;1)*	H *(0,25;0,5;0,75)*	VH *(0,75;1;1)*	H *(0,5;0,75;1)*	M *(0,25;0,5;0,75)*
$C_{3,2}$: Efficiency	Max	50 *0,55555*	17 *0,188889*	19 *0,211111*	90 *1*	90 *1*	26 *0,2888889*
$C_{3,3}$: Resource availability	Max	L *(0;0,25;0,5)*	M *(0,25;0,5;0,75)*	M *(0,25;0,5;0,75)*	VH *(0,75;1;1)*	VH *(0,75;1;1)*	H *(0,5;0,75;1)*
$C_{3,4}$: Regulation technology	Max	VL *(0;0;0,25)*	L *(0;0,25;0,5)*	L *(0;0,25;0,5)*	VH *(0,75;1;1)*	VH *(0,75;1;1)*	H *(0,5;0,75;1)*
$C_{3,5}$: Local technical knowhow	Max	17 *0,18888*	90 *1*	22 *0,244444*	11 *0,12222*	9 *0,1*	15 *0,166667*
$C_{4,1}$:Inicial investment	Min	5,14 *0,647859*	16 *0,208125*	21,6 *0,1541667*	3,33 *1*	4 *0,825*	6 *0,555*
$C_{4,2}$: Economic value	Max	7,6 *0,767676*	7,5 *0,757575*	6,3 *0,636364*	7,87 *0,794949*	8 *0,80808*	9,9 *1*
$C_{4,3}$: Investment recovery period	Min	8,36 *0,5287*	10,29 *0,429543*	11,08 *0,3979169*	4,42 *1*	5,11 *0,86497*	9,46 *0,4672304*
$C_{4,4}$: Total annual cost	Min	6,81 *0,741556*	30 *0,168333*	23,23 *0,2173913*	5,05 *1*	5,55 *0,909909*	13,7 *0,368613*

(d) the performance value of each alternative on each criterion is defined in exact numerical values or in linguistic terms if the criterion is quantitative or qualitative, respectively, (e) depending on the scale and the judgments of experts, expert weight was obtained for each group of criteria, (f) the implemented algorithm that operate with triangular fuzzy number does not require cumbersome computations.

However, the method is mainly limited by the quality of the information given by the experts and it depends on the consistency concept. The wake transitivity concept has been chosen as the consistency border.

The proposed method provides a systematic framework for selecting the optimal technology for electricity generation in a fuzzy environment that can be easily extended to the analysis of other decision problems in energy area. This method represents an improvement over other previous works especially on the following aspects: (1) the development of a model to distinguish experts' competence, because different experts have different impacts on the final decision, (2) the selection of fuzzy numbers which represents the meaning of evaluation verbal term, defining six scales according to the linguistic terms used associated with fuzzy numbers.

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