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A Fuzzy Analitic Hierarchy Process (FAHP) Application for a Renewable election in Azerbaijan

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***Abstract* −Azerbaijan is an energy-independent country and oil and gas resources are driving forces for the country economics. But heavy reliance on hydrocarbons has two serious implications: traditional energy systems are environmentally harmful; all non-renewable resources have a limited lifecycle of production. In such circumstances, the development of renewables-based energy systems is of interest for Azerbaijan as well. Geographical features of the country provide a list of the country-level available renewables: solar, wind and hydro resources. Renewables selection is a multicriteria decision-making process and requires a comprehensive study of the social, economic, technological and other specific aspects of renewable development. Like any other unique undertakings and innovation, it is characterized by insufficient information, uncertainties and intangibles, competitive priorities and contradictory decisions. The necessity to rely on experts` opinion also contributes to the subjectivity and vagueness of decision-making problem. Taking into consideration these circumstances, Fuzzy Analytic Hierarchy Process has been used. According to the research results, available renewables are ordered, in accordance with priority, as following: solar → wind → hydro. A high priority for the solar resource presumably related to its availability almost all around the country, technical solutions affordability and relatively low per unit cost. The hydro has limited geographical availability, relatively high investment cost and some negative implications for nature. The wind is in the intermediate position.**

***Index Terms*− fuzzy AHP, linguistic estimates, multi-criteria decision analysis, renewables.**

I. INTRODUCTION

Energy resources are playing a crucial role in economic development of the world, regional and country economies, and, due to this decisive role, energy resources selection, energy production, distribution, export and import are hot topics for policymakers and economists. In the most cases energy projects are complex, large-scale and multidimensional undertakings. During the last decades an environmental factor becomes a key point in energy projects and this sensitive issue increases a complexity of the energy resources selection process.

Azerbaijan is an energy-independent country with a rich history of the oil and gas production and export. Reserves of the oil and gas allow country to fully satisfy own demand in energy resources and to use them as a key driving force for the country economic development. But it is necessary to emphasize that heavy reliance of the country economy on hydrocarbons has two serious implications: traditional energy systems are environmentally harmful; all non-renewable resources have a limited life-cycle of production, and long-term sustainability of the lopsided economy is questionable. In such circumstances, in spite of energy-independency, development of renewables-based energy systems is of interest for Azerbaijan as well. Moreover, development of the renewables will further country`s energy export.

Objective of our research is to study an opportunity of using a fuzzy AHP method for selection of the appropriate renewable for the Azerbaijan.

II. LITERATURE STUDY

The Analytic Hierarchy Process developed in 1971-1975 by T. L. Saaty was first introduced in the paper (T. L. Saaty, 1977) and then in details presented in the book (T. L. Saaty, 1980). Since then, with some modifications and developments, it has been successfully used by researchers and decision-makers in various areas (Ali Kamil TASLICALI, Sami ERCAN, 2006; Ishizaka A., Labib A., 2011; Eric W. Stein, 2013; Alessio Ishizaka, 2014; Brijendra Singh et al., 2016; Andrejs Radionovs, Oleg Uzhga-Rebrov, 2017; Ali Emrouznejad & Marianna Marra, 2017) as a powerful tool for multicriteria decision analysis. In an extensive review, covering time period from 1979 to 2017 (Ali Emrouznejad & Marianna Marra, 2017), authors provide a detailed analysis of the AHP research developments and its integration with other Multi Criteria Decision Analysis (MCDA) tools, cooperation in research, advantages of use and criticisms, main areas of interest and applications. Ishizaka A., Labib A. (2011) review methodological developments of the Analytic Hierarchy Process (AHP) since its inception. Developments of the decision process modelling, pair-wise comparisons, judgement scales, priority derivation methods, consistency indices, incomplete matrix, synthesis of the weights, sensitivity analysis and group decisions are analyzed. Brijendra Singh et al. (2016) review applications of the classical and fuzzy AHP for solution of the MCDA problems in management and business, design and development, health care and medicine, education and other areas since 2010 to 2015. Ali Kamil TASLICALI & Sami ERCAN (2006) provide a comparative study and review of the AHP and ANP as the most important MCDA methods based on their usefulness, reliability, usability and time effectiveness.

There are several publications on application of the AHP, ANP and FAHP in renewables selection on country or regional level.

Eric W. Stein (2013) has been developed a multi-criteria model for ranking various renewable and non-renewable electricity production technologies in USA. The AHP-based model ranks electric power plants using wind, solar, geothermal, biomass, hydropower, nuclear, oil, natural gas and coal in terms of financial, technical, environmental and socio-economic-political criteria. The results indicate that wind, solar, hydropower and geothermal provide significantly more overall benefits than the rest.

Adek Tasria, Anita Susilawatib (2014) have been applied FAHP, based on a new procedure for the aggregation of expert opinions, for selection of the most appropriate renewable energy sources for electricity generation in Indonesia.

Madhuri, SudeepYadav, Ajay Devidas Hiwarkar (2017) have been applied AHP model for the selection of the best alternative renewable energy resource for Uttar Pradesh energy sector. In AHP model 4 criteria (technical, economic, social and environmental) and 8 sub-criteria (maturity, efficiency, technical cost, operational cost, public acceptance, job creation, availability of renewable energy and geographical condition) have been considered. Solar energy is observed as the best energy alternative.

In (Guido C. Guerrero-Liquet et al, 2016) AHP method has been combined with other risk analysis tools for the risk evaluation in Sustainable Renewable Energy Facilities in the Dominican Republic.

Brahim Haddada, Abdelkrim Liazida, Paula Ferreirab (2017) address the sustainability objectives of the Algeria program on renewable energy and energy efficiency. The study is based on methodology, which combines an analytic hierarchy process (AHP) and experts' feedback for an evaluation of the different renewable energy options. The performance of solar, wind, biomass, geothermal and hydropower RES options was assessed against 13 sub-criteria reflecting social, environmental, economic and technical concerns. It is shown that solar power is particularly well suited for Algeria, outperforming most of the other renewable options in a large set of highly weighted criteria.

Hesham A. Hefny, Hamed M. Elsayed, Hisham F. Aly (2013) discuss a fuzzy ANP approach using the linguistic variables and Gaussian fuzzy numbers to represent decision makers' comparison judgments and extent analysis method to decide the final priority of different decision criteria. The priority weights for 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 alternative. Based on research results it is recommended to decision-makers in the Egyptian government to build more nuclear power stations to cover 25% of the generated electricity in Egypt and to construct solar power stations to cover 5% of the generated electricity.

Esra Karakaş, Ozan Veli Yildiran (2019) based on four main criteria and eight sub criteria evaluate the renewable energy alternatives of Turkey using Modified Fuzzy Analytic Hierarchy Process. In this approach reciprocals evaluated by using negative fuzzy numbers. Hydro, wind, solar, biomass and geothermal energy are analyzed as the renewable energy alternatives. According the results, solar energy is the best alternative, and wind energy is the second-best alternative for Turkey. In another research (Merve CENGİZ TOKLU1, Harun TAŞKIN, 2018), based on fuzzy AHP and fuzzy TOPSIS methods, wind energy was determined as the most suitable energy for Turkey.

Serhan Hamal, Ozlem Senvar, Ozalp Vayvay (2018) determine the optimal renewable energy investment project via 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 literature review. FANP captures inherent to project solutions vagueness along with uncertainties in the evaluation. According the results of applying FANP method, hydropower is selected as optimum renewable energy investment project for the firm.

Yakup Çelikbilek and Fatih Tüysüz (2015) have been combined fuzzy multi criteria decision model with fuzzy VIKOR method to evaluate the renewable energy sources. According the results solar energy is the best alternative and the geothermal energy is the least preferable RES alternative.

In (Andrejs Radionovs, Oleg Uzhga-Rebrov, 2017) three the most frequently used FAHP methods are analyzed (the van Laarhoven and Pedrycz, Buckley, Chang FAHP methods). Chang`s method is used for the environmental risk assessment.

Ozgur Demirtas (2013) has applied AHP method for the selection of the best renewable option for sustainable energy planning. As information sources literature review and expert`s opinion study have been used.

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

A brief overview of the research publications on application of the AHP, ANP and FAHP in renewables selection on country and regional level demonstrates that these powerful approaches can be successfully applied for the detailed analysis of the various aspects of the renewables evaluation and selection.

III. CONCEPT OF THE ANALYTICAL HIERARCHY PROCESS

AHP is a multi-step process (T. L. Saaty, 1980) and, depending on problem content and its complexity, various tools can be applied on each step.

1. Subject area analysis, an overall objective setting and problem statement.
2. Identification of the decision criteria and factors influencing the decision.
3. Structuring the problem as a hierarchical structure of the overall objective, level criteria and sub-criteria, alternatives.
4. Preference scale selection. Nine-point linguistic scale used in AHP (Equal importance, Weak, Weak importance, Moderate plus, Strong, Strong plus importance, Very strong importance, Very very strong importance, Absolute importance) allows to interpret these comparison estimates as a crisp or fuzzy number.
5. Construction of the pairwise comparison matrix for criteria and sub-criteria comparisons. According to

scale chosen, crisp $A = (a_{ij})_{nxn}$or fuzzy comparison matrix $\tilde{A} = (\tilde{a}_{ij})_{nxn}$ should be used.

Effectiveness of applying FAHP method in MCDM in general, and in renewables selection , in particular illustrated in various publications (Brijendra Singh et al, 2016; Mustafa Batuhan Ayhan, 2013; İhsan Kaya, Murat Çolak, FulyaTerzia, 2019; Aşkın ÖZDAĞOĞLU, Güzin ÖZDAĞOĞLU, 2007 etc.) In case of fuzzy matrix, we must decide on membership functions of the fuzzy set. It would be useful to notice that a membership function is a graphical representation of a fuzzy set. In general, triangular, trapezoidal, Gaussian, sigmoidal, L-R and many other functions can be used as a model of the fuzzy set. Fuzzy concepts are based on subjective perception and opinions, and, by using too much complicated membership functions, we could not add more precision. Moreover, as it is shown in various subject-area related comparative studies of the various functions, results, in some cases, are contradictory, and these contradictions, presumable, generated by the content of the applied problem.

In the most cases in applications triangular or trapezoidal membership functions have been used (Buckley, J.J., 1985; P.J.M. van Laarhoven, W. Pedrycz, 1983; Da-Yong Chang, 1996).

The support M of the triangular fuzzy number (l, m, u) is {x ∈R I $l<x< u$}. A membership function $\mu_M(x): R \rightarrow [0,1]$ of a triangular fuzzy number is equal to

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

The formulas (2)-(4) describe basic fuzzy calculation operations used in pairwise comparisons (Da-Yong Chang, 1996):

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

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

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

6. Determining criteria priorities with respect to the overall objective.
7. Pairwise comparisons-related questions formulation.
8. Determining sub-criteria priorities with respect to the related criteria.
9. Inputting pairwise judgements and reciprocals into pairwise comparison matrix.
10. Priorities calculations.

If there is a group of decision-makers, each decision-maker inputs data into matrix $\tilde{A}^k = (\tilde{a}_{ij})^k$ and then fuzzy judgements data $\tilde{a}_{ij}^k$ are averaged according to formula (5):

$$\tilde{a}_{ij} = \frac{\sum_{k=1}^{K} \tilde{a}_{ij}^k}{K} \quad (5)$$

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

Matrix:

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

is composed of the averaged preferences.

As a mean value of the fuzzy comparison geometric mean of each criteria (alternative) (Buckley, J.J.,1985) is calculated:

$$\tilde{r}_i = (\prod_{j=1}^{n} \tilde{a}_{ij})^{1/n} \quad (6)$$

A fuzzy weight $\widetilde{w}_i$ of criterion ***i*** is calculated by the formula (7):

$$\widetilde{w}_i = \tilde{r}_i \odot \left(\tilde{r}_1 \oplus \tilde{r}_2 \bigoplus \quad ... \oplus \tilde{r}_n\right)^{-1} \quad (7)$$

11. Defuzzification of the fuzzy weights. Most widely used approach for the defuzzification is the Center of Area (COA):

$$X_{COA} = \frac{\int x\mu_A(x)dx}{\int \mu_A(x)dx} \quad (8)$$

In case of the triangular fuzzy numbers it has more simple form:

$$W_i = (l_{w_i} + m_{w_i} + u_{w_i})/3 \quad (9)$$

12. Normalization of the non-fuzzy number:

$$W_i^N = W_i / \sum_{i=1}^{n} W_i \quad (10)$$

13. Selection of the alternative with higher priority.

Intensity of the criteria and sub-criteria on linguistic scale were evaluated by a group of experts. Factors (criteria) and sub-factors influencing renewables selection are presented as a hierarchical structure in Table 1.

Table 1: The renewables selection objective, criteria and alternatives

Objective	Factors	Sub-factors	Alternatives
	Social	Government policy and regulation	
		Social acceptance	
		Labor impact	

Renewable selection	Economics	Cost Efficiency	**Solar**
		Spillover effects (R&D, Education)	
	Technological and management	Technical efficiency	**Wind**
		Technology availability	
		Technology maturity	
		Technology reliability	**Hydro**
	Environmental	Renewables availability	
		Environmental impact	

Fuzzy pairwise evaluations of the factors are presented in the Table 2. Data provided in table are based on interviews conducted with experts in economics and energy systems. Opinions of the experts aggregated (averaged).

Table 2: Pair wise comparison of criteria

	Expert	Economical	Social	Technological and Management	Environmental	Geometric mean of the criterion, $\tilde{r}_i$	Fuzzy weight of the criterion, $\tilde{w}_i$
Economical	E1	(1,1,1)	(2,3,4)	(4,5,6)	(3,4,5)		
	E2	(1,1,1)	(1,2,3)	(4,5,6)	(2.3,4)		
	E3	(1,1,1)	(2.3,4)	(5,6,7)	(4,5,6)		
	Eavg	**(1,1,1)**	**(1.666, 2.666, 3,666)**	**(4.666, 5.333, 6.333**	**(3,4,5)**	(2.2,2.75,3.28)	(0.136,0.212,0.318)
Social	E1	(1/4.1/3,1/2)	(1,1,1)	(3,4,5)	(2,3,4)		
	E2	(1/3,1/2,1)	(1,1,1)	(2,3,4)	(1,2,3)		
	E3	(1/4,1/3,1/2)	(1,1,1)	(3,4,5)	(3,4,5)		
	Eavg	**(0.273, 0.375, 0.667)**	**(1,1,1)**	**(2.666, 3.666, 4.666)**	**(2,3,4)**	(1.098,1.425,1.829)	(0.06,0.177,0.307)
Technological and Management	E1	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(1,1,1)	(1/5,1/4,1/3)		
	E2	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)		
	E3	(1/7,1/6,1/5)	(1/5,1/4/1/3)	(1,1,1)	(1/6,1/5,1/4)		
	Eavg	**(0.157, 0.188, 0.214)**	**(0.214, 0.273, 0.375)**	**(1,1,1)**	**(0.2, 0.25, 0.333)**	(0.286,0.333,0.405)	**(0.149,0.193,0.258)**
Environmental	E1	(1/5,1/4,1/3)	(1/4,1/3,1/5)	(3,4,5)	(1,1,1)		
	E2	(1/4,1/3,1/2)	(1/3,1/2,1)	(2,3,4)	(1,1,1)		
	E3	(1/6,1/5,1/4)	(1/5,1/4.1/3)	(4,5,6)	(1,1,1)		
	Eavg	**(0.2, 0.25, 0.333)**	**(0.25, 0.333, 0.5)**	**(3,4,5)**	**(1,1,1)**	(0.622,0.76,0.955)	**(0.096,0.136,0.140**

IV. ALTERNATIVES EVALUATION

Alternatives should be evaluated with respect to each criterion. In our case we have to evaluate solar, wind and hydro renewables with respect to economic, social, technological and environmental criteria. Techniques applied is the same as in case of factors analysis.

We provide all details of the alternatives pairwise comparison with respect to economical criterion. Other criteria are analyzed with respect to alternatives in the same way and based on this information a summary table for the alternative selection is composed (Table 3-5).

Table 3: Fuzzy pairwise evaluations of the alternatives with respect to Economic criterion

		Expert	**Solar**	**Wind**	**Hydro**	**Geometric mean of the criterion,$\tilde{r}_i$**	**Fuzzy weight of the crit3rion, $\tilde{w}_i$**
Solar		E1	(1,1,1)	(4,5,6)	(6,7,9)		
		E2	(1,1,1)	(1,2,3)	(4,5,6)		
		E3	(1,1,1)	(2.3,4)	(5,6,7)		
		Eavg	**(1,1,1)**	**(1.666,2.666,3,666)**	**(4.666,5.333,6.333**	(2.2,2.75,3.28)	(0.136,0.212,0.318)
Wind		E1	(1/4.1/3,1/2)	(1,1,1)	(3,4,5)		
		E2	(1/3,1/2,1)	(1,1,1)	(2,3,4)		
		E3	(1/4,1/3,1/2)	(1,1,1)	(3,4,5)		
		Eavg	**(0.273,0.375,0.6)**	**(1,1,1)**	**(2.666,3.666,4.666)**	(1.098,1.425,1.829)	(0.06,0.177,0.307)
Hydro		E1	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(1,1,1)		
		E2	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)		
		E3	(1/7,1/6,1/5)	(1/5,1/4/1/3)	(1,1,1)		
		Eavg	(**0.157, 0.188,0.214)**	**(0.214,0.273,0.375)**	**(1,1,1)**	(0.286,0.333,0.405)	**(0.149,0.193,0.258)**

Table 4: Fuzzy pairwise comparison of Social sub-criteria

	Expert	**GP&RSolar**	**Acceptance**	**Labor Impact**	**Geometic mean of the criterion, $\tilde{r}_i$**	**Fuzzy weight of the criterion, $\tilde{w}_i$**
Government Policy and Regulations (GP&R)	E1	(1,1,1)	(4,5,6)	(2,3,4)		
	E2	(1,1,1)	(3,4,5)	(3,4,5)		
	E3	(1,1,1)	(4,5,6)	(2,3,4)		
	Eavg	**(1,1,1)**	**(3.667,4.667,5,667)**	**(2,333,3,333,4,333)**	2.045,2.496,2.907	(0.622, 0.630,0.621)
Acceptance	E1	(1/6.1/5,1/4)	(1,1,1)	(1/5,1/4,1/3)		
	E2	(1/5,1/4,3)	(1,1,1)	(1/5,1/4,1/3)		
	E3	(1/4,1/3,1/2)	(1,1,1)	(1/6,1/5,1/4)		
	Eavg	**(0.178,0.217,0.278)**	**(1,1,1)**	**(0.189,0.233,0.306)**	(0.323,0.370,0.439)	(0.098,0.093,0.094)
Labor Impact	E1	(1/4,1/3,1/2)	(3,4,5)	(1,1,1)		
	E2	(1/5,1/4,1/3)	(3,4,5)	(1,1,1)		
	E3	(1/4,1/3,1/2)	(4,5,6)	(1,1,1)		
	Eavg	**(0.233, 0.306,0.444)**	**(3.333,4.333,5.333)**	**(1,1,1)**	(0.919,1.098,1.333)	**(0.280,0.277,0.285)**

Table 5: Aggregated results for the renewable selection

Objective	Factors	Weights	Sub-factors	Weights	Solar	Wind	Hydro
Renewable selection	Social	0.1816	Government policy and regulation	0.1133	0.0518	0.0506	0.0110
			Social acceptance	0.1172	0.0099	0.0056	0.0017
			Labor impact	0.0511	0.0294	0.0161	0.0056
	Economics	0.2711	Cost Efficiency	0.2309	0.0738	0.0713	0.0858
			Spillover effects (R&D, Education)	0.0599	0.0370	0.0162	0.0067
	Technological and management	0.1438	Technical efficiency	0.0389	0.0034	0.0076	0.0024
			Technology availability	0.0542	0.0240	0.0169	0.0132
			Technology maturity	0.0317	0.0074	0.0050	0.0193
			Technology reliability	0.0190	0.0123	0.0024	0.0043
	Environmental	0.4036	Renewables availability	0.3264	0.2268	0.0710	0.0287
			Environmental impact	0.0772	0.0083	0.0228	0.0461
				Total weight of alternatives	**0.4841**	**0.2855**	**0.2247**

According to the experts` opinion and the method applied, solar renewables significantly outperform wind and hydro and wind has some advantages in comparison with hydro.

V. CONCLUSION

Renewables selection on country level is the serious economic policy-making issue and requires multidimensional and comparative analysis and evaluation of the alternatives available within the given priorities and criteria.

The paper provides a model supporting renewables selection process based on experts` opinion study. As a decision-making tool FAHP has been used. The model evaluates renewables available in Azerbaijan (solar, wind and hydro) in comparison with economic, social, technological and environmental criteria and 12 sub-criteria. Spreadsheet based model is flexible and can be successfully used for analysis of the other cases with various lists of renewables, criteria and sub-criteria, number of experts and etc.

Based on study results we can conclude that higher priority in development in our case has solar energy, followed by wind and hydro. Solar has 20 percent priority margin in comparison with the “next best” alternative-wind, and this circumstances actually rule out possibility of inversing priorities due to reasonable variations in experts` opinions and criteria and sub-criteria priorities.

One promising area for future research is a selection of the regions for renewables location via FAHP and Z-information based AHP.

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