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Fuzzy Information and Z-number-based Approaches to Energy Resource Selection

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ABSTRACT

In this paper, we study models for ranking renewables and a mix of energy resources in the development of long-term energy policy. Energy resource selection is a multi-criteria decision-making problem, characterized by incomplete information, uncertainties and intangibles, competitive priorities and contradictory requirements. The uniqueness of the problem and the limited relevant data necessitates the use of expert opinion as a principal source of information. All these factors contribute to subjectivity and vagueness in the decision-making process. Taking into consideration these circumstances, fuzzy information and a Z-number-based analytic hierarchy process (AHP) has been used as a decision-making tool. Z-number represents both the restriction and the reliability of evaluation and, due to these characteristics, it provides a better description of the uncertainty. Numerical examples and comparative analysis of fuzzy and Z-number-based models illustrate the process to solution and results.

Keywords: Energy Resources, Fuzzy Information, Analytic Hierarchy Process, Z-number, Multi-criteria Decision

JEL Classifications: Q42, Q48, Q35

1. INTRODUCTION

Energy is a driving force of any economy and has a decisive role in production and service systems. Depending on a country's geographical location, its natural resources, level of economic development and environmental setting, various energy resources are available, and, in such circumstances, the development of a sustainable energy policy requires multidimensional analysis of the multiple alternatives within the limits of constraints and priorities. The issues of global warming and pollution have put on the forefront task of green energy resources development and selection, the gradual replacement of environmentally harmful resources and rationale combination of renewables with non-renewables during a transition time. Energy resource selection is characterized by a variety of uncertainties, incomplete information and subjectively defined priorities. In such a decision-making environment, it is necessary to give special attention to the relevance of the approach applied and models developed. Fuzzy information and Z-number-based models are powerful tools for

dealing with uncertainties and imprecisions. The objective of this paper is to develop a fuzzy information and Z-number-based AHP for a renewables and energy resources mix ranking and selection and conduct a comparative analysis of these models.

Energy resource selection is a classic example of multi-criteria decision making (MCDM) and various tools are used to resolve the problem. Researchers and practitioners give special attention to the pairwise comparison method developed in the mid-1970s (Saaty, 1977) and apply it successfully with some modifications and developments in various fields (Ishizaka, Labib, 2011; Ishizaka, 2014; Singh et al., 2016; Emrouznejad and Marra, 2017) as a powerful tool for multicriteria decision making. In an extensive review, covering the period from 1979 to 2017 (Emrouznejad and Marra, 2017), the authors provide a detailed analysis of developments in AHP research and its integration with other multi criteria decision analysis (MCDA) tools, cooperation in research, advantages of use and criticisms, and principal areas of interest and applications. Ishizaka and Labib (2011) review methodological

developments of the analytic hierarchy process (AHP) since its inception. Developments in decision process modelling, pairwise comparisons, judgment scales, priority derivation methods, consistency indices, incomplete matrices, syntheses of weights, sensitivity analyses, and group decisions are analysed. Singh et al. (2016) review applications of classical and fuzzy AHPs in the resolution of MCDA problems in management and business, design and development, health care and medicine, education and other areas from 2010 to 2015.

Since our objective is multi-criteria decision making for energy resource selection and policy development in a fuzzy and Z-information environment, the next part of the literature study briefly reviews fuzzy and Z-number-based approaches to decision making.

Tasria and Susilawatib (2014) have applied fuzzy AHP, based on a new procedure for the aggregation of expert opinion in selecting the most appropriate renewable energy sources to generate electricity in Indonesia.

Hesham et al. (2013) discuss a fuzzy analytic network process (ANP) approach using linguistic variables and Gaussian fuzzy numbers to represent decision-makers' judgments by comparison and the extent analysis method to decide the final priority of different decision criteria. The priority weights of main attributes, sub-attributes and alternatives are combined to determine the priority weights of the alternatives. The alternative with the highest priority weight is selected as the best of the alternatives. From the results of research, decision-makers in the Egyptian government are recommended to build more nuclear power stations to provide 25% of the electricity generated in Egypt and to construct solar power stations to cover 5% of the electricity generated.

Kaya et al. (2019) evaluate the renewable energy alternatives for Turkey using the Modified Fuzzy AHP based on four main criteria and eight sub-criteria. In this approach, reciprocals are evaluated with the use of negative fuzzy numbers. Hydro, wind, solar, biomass and geothermal energy are analysed as the renewable energy alternatives. The results indicate that solar energy is the best of the alternatives, with wind energy is the second-best for Turkey. In other research (Toklu and Taşkin, 2018), based on the fuzzy AHP and fuzzy TOPSIS methods, wind energy was determined to be the most suitable for Turkey.

Hamal et al. (2018) determine the optimal renewable energy investment project via the fuzzy analytic network process (FANP) model. The study presents a comprehensive mathematical approach based on Chang's extent analysis method. Four critical success factors and five renewable energy sources are identified from the review of literature. In the evaluation, FANP captures the vagueness and uncertainties inherent in project solutions. Application of the FANP method resulted in hydropower being selected as an optimum renewable energy investment project for the firm.

Çelikbilek and Tüysüz (2015) combined the fuzzy multicriteria decision model with the fuzzy VIKOR method to evaluate the renewable energy sources. The result was that solar energy was

the best of the alternatives, with geothermal energy the least preferable RES alternative.

Chia-Nan et al. (2018) applied a hybrid approach, based on the FAHP and TOPSIS models, for the selection of location for a wind power plant in Vietnam under fuzzy environment conditions.

Decision-making approaches were recently enriched by application of the Z-number concept introduced by Zadeh (Zadeh, 2011). Bingyi et al. (2012b) developed a methodology of linguistic decision making based on Z-numbers. The process of resolution is illustrated by an example. Bingyi et al. (2012a) developed a method of transforming Z-number to fuzzy number based on Fuzzy Expectation of the fuzzy set. In (Krohling et al., 2016) the Z-numbers converted to fuzzy numbers and Z-versions of TODİM and TOPSİS are presented as a direct extension of fuzzy TODİM and TOPSİS. In (Chatterjee and Kar, 2018) a detailed review is given of Z-number-based multicriteria decision making for renewables selection (Mustafa, 2018 and Zhang, 2017).

The brief overview of publications on the application of AHP and FAHP in energy resource selection at country and regional levels demonstrates that these powerful approaches can be applied successfully to a detailed analysis of the various aspects of the evaluation and selection of renewable energy resources.

2. FUZZY INFORMATION AND Z-NUMBER-BASED ANALYTICAL HIERARCHY PROCESS (FZ AHP)

Before a description of the features of fuzzy information and Z-number-based AHP, it would be useful to briefly review preliminaries on fuzzy and Z-numbers, and operations.

If X is a collection of objects denoted generically by x , then a fuzzy set \tilde{A} in X is a set of ordered pairs: $A = \{(x, \mu_{\tilde{A}}(x)) | x \in X\}$, $\mu_{\tilde{A}}(x)$ is called the membership function of x in \tilde{A} that maps X to the membership space M (Zimmermann, 2001).

If $u: R \rightarrow [0, 1]$ is a fuzzy subset of the real line u . Then u is a fuzzy number if it satisfies the following properties: (i) u is normal, i.e. $\exists x_0 \in R$ with $u(x_0) = 1$; (ii) u is fuzzy convex (i.e. $u(tx + (1-t)y) \geq \min\{u(x), u(y)\}$, $\forall t \in [0, 1]$, $x, y \in R$); (iii) u is upper semi-continuous on R (i.e. $\forall \varepsilon > 0 \exists \delta > 0$ such that $u(x) - u(x_0) < \varepsilon$, $|x - x_0| < \delta$). (iv) u is compactly supported i.e. $cl\{x \in R; u(x) > 0\}$ is compact, where $cl(A)$ denotes the closure of the set A .

A Z-number (Zadeh, 2011), Z , has two components, $Z = (\tilde{A}, \tilde{B})$.

The first component, \tilde{A} , is a restriction (constraint) on the values which a real-valued uncertain variable, X , can take. The second component, \tilde{B} , is a measure of reliability (certainty) of the first component.

In applications, various types of membership functions have been used: triangular, trapezoidal, Gaussian, sigmoidal, L-R and many others. Most widely used membership functions are triangular and

trapezoidal membership functions (Buckley, 1985; van Laarhoven and Pedrycz, 1983; Chang, 1996). In this paper, we are using triangular functions.

The support M of the triangular fuzzy number (l, m, u) is $\{x \in R \mid l < x < u\}$ and its membership function $\mu_M(x): R \rightarrow [0, 1]$ is equal to:

$$\mu_M(x) = \begin{cases} \frac{x}{m-l} - \frac{l}{m-l}, & x \in [l, m], \\ \frac{x}{m-u} - \frac{u}{m-u}, & x \in [m, u], \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

Basic fuzzy calculation operations used in pairwise comparisons (Chang, 1996) are presented below:

$$(l_1, m_1, u_1) \oplus (l_2, m_2, u_1) = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (2)$$

$$(l_1, m_1, u_1) \odot (l_2, m_2, u_1) = (l_1 l_2, m_1 m_2, u_1 u_2) \quad (3)$$

$$(l, m, u)^{-1} \approx \left(\frac{1}{u}, \frac{1}{m}, \frac{1}{l} \right) \quad (4)$$

As it is shown in (Shahila and Velammal, 2015), direct computations with Z-numbers, especially in large-scale problems, are complicated, sensitive to the probability density functions and do not in all cases ensure successful solution of the task. In applications, an approach based on converting the Z-number to a classical fuzzy number (Bingyi et al., 2012) can be used.

- a. Accordingly, the approach at the first step reliability of the Z-number B should be converted into a crisp number:

$$\alpha = \frac{\int x \mu_{\tilde{B}}(x) dx}{\int \mu_{\tilde{B}}(x) dx} \quad (5)$$

where \int is an algebraic integration.

- b. At the second step the weight of reliability should be added to the restriction \tilde{A} . The weighted Z-number is denoted as:

$$\tilde{Z}^\alpha = \left\{ \left\langle x, \mu_{\tilde{A}^\alpha}(x) \right\rangle \middle| \mu_{\tilde{A}^\alpha}(x) = \alpha \mu_{\tilde{A}}(x), x \in [0, 1] \right\} \quad (6)$$

- c. Finally, the irregular fuzzy number (weighted restriction) should be converted to a regular fuzzy number:

$$\tilde{Z}' = \left\{ \left\langle x, \mu_{\tilde{A}'}(x) \right\rangle \middle| \mu_{\tilde{A}'}(x) = \mu_{\tilde{A}} \left(\frac{x}{\sqrt{\alpha}} \right), x \in [0, 1] \right\} \quad (7)$$

\tilde{Z}' and \tilde{Z}^α are equal with respect to Fuzzy Expectation.

AHP procedures have been modified in accordance with the fuzziness and reliability of the information related to the subject area and the solution process includes the following steps.

1. Problem statement, identification of criteria, sub-criteria and key factors.
2. Development of the problem's hierarchical structure
3. Approximating classical nine point AHP scale by means of fuzzy and Z-numbers, $Z = (\tilde{A}, \tilde{B})$.
4. Transforming reliability \tilde{B} into a crisp number and adding

the weight of reliability to the restriction \tilde{A} .

5. Transforming the irregular fuzzy number to a regular fuzzy number.
6. Matrix representations of the criteria and sub-criteria pairwise comparisons. In the case of fuzzy information, matrix $\tilde{A} = (\tilde{a}_{ij})_{n \times n}$ should be used.
7. Criteria and sub-criteria prioritization.
8. Formulation of comparisons-related questions.
9. Inputting pairwise judgments and reciprocals into pairwise comparison matrix.
10. Calculation of priorities.

In case of a group of decision-makers, fuzzy judgements data \tilde{a}_{ij}^k are averaged according to the formula:

$$\tilde{a}_{ij} = \frac{\sum_{k=1}^K \tilde{a}_{ij}^k}{K} \quad (8)$$

K is the number of decision-makers (experts).

Based on averaged preferences matrix \tilde{A} is composed:

$$\tilde{A} = \begin{pmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \vdots & \tilde{a}_{ij} & \dots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{r2} & \dots & 1 \end{pmatrix}$$

The geometric mean of each criteria (alternative) (Buckley, 1985) is used as a mean value of the fuzzy comparisons:

$$\tilde{r}_i = \left(\prod_{j=1}^n \tilde{a}_{ij} \right)^{1/n} \quad (9)$$

A fuzzy weight \tilde{w}_i of criterion i is calculated by the formula (10):

$$\tilde{w}_i = \tilde{r}_i \odot (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \dots \oplus \tilde{r}_n)^{-1} \quad (10)$$

11. Centre of area (COA) is used for defuzzification of fuzzy weights:

$$X_{COA} = \frac{\int x \mu_A(x) dx}{\int \mu_A(x) dx} \quad (11)$$

For triangular fuzzy numbers it has a simple form:

$$W_i = (l_{w_i} + m_{w_i} + u_{w_i}) / 3 \quad (12)$$

12. Normalization of weights:

$$W_i^N = W_i / \sum_{i=1}^n w_i \quad (13)$$

13. Selection of the best alternative by higher priority.

3. ENERGY RESOURCES EVALUATION

In this section, as an example of energy resource selection, we

analyse the case of Azerbaijan. We formulated and resolved the problem of energy resource selection for the same set of alternatives by applying the fuzzy AHP and Z-number-based AHP. In order to maintain comparability of the approaches, we use the same linguistic variables as in a fuzzy model in the restriction parts of the Z-number-based model. We examine four tasks: ranking renewables based on a fuzzy model; ranking renewables based on Z-numbers; ranking an energy resources mix (renewables + natural gas) based on a fuzzy model; ranking an energy resources mix based on Z-numbers.

Energy resource alternatives are evaluated with respect to social, economic, technological and environmental criteria. The intensity of the criteria and sub-criteria are evaluated on the linguistic scale. Factors (criteria) and sub-factors influencing the selection of energy sources are presented as a hierarchical structure in Table 1.

Z-number-based pairwise evaluations of the factors are presented

in Table 2. Data provided in the table are based on interviews conducted with experts in economics and energy systems.

Alternatives should be evaluated with respect to each criterion. In our case, we analyse separately renewables (solar, wind and hydro) and an energy resources mix (solar, wind, hydro and natural gas) with respect to economic, social, technological and environmental criteria. The techniques applied are the same as in the case of factors analysis.

We provide as examples details of the alternatives pairwise comparison with respect to the economic criterion (Tables 3 and 4) and social sub-criteria (Table 5). Other criteria and sub-criteria are analysed in the same way and, based on this information, summary tables for the selection of alternative are composed (Tables 6-9).

The fuzzy information version is similarly analysed.

Table 1: The objective, criteria and alternatives for the selection of energy options

Objective	Factors	Sub-factors	Alternatives
Selection of energy options	Social	Government policy and regulation (GP&R) Social acceptance Labour impact	Solar Wind Hydro
	Economics	Cost efficiency Spillover effects (R&D, education)	Natural gas
	Technological and management	Technical efficiency Technology availability Technology maturity Technology reliability	
	Environmental	Renewables availability Environmental impact	

Table 2: Z-number-based pairwise comparison of criteria

	Environmental	Economical	Social	T&M
Environmental	(1,1,1)	(1,2,3); (0.5,0.75,1)	(2,3,4); (0.75,1,1)	(2,3,4); (0.75,1,1)
Economical		(1,1,1)	(1,2,3); (0.75,1,1)	(2,3,4); (0.5,0.75,1)
Social			(1,1,1)	(1,2,3); (0.5, 0.75,1)
T&M				(1,1,1)

Table 3: Z-number-based pairwise comparison of renewables to the economic criterion

	Solar	Wind	Hydro	Weights
Solar	(1,1,1)	(1,2,3); (0.25,0.5,1)		0.1431
Wind		(1,1,1)		0.5937
Hydro	(2,3,4); (0.5,0.75,1)	(3,4,5); (0.25,0.5,0.75)	(1,1,1)	0.2632

Table 4: Z-number-based pairwise comparison of the energy mix alternatives to the economic criterion

	Solar	Wind	Hydro	NG	Alternatives weights, W_i
Solar	(1,1,1)		(1,2,3); (0.25,0.5,0.75)	(2,3,4); (0.5,0.75,1)	0.2129
Wind	(3,4,5); (0.5,0.75,1)	(1,1,1)	(2,3,4); (0.5,0.75,1)	(3,4,5); (0.5,0.75,1)	0.4881
Hydro			(1,1,1)	(2,3,4); (0.25,0.5,0.75)	0.1947
NG				(1,1,1)	0.1044

Table 5: Z-number-based pairwise comparison of Social sub-criteria

	Government policy and regulations	Labour impact	Acceptance	Sub-criteria weights, W_i
GP&R	(1,1,1)	(2,3,4); (0.5,0.75,1)	(4,5,6); (0.75,1,1)	0.5977
Labour impact		(1,1,1)	(3,4,5); (0.75,1,1)	0.3021
Acceptance			(1,1,1)	0.1001

Table 6: Fuzzy Information-based renewables ranking

Objective	Factors	Weights	Sub-factors	Weights	Solar	Wind	Hydro	
Renewable selection	Social	0.1713	GP&R	0.1072	0.0236	0.0720	0.0116	
			Social acceptance	0.0165	0.0088	0.0059	0.0018	
			Labour impact	0.0476	0.0105	0.0327	0.0045	
	Economics	0.3198	Cost efficiency	0.2516	0.0456	0.1296	0.0763	
			Spillover effect	0.0682	0.0171	0.0396	0.0115	
			Technical efficiency	0.0201	0.0024	0.0054	0.0120	
	T&M	0.1183	Technology availability	0.0537	0.0170	0.0252	0.0115	
			Technology maturity	0.0184	0.0026	0.0026	0.0131	
			Technology reliability	0.0261	0.0161	0.0035	0.0065	
	Environ	0.3906	Renewables availability	0.3134	0.0525	0.2264	0.0346	
			Environmental impact	0.0772	0.0462	0.0228	0.0082	
	Total weights of alternatives					0.2424	0.5658	0.1018
	Normalized weights of alternatives					0.2424	0.5658	0.1918

Table 7: Z-number-based renewables ranking

Objective	Factors	Weights	Sub-factors	Weights	Solar	Wind	Hydro	
Renewable selection	Social	0.2197	GP&R	0.1314	0.0322	0.0660	0.0332	
			Social acceptance	0.0220	0.0120	0.0092	0.0029	
			Labor impact	0.0664	0.0144	0.0452	0.0452	
	Economics	0.2895	Cost efficiency	0.2177	0.0489	0.1287	0.0401	
			Spillover effect	0.0718	0.0190	0.0396	0.0132	
			Technical efficiency	0.0175	0.0021	0.0050	0.0105	
	T&M	0.1089	Technology availability	0.0528	0.0171	0.0231	0.0126	
			Technology maturity	0.0103	0.0015	0.0018	0.0070	
			Technology reliability	0.0282	0.0169	0.0058	0.0071	
	Environ	0.3819	Renewables availability	0.3014	0.0519	0.2122	0.0373	
			Environmental impact	0.0804	0.0462	0.0235	0.0108	
	Total weights of alternatives					0.2621	0.5601	0.2198
	Normalized weights of alternatives					0.2515	0.5375	0.2110

Table 8: Energy resources mix, fuzzy information-based ranking

Objective	Factors	Weight	Sub-factors	Weight	Solar	Wind	Hydro	NG	
Energy resource selection	Social	0.1713	GP&R	0.1072	0.0251	0.0619	0.0092	0.0110	
			Social acceptance	0.0165	0.0078	0.0058	0.0019	0.0009	
			Labor impact	0.0476	0.0106	0.0294	0.0047	0.0030	
	Economics	0.3198	Cost efficiency	0.2516	0.0474	0.1227	0.0696	0.0119	
			Spillover effect	0.0682	0.0167	0.0335	0.0113	0.0067	
			Technical efficiency	0.0201	0.0014	0.0027	0.0104	0.0056	
	T&M	0.1183	Technology availability	0.0537	0.0090	0.0120	0.0061	0.0266	
			Technology maturity	0.0184	0.0014	0.0013	0.0050	0.0107	
			Technology reliability	0.0261	0.0082	0.0023	0.0036	0.0121	
	Environ	0.3906	Renewables availability	0.3134	0.0595	0.1319	0.0262	0.0957	
			Environmental impact	0.0772	0.0406	0.0239	0.0094	0.0033	
	Total weights of alternatives					0.2275	0.4275	0.1574	0.1875
	Normalized weights of alternatives					0.2275	0.4275	0.1574	0.1875

Table 9: Energy resources mix, Z-number-based ranking

Objective	Factor	Weight	Sub-factors	Weight	Solar	Wind	Hydro	NG	
Energy resources selection	Social	0.1651	Government policy and regulation	0.0987	0.0243	0.0522	0.0114	0.0108	
			Social acceptance	0.0165	0.0069	0.0061	0.0026	0.0053	
			Labor impact	0.0499	0.0111	0.0301	0.0052	0.0035	
	Economics	0.3251	Cost efficiency	0.2566	0.0575	0.1317	0.0499	0.0176	
			Spillover effects	0.0685	0.0171	0.0320	0.0118	0.0076	
			Technical efficiency	0.0256	0.0020	0.0039	0.0010	0.0066	
	T&M	0.1306	Technology availability	0.0614	0.0107	0.0137	0.0081	0.0289	
			Technology maturity	0.0134	0.0010	0.0011	0.0036	0.0076	
			Technology reliability	0.0303	0.0098	0.0034	0.0036	0.0135	
	Environ	0.3791	Resource availability	0.2992	0.0579	0.0979	0.0212	0.1222	
			Environmental impact	0.0799	0.0377	0.0263	0.0118	0.0040	
	Total weights of alternatives					0.2360	0.3985	0.1302	0.2276
	Normalized weights of alternatives					0.2378	0.4016	0.1312	0.2294

Table 10: Comparison of the fuzzy and Z-number-based approaches

Approach	Renewables				Energy resources mix				
	S	W	H	Min $ \Delta W $	S	W	H	NG	Min $ \Delta W $
Fuzzy AHP	0.2424	0.5658	0.1918	0.0506	0.2275	0.4275	0.1574	0.1875	H-NG 0.0301
Z-number-based AHP	0.2515	0.5375	0.2110	0.0405	0.2378	0.4016	0.1312	0.2294	S-NG 0.0084
Fuzzy and Z-approach $ \Delta W $	0.0091	0.0283	0.0192		0.0217	0.0498	0.0261	0.0020	

Comparisons of the alternative weights in fuzzy and Z-number-based models for renewables and an energy resources mix are given in Table 10.

Data from the table demonstrate that fuzzy and Z-number-based models have the same rank order: $W \rightarrow S \rightarrow H$ for renewables and $W \rightarrow S \rightarrow NG \rightarrow H$ for an energy resources mix. In the case of an energy resources mix and Z-number-based AHP, weights for solar and NG are very close to each other and there could be a reverse of ranking for the second and third alternatives due to variations in parameters and subjective error in evaluation. This is not crucial for the best of the alternatives - wind, with a higher priority margin. In the case of renewables only change of weights $>10\%$ could reverse the ranking of the second and third alternatives. Wind would not be subject to a reverse due to its very high priority. According to the opinions of the experts and the method applied, wind significantly outperforms solar, hydro and natural gas. But the rankings of other alternatives require additional analysis, especially the small difference between the weights of solar and NG; this requires a sensitivity analysis, firstly, of linguistic variables and variations in Z-number reliability. Key differences between the fuzzy and Z-number-based approaches are related to data content: in the fuzzy approach, finally, we evaluate a restriction, in the case of Z-numbers, both restriction and its reliability are evaluated.

4. SENSITIVITY ANALYSIS

In order to evaluate the influence of linguistic variables (LV) and reliability variations on ranking results, we simulate a one-term increase and decrease of the LV for fuzzy and Z-number-based models and one-term variations in the reliability for the Z-number-based models. Results are given in Tables 11-13.

As it is shown in Tables 11 and 12, in the case of Z-number-based models, a one-term decrease of the linguistic variables causes a reversal of the second and third alternatives. Table 13 illustrates that in both scenarios, with decreased linguistic terms of reliability, the ranking of energy alternatives does not change.

5. CONCLUSION

The selection of energy resources at country level requires multicriteria analysis and decision making within the alternatives available, a variety of criteria, sub-criteria and priorities.

Uncertainties and incomplete information, limited data and experience in energy resource selection necessitates the use of expert opinion as a key information source. Fuzzy and Z-information-based AHP have been developed for the selection of renewables and an energy resources mix. Models evaluate

Table 11: Variations of ranking of the energy resources mix

Models	Scenario (Linguistic variables changes)	Solar	Wind	Hydro	NG
Fuzzy model	Base version	0.2275	0.4273	0.1574	0.1875
	Linguistic variables one term decrease	0.2128	0.4145	0.1825	0.1902
	Linguistic variables one term increase	0.2369	0.4313	0.1446	0.1871
Z-model	Base version	0.2378	0.4016	0.1312	0.2276
	Linguistic variables one term decrease	0.2201	0.3703	0.1744	0.2352
	Linguistic variables one term increase	0.2516	0.4131	0.1023	0.2299

Table 12: Variations of ranking of the renewables

Models	Scenario (Linguistic variables changes)	Solar	Wind	Hydro
Fuzzy model	Base version	0.2424	0.5658	0.1918
	Linguistic variables one term decrease	0.2387	0.5266	0.2347
	Linguistic variables one term increase	0.2433	0.5802	0.1764
Z-model	Base version	0.2515	0.5375	0.2110
	Linguistic variables one term decrease	0.2437	0.4915	0.2648
	Linguistic variables one term increase	0.2594	0.5626	0.1780

Table 13: Reliability changes and alternative ranking of weight variations

Resources	Scenario (Reliability changes)	Solar	Wind	Hydro	NG
Mix	Base version	0.2378	0.4016	0.1312	0.2294
	Reliability one term decrease	0.2364	0.3955	0.1527	0.2154
	Reliability one term increase	0.2377	0.4116	0.1215	0.2200
Renewables	Base version	0.2515	0.5375	0.2110	
	Reliability one term decrease	0.2562	0.5046	0.2494	
	Reliability one term increase	0.2508	0.5515	0.1977	

renewables and a mix of energy resources based on economic, social, technological and environmental criteria, and 11 sub-criteria. The flexibility of the models enables analysis of different scenarios with various lists of resources, criteria and sub-criteria etc.

The results of the study are that at present wind energy is a higher priority for development in Azerbaijan, followed by solar and natural gas. Wind has approximately a 25% priority margin compared with the "next best" alternative - solar, and these circumstances rule out the possibility of overturning that priority

because of subjective variations in experts' opinions or the priorities of criteria and sub-criteria. Natural gas ranks very close to solar. With easy access to natural gas and renovation of power plants, the approximately 18 % increase in the country's electricity production over the last decade was mainly due to NG-based power plants.

Fuzzy and Z-number-based models provide comparable results, but in the case of Z-numbers decision makers have supplementary information about the reliability of the estimates.

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