An Evaluation of Energy Alternatives for Turkey via Fuzzy Multicriteria Approach

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Abstract--**Economical development of countries is greatly affected by right energy strategies. However, strategic energy investment decisions are often complex and multifaceted and involve many different stakeholders with different priorities or objectives. Thus, a systematic approach is needed to find the best energy investment option for countries' future. In this research, a fuzzy multicriteria decision making methodology is suggested for the selection among energy policies. The methodology is based on fuzzy set theory because of its ability to cope with vague and incomplete information. As a case study suggested method is tested to rank several energy alternatives namely hydro-power, solar, wind, coal, biomass, oil, natural gas and nuclear energy for Turkey. The numerical results reveal insights for feasibility and effectiveness of proposed method. Finally, sensitivity analysis is performed to test the stability of the rankings for each alternative.**

I. INTRODUCTION

The current trend of rising fossil fuel prices and observed climate change, and other adverse environmental and societal impacts of energy use, make the exploration for more sustainable ways to use energy more important than ever. The public, industry, and government are aware of the fact that protecting, improving, and managing energy resources are extremely important. Therefore, the goal of this paper is to help decision makers for managing energy sources efectively by evaluating energy investment policies for particularly Turkey. In Turkey, the growing population, industrialization and increasing standard of living have considerably increased the dependence on imported energy. Consequently, in addition to the development of conventional energy resources, exploitation of non-conventional energy resources and energy conservation has become inevitable [1].

In order to provide Turkey's national energy security in the 21st century, establishing a long-term strategic energy investment planning is essential through selection and specialization. Yet, the selection among various energy investment alternatives is a laborious task involving numerous players, conflicting priorities with separate weights, and different scenarios. Consequently, selecting from among many different alternatives often involves making trade-offs that fail to satisfy 1 or more stakeholder groups [2]. Thus, a systematic approach is needed in energy investment planning. Moreover, systematic approach would be beneficial in order to find most appropriate solutions to give the right decision for managing current scare energy resources.

The primary energy sources are [3]: Solid fuels, liquid fuels, gaseous fuels, hydropower, nuclear energy, solar energy, biomass energy, wind energy, ocean energy, and geothermal energy. In this paper, these alternatives except ocean and geothermal energy are considered to determine the most appropriate energy policy for Turkey. To sum up, the main contribution of this research is to rank of energy technology alternatives by proposed Hybrid Fuzzy Multi Criteria Decision methodology (H-FMCDM). H-FMCDM can be thought as mixture of modified fuzzy logarithmic least square method [4] and the methodology presented in [5] which integrates the fuzzy theory into the AHP approach, to calculate the weights of energy alternatives. The rest of paper is organized as follows: literature review is presented in section 2. This section is mostly related to current studies that have concentrated on selecting the best energy policy and determining the best energy alternatives. In section 3, the proposed method is introduced and some background information is given about fuzzy multi-criteia decision making. Application of discussed procedure is given in also Section 3. In following section, sensitivity analysis is described and several different scenarios are tested to discuss stability of ranking results. Finally, the conclusions remarks and further research directions are presented in section 5.

II. LITERATURE REVIEW

Energy planning by utilizing multi-criteria analysis has attracted the attention of decision-makers and researchers for a long time. Multiple criteria decision-making (MCDM) is an operational evaluation and decision support approach suitable for addressing complex problems featuring high uncertainty, conflicting objectives, multi interests and perspectives [6]. Due to this capability of MCDM, there exists several MCDM applications related to energy investment planning and management of energy sources. The methods that are used in mentioned applications can be divided in three main groups; value measurement models, goal, aspiration and reference level models, and outranking models. Methods from all of these groups have been applied to energy planning problems Each of the methods has its advantages and drawbacks [7]. However, it cannot be concluded that one method generally is better suited than the others for energy planning and evaluation problems. The literature on the area mainly focuses on renewable energy planning, electric utility planning, energy resource allocation, energy management building, and project planning issues. The remainder of this section presents brief review of existing literature about energy planning in which MCDM techniques are employed such us PROMETHEE, ELECTRE, TOPSIS, AHP, Fuzzy AHP etc...

Study [8] considers whether small scale or large-scale approaches to renewable energy provision are the best placed to help meet these targets at the lowest social, economic and environmental cost. Two main methods of data analysis were utilized in this study: A MCDA study using the MACBETH method and a cost benefit analysis. The Results indicate that small-scale approaches have more merit from a social and environmental perspective and that large-scale approaches are more economically viable given current cost structures. In terms of overall social, economic and environmental cost, the results demonstrate that small scale approaches are more effectual in this case study. In the research [9], MCE is used in a national context to structure the participatory process and to foster deliberation. There is strong support for enhancing the use of renewable energy sources to produce electricity and for increasing energy efficiency while keeping an eye on energy costs. A minority of the population supports nuclear energy. The aim of the paper [10] is to investigate the prospects for the exploitation of the Kyoto Protocol's Clean Development Mechanism (CDM) in Greece. The paper is addressing 3 questions: in which country, what kind of investment, with which economic and environmental return? The proposed approach is based on a multicriteria analysis for identifying priority countries and interesting investment opportunities in each priority country. A Multi-Criteria Decision Analysis (MCDA) method is applied in order to obtain a unique measure of other countries relative advantages against which the countries are ranked in a descending order of preference. An extensive sensitivity analysis is used to confirm the stability of the resulting ranking. In this study the PROMETHEE method was selected because of its simplicity and its capacity to approximate the way human mind expresses and synthesizes preferences in front of multiple contradictory decision perspectives. The obtained results show that the electricity generation sector offers quite promising investment opportunities for Greek interests. Especially, with the support provided by CDM, power units modernization represents very attractive investment opportunities in most of the examined countries. Wind energy can also be exploited at very satisfactory rates in Armenia, while hydro projects may be viable only under very favorable circumstances. The performed sensitivity analysis shows that among the several uncertain parameters, the value of CERs (certified emission reductions) in the carbon market and the baseline emission factor, have a relatively minor impact on the project's profitability. On the contrary, load factors, electricity tariffs and investment costs thus the major parameters of financial return outside the CDM—appear as the most crucial factors for the realization and viability of the projects. The objectives of [11] are to: 1) determine which land cover classes are affiliated with high wind and solar potential; and 2)identify areas that are suitable for wind and solar farms using multicriteria. GIS modeling techniques. GIS overlay techniques were used to examine the relationship between landcover classes and NREL (national renewable energy laboratory) solar and wind potential data. The multicriteria GIS wind model suggests that wind farms should be located in northeastern Colorado. Ideal areas for solar farms are located east of Denver and in the northwestern part of the state. Although GIS model scores vary significantly, NREL solar potential data indicate that there is only a slight difference between model classes; the variables included in this analysis have a greater effect at eliminating non-suitable areas. In [12] a novel multiobjective, multiarea and multistage model for the integrated generation mix and transmission corridors expansion/investment planning incorporating some sustainable energy development criteria is presented. The proposed MESEDES model is a ‘‘bottom-up’’ energy model which consider the electricity value-chain. The model decides the optimal location and timing of the electricity generation/transmission abroad the multistage planning horizon. In the sustainability context the carbon capture technologies are useful to help the GHG emission reduction in complementary form with removable technologies and energy efficiency programs. However, this is true only for short and medium terms. The energy diversification is not always expensive. The energy diversification under any DSM(demand side management) programs and renewable energy, such as biomass and wind technologies, has a strong positive impact in the GHG emission reduction with low impact in the cost. In [13] a multicriteria method of ranking alternative projects, PROMETHEE, is extended to deal with fuzzy input data. The method is applied for the evaluation and ranking of alternative energy exploitation schemes of a low temperature geothermal field. [14] analyses the combined use of scenario building and participatory multi-criteria analysis (PMCA) in the context of renewable energy from a methodological point of view. In this study, five renewable energy scenarios for Austria for 2020 were appraised against 17 sustainability criteria. In [15] Analytic Network Process (ANP) is applied to the selection of photovoltaic (PV) solar power projects. In the case study presented in this paper a top manager of an important Spanish company that operates in the power market has to decide on the best PV project (from four alternative projects) to invest based on risk minimization. [16] applied the method in the selection of a Renewable Energy project corresponding to the Renewable Energy Plan launched by the Spanish Government. The method is combined with the Analytical Hierarchy Process method for weighting the importance of the different criteria, which allows decision-makers to assign these values based on their preferences. The results show that the Biomass plant option (Co-combustion in a conventional power plant) is the best choice, followed by the Wind power and Solar Thermo-electric alternatives. Paper [17] describes an applicable group decision-making framework for assisting with multi-criteria analysis in renewable energy projects, utilizing the PROMETHEE II outranking method. The proposed framework is tested in a case study concerning the exploitation of a geothermal resource, located in the island of Chios, Greece. In [6] the MCDM techniques modified fuzzy TOPSIS methodology applied to propose for the selection of the best energy technology alternatives. In this study , evaluation criteria for alternative energy sources can be grouped into four main categories (Technical, economic, environmental, and social) and wind energy is found to be the best alternative among other 7 energy technologies. Study [18] considers both determining the best renewable energy alternative for Istanbul by using an integrated VIKOR-AHP methodology and a selection among alternative energy production sites in this city by using same approach. This study focused on the selection of the most appropriate renewable energy investment its location in Istanbul. The results of the multi-criteria decision analysis suggest that the wind energy is the best renewable energy alternative for the region. Catalca is the best area for the Istanbul. In [19] fuzzy multi-criteria decision making methodologies are suggested for the selection among renewable energy alternatives. In this paper, to make a decision for selecting the best renewable energy for Turkey, fuzzy AHP and fuzzy AD are used. The results of the proposed methodologies suggest the wind energy as the best alternative.

III. METHODOLOGY AND APPLICATION

In this study, a fuzzy multi criteria decision making procedure which was proposed for a first time by Zeng et al. [20] is modified and integrated by logarithmic least square method (LLSM) [21] in order to compensate flaws of previous method.

The Analytic Hierarchy Process (AHP) is a structured technique for dealing with complex decisions. Rather than prescribing a "correct" decision, the AHP helps the decision makers find the one that best suits their needs. Users of the AHP first decompose their decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently. Once the hierarchy is built, the decision makers (experts) systematically evaluate its various elements by comparing them to one another two at a time (pair-wise comparison) [22]. In making the comparisons, experts have to give a definite number within a 1-9 scale in order to compute priority vectors. The fundamental scale for pair-wise comparison is summarized at Table 1. Moreover, the corresponding reciprocals 1, 1/2, 1/3, …, 1/9 are used for reverse comparison. Although AHP method has some advantages during decision making process, on the other hand, factor comparisons often involve some amount of uncertainty and subjectivity which cannot be handled by typical AHP methodology. To illustrate, the expert might provide a range rather than a single number to compare two factors or may not give a definite scale to the comparison because of lack of adequate information and expertise.

Due to the indicated reasons, flows of classical AHP method may be compensated by employing fuzzy AHP approach. Fuzzy AHP (FAHP) method was first introduced by Laarhoven and Pedrycz [23]. In following years, many FAHP method have been constructed by researchers ([24]-[27]) and tested on several real life instances. Although FAHP's widespread application, it may lead to inconsistencies and misinterpretations during implementation in practice. To overcome these difficulties, newly proposed method of [20] is slightly modified by adding additional step to rank trapezoidal fuzzy numbers by sign distance method [28]. Than, depending upon results of sign distance value calculations extra step namely LLSM procedure is executed or not. Following are steps of the suggested methodology: Fuzzy aggregation is used to create group decisions and then defuzzification is employed to transform the fuzzy scales into crisp scales to calculate weights of priorities in this method. By applying fuzzy aggregation operators group preference of each factor is computed. Afterwards, trapezoidal fuzzy scores of each alternative are ranked by their sign distance values and LLSM method is utilized to get final rankings. Flow of proposed method is illustrated in Figure 1.

Step 1: ***Define the evaluation attributes used to select and evaluate the most appropriate main engine for ships, and establish a hierarchical framework***

This study employs the Delphi method to determine selection criteria and sub-criteria through anonymous experts with interviews and surveys. The Delphi method accumulates and analyzes the results of anonymous experts that communicate in written, discussion and feedback formats on a particular topic. Anonymous experts share knowledge skills, expertise and opinions until a mutual consensus is achieved ([29]). The Delphi method consists of five procedures: (a) Select the anonymous experts; (b) Conduct the first round of survey; (c) Conduct the second round of a questionnaire survey; (d) Conduct the third round of a questionnaire survey; (e) Integrate expert opinions to reach a consensus. Steps (c) and (d) are usually repeated until consensus is reached on a particular topic. For this reason, several decision makers are selected from different areas and backgrounds. Finally, results of the literature review and expert interviews are used to identify synthesize all common views expressed in the surveys. The energy investment selection attributes which reveals from Delphi method are listed in Table 2.

TABLE 1. PAIR-WISE COMPARISON SCALE

Scale for Pair-wise Comparisons		
Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
Even scales of 2, 4, 6 and 8 are used to compromise slight differences between two classifications.		

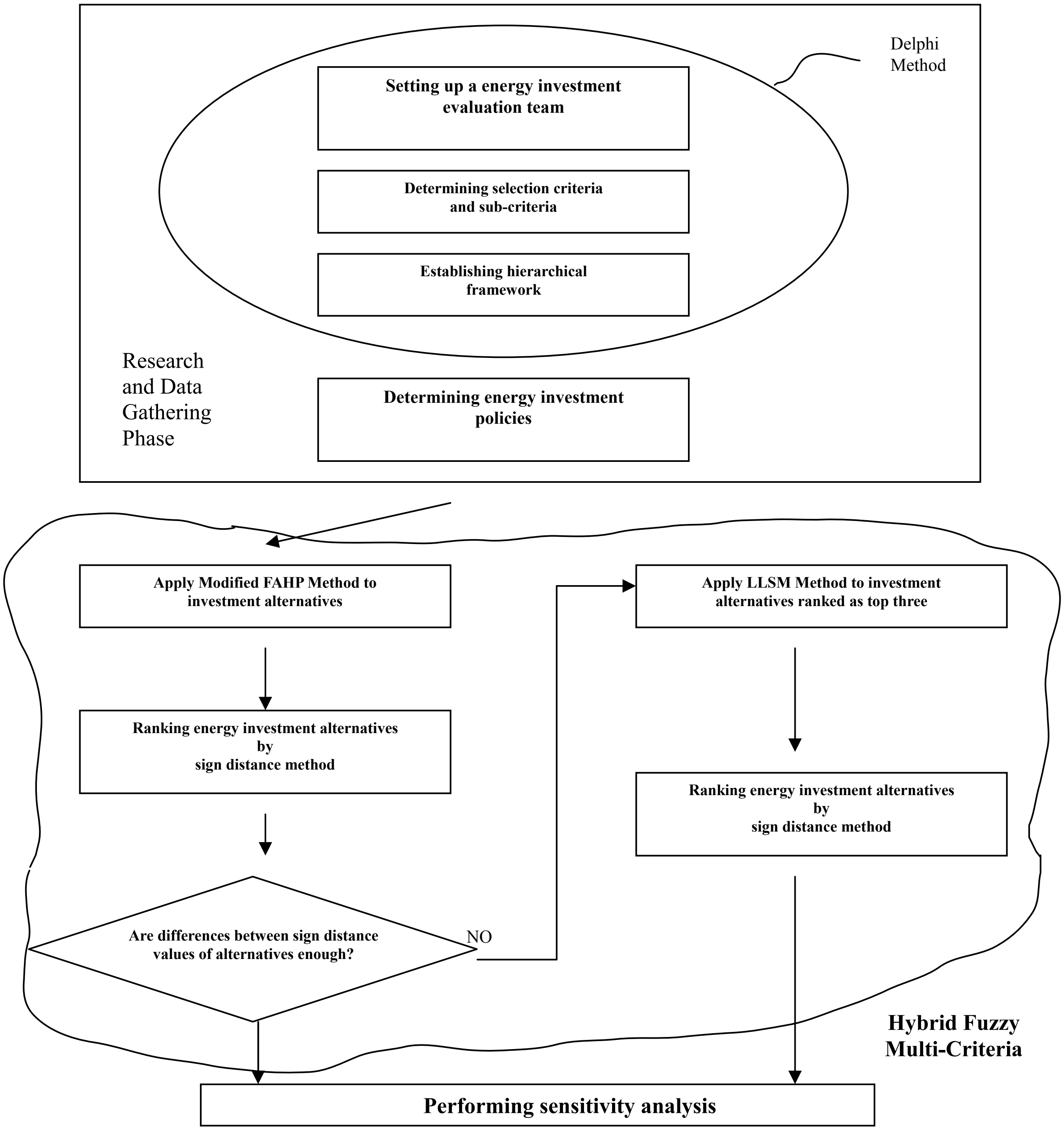

Figure 1. Flow of proposed method

TABLE 2. LIST OF EVALUATION CRITERIA USED IN HYBRID FUZZY MULTI-CRITERIA METHODOLOGY

Aspects	Criteria
Technological	Flexibility
	Risk
	Reliability
	Safety
	Efficiency
Environmental	Land Use
	Noise
	Pollutant Emission
Social	Social Benefit
	Job creation
	Social Acceptability
Economical	Investment cost
	Operation and Maintenance cost
	Service life
	Net present value

Step 2: *Define the each energy investment alternative to select and evaluate for Turkey*

The proposed main investment selection procedure is demonstrated with a eight alternative such as hydro-power, solar, wind, coal, biomass, oil, natural gas and nuclear energy for Turkey. In this subsection the brief information is given about these alternatives respectively.

Hydro-power: Hydro-power or hydraulic power is the power derived from the force or energy of moving water, which may be harnessed for useful purposes. Hydraulic energy is one of the major resources in Turkey. Turkey has a total gross hydropower potential of 433,000 GW h/year, which is almost 1% of the world total potential. There are 436 sites available for hydroelectric plant construction, distributed on 26 main river zones.

Solar energy: Solar energy can be used to generate electricity, provide hot water, and to heat, cool, and light buildings. Photovoltaic (solar cell) systems convert sunlight directly into electricity. Turkey lies in a sunny belt between 36 N and 42 N latitudes. The yearly average solar radiation is 3.6 kWh/m2 day, and the total yearly radiation period is approximately 2620 h which is sufficient to provide adequate energy for solar heating applications.

Wind energy: Wind turbines capture the wind's energy with two or three propeller-like blades, which are mounted on a rotor, to generate electricity. According to studies on the determination of Turkey's wind energy potential, Turkey's gross wind energy potential has been estimated as 400 billion kWh/year and technical potential has been estimated as 120 billion kWh/year which is equal the 1.2 times or the current annual electricity production of Turkey.

Coal: Coal is a fossil fuel formed in ecosystems where plant remains were preserved by water and mud from oxidization and biodegradation, thus sequestering atmospheric carbon. Coal is a readily combustible black or brownish-black rock. Turkey has both hard coal and lignite deposits. The hard coal is mostly located in the western part of the country, in the Zonguldak Basin, which hasmore than 700 millionmetric tons of workable reserves, about 80% of which can be cooked.

Biomass: Biomass refers to living and recently dead biological material that can be used as fuel or for industrial production. Among the different forms of renewable energy, biomass energy is one of the major resources in Turkey. Turkey's domestic energy consumption accounts for about 37% of total energy consumption. Of this, about 52% is from biomass-based fuels.

Petroleum: Petroleum can be used not only for generating electricity; it is also used in widespread areas of daily life. Turkey has proven reserves of approximately 229 million barrels of oil, most of which is in the Hakkari Basin in the southeast of Turkey.

Natural gas: Natural gas is a vital component of the world's supply of energy. It is one of the cleanest, safest, and most useful of all energy sources. Turkey's natural gas reserves seem limited. 20 billion cubic feet (bcf) of natural gas that was produced in Turkey in 2000 met only 3.8% of domestic consumption.

Nuclear energy: Nuclear energy is energy due to the splitting (fission) or merging together (fusion) of the nuclei of atom(s). As of 2005, nuclear power provided 6.3% of the world's energy and 15% of the world's electricity. In July 2000, Turkey canceled its plans for building a 1400 MW nuclear power plant at Akkuyu Bay on its Mediterranean coast.

Step 3: *Apply Modified FAHP method to evaluate energy investment alternatives*

Zadeh introduced the fuzzy set theory to deal with the uncertainty due to imprecision and vagueness. A major contribution of fuzzy set theory was its capability of representing vague data. The theory also allowed mathematical operators and programming to apply to the fuzzy domain. A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership function, which assigns to each object a grade of membership ranging between zero and one.

Step 3.1: Measure factors in the hierarchy. The experts are required to provide their judgments on the basis of their knowledge and expertise for each factor at the bottom level in the hierarchy. The experts can provide a precise numerical value, a range of numerical values, a linguistic term or a fuzzy number. Table 3 presents scores and converted STFN of energy policy criteria for nuclear energy.

Step 3.2: Compare factors using pair-wise comparisons.

The experts are required to compare every factor pair-wise in their corresponding section structured in the hierarchy and calibrate them on either a crisp or a fuzzy scale. Table 4 illustrates pair-wise comparisons of environmental criteria.

Step 3.3: Convert preferences into standardized trapezoidal fuzzy number (STFN). As described in steps 1 and 2, because the values of factors provided by experts are crisps, e.g. a numerical value, a range of numerical value, a linguistic term or a fuzzy number, the STFN is employed to convert these experts' judgments into a universal format for the composition of group preferences. Let U be the universe of discourse, U=[0,u]. A STFN can be defined as $\tilde{A}=(a^l, a^m, a^n, a^u)$, where $0 \le a^l \le a^m \le a^n \le a^u$ as shown in Figure 2, and its membership function is as follows in (1):

$$\mu_{\tilde{A}}(x) = \begin{cases} \dfrac{(x-a^l)}{(a^m-a^l)} & \text{for } a^l \le x \le a^m \\ 1 & \text{for } a^m \le x \le a^n \\ \dfrac{(a^n-x)}{(a^u-a^n)} & \text{for } a^n \le x \le a^u \\ 0 & \text{for otherwise} \end{cases} \quad (1)$$

TABLE 3. SCORES AND CONVERTED STFN OF ENERGY POLİCY CRİTERİA FOR NUCLEARA

Energy policy criteria		Expert-1(E1)		Expert-2(E2)		Expert-3(E3)		Aggregated STFN
		Score	STFN	Score	STFN	Score	STFN	
technological	flexibility	6 7	(6,6,7,7)	6 7	(6,6,7,7)	7 8	(7,7,8,8)	(6.333,6.333,7.333,7.333)
	risk	5 6	(5,5,6,6)	About 6	(5,6,6,7)	About 6	(5,6,6,7)	(5,5.666,6,6.666)
	reliability	About 8	(7,8,8,9)	6 7	(6,6,7,7)	7 8	(7,7,8,8)	(6.666,7,7.666,8)
	safety	3 4	(3,3,4,4)	About 6	(5,6,6,7)	About 4	(3,4,4,5)	(3.666,4.333,4.666,5.333)
	efficiency	5	(5,5,5,5)	About 7	(6,7,7,8)	About 8	(7,8,8,9)	(6,6.666,6.666,7.333)
environmental	land use	About 7	(6,7,7,8)	6 7	(6,6,7,7)	6	(6,6,6,6)	(6,6.333,6.666,7)
	noise	7 8	(7,7,8,8)	7 8	(7,7,8,8)	About 5	(4,5,5,6)	(6,6.333,7,7.333)
	pollutant emission	5 6	(5,5,6,6)	About 6	(5,6,6,7)	About 4	(3,4,4,5)	(4.333,5,5.333,6)
socio-political	social benefits	About 5	(4,5,5,6)	About 4	(3,4,4,5)	4	(4,4,4,4)	(3.666,4.333,4.333,5)
	job creation	3 4	(3,3,4,4)	About 5	(4,5,5,6)	6 7	(6,6,7,7)	(4.333,4.666,5.333,5.666)
	social acceptability	4 5	(4,4,5,5)	About 4	(3,4,4,5)	1 2	(1,1,2,2)	(2.666,3,3.666,4)
economic	investment cost	9 10	(9,9,10,10)	VH	(7.5,10,10,10)	8 9	(8,8,9,9)	(8.166,9,9.666,9.666)
	operation and maintenance	About 8	(7,8,8,9)	6 7	(6,6,7,7)	9	(9,9,9,9)	(7.333,7.666,8,8.333)
	service life	5 5	(5,5,5,5)	4 5	(4,4,5,5)	About 8	(7,8,8,9)	(5.333,5.666,6,6.333)
	net present value	About 8	(7,8,8,9)	8 9	(8,8,9,9)	About 8	(7,8,8,9)	(7.333,8,8.333,9)

TABLE 4. FUZZY AGGREGATION OF ENVIRONMENTAL CRITERIA

Fuzzy aggregation of environmental criteria							
	Land use			Noise		Pollutant Emission	
	Experts	Scale	Converted STFN	Scale	Converted STFN	Scale	Converted STFN
Land use	E1			6,000	(6,6,6,6)	About 9	(8,9,9,10)
	E2			5,000	(5,5,5,5)	8,000	(8,8,8,8)
	E3			(8,9	(8,8,9,9)	7,000	(7,7,7,7)
	Aggregation		1.000		(6.33,6.33,6.66,6.66)		(7.66,8,8,8.33)
Noise	E1					6,000	(6,6,6,6)
	E2					About 6	(5,6,6,7)
	E3					About 8	(7,8,8,9)
	Aggregation				1.000		(6.66,6.66,6.5,7.33)
Pollutant emission	E1						
	E2						
	E3						
	Aggregation						1.000

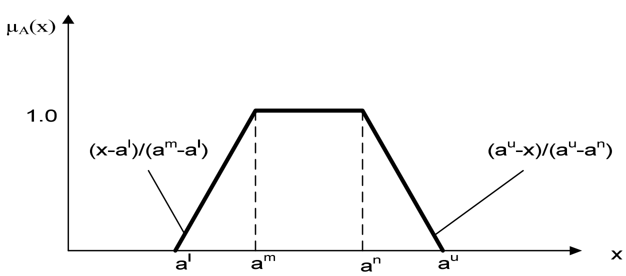

Figure 2. Membership function of the STFN A˜

Step 3.4: Aggregate individual STFNs into group STFNs. The aim of this step is to apply an appropriate operator to aggregate individual preferences made by individual expert into a group preference of each factor. The aggregation of STFN scores is performed by applying the fuzzy weighted trapezoidal averaging operator, which is defined by

$$\tilde{S}_i = \tilde{S}_{i1} \otimes c_1 \oplus \tilde{S}_{i2} \otimes c_2 \oplus ... \oplus \tilde{S}_{im} \otimes c_m$$

where $\tilde{S}_i$ is the fuzzy aggregated score of the factor F_i, $\tilde{S}_{i1}, \tilde{S}_{i2}, ..., \tilde{S}_{im}$ are the STFN scores of the factor F_i measured by *m* experts $E_1, E_2, ..., E_m$, respectively, $\otimes$ and $\oplus$ denote the fuzzy multiplication operator and fuzzy addition operator, respectively, and $c_1, c_2, ..., c_m$ are contribution factors (CFs) assigned to experts, $E_1, E_2, ..., E_m$ and $\sum_{i=1}^{m} c_i = 1.$ Similarly, the aggregation of STFN scales is defined as

$$\tilde{a}_{ij} = \tilde{a}_{ij1} \otimes c_1 \oplus \tilde{a}_{ij2} \otimes c_2 \oplus ... \oplus \tilde{a}_{ijm} \otimes c_m$$

Where $\tilde{a}_{ij}$ is the aggregated fuzzy scale of F_i comparing to F_j; $\forall$i,j $\in \{0,1,...,n\}$; $\tilde{a}_{ij1}, \tilde{a}_{ij2}, ..., \tilde{a}_{ijm}$ are the corresponding STFN scales of F_i comparing to F_j measured by experts $E_1, E_2, ..., E_m$ respectively.

Step 3.5: Defuzzify the STFN scales. In order to convert the aggregated STFN scales into matching crisp values that can adequately represent the group preferences, a proper defuzzification is needed. Assume an aggregated STFN scale $\tilde{a}_{ij} = (\tilde{a}^l_{ij}, \tilde{a}^m_{ij}, \tilde{a}^n_{ij}, \tilde{a}^u_{ij})$, the matching crisp value a_{ij} can be obtained by (2)

$$a_{ij} = \frac{\tilde{a}^l_{ij} + 2(\tilde{a}^m_{ij} + \tilde{a}^n_{ij}) + \tilde{a}^u_{ij}}{6} \qquad (2)$$

where $a_{ii} = 1$, $a_{ji} = 1 / a_{ij}$. Consequently, all the aggregated fuzzy scales $\tilde{a}_{ij}$ ($\forall$i,j $\in \{0,1,...,n\}$) are transferred into crisp scales a_{ij} within the range of [0,9].

Step 3.6: Calculate the priority weights of factors. Let

$F_1, F_2, ..., F_n$ be a set of factors in one section, a_{ij} is the defuzzified scale representing the quantified judgment on F_i comparing to F_j. Pair-wise comparison between F_i and F_j in the same section thus yields a n-by-n matrix defined as follows

$$A = \begin{array}{c} \\ \end{array}\begin{array}{cccc} F_1 & F_2 & \dots & F_n \end{array}$$

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \dots & 1 \end{bmatrix}, \quad \forall i,j \in \{1,2,...,n\}$$

where $a_{ii} = 1, a_{ji} = \frac{1}{a_{ij}}$. The priority weights of factors in the matrix A can be calculated by using the arithmetic averaging method by (3)

$$w_i = \frac{1}{n} \sum_{j=1}^{n} \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}}, \quad \forall i,j \in \{1,2,...,n\} \tag{3}$$

where w_i is the section weight of F_i. Assume F_i has t upper sections at different level in the hierarchy, and $w_{section}^{(i)}$ is the section weight of the i^{th} upper section which contains F_i in the hierarchy. The final weight W_i' of F_i can be derived by (4)

$$W_i' = w_i \times \prod_{i=1}^{t} w_{section}^{(i)} \tag{4}$$

All individual upper section weights of $w_{section}^{(i)}$ can also be derived by equation to prioritize sections within the corresponding cluster in the hierarchy.

Step 3.7: Calculate final fuzzy scores. When the scores and the priority weights of factors are obtained, the final fuzzy scores by (5)

$$(\tilde{F}S) = \sum_{i=1}^{n} \tilde{S}_i W_i', \quad i = 1,2,...,n \tag{5}$$

Table 5 shows final fuzzy scores of energy investment alternatives.

Step 4: *Rank final fuzzy scores of energy investment alternatives by sign distance method*

The trapezoidal fuzzy number $u = (x_0, y_0, \sigma, \beta)$, with two defuzzifier x_0, y_0 left fuzziness $\sigma > 0$ and the right fuzziness $\beta > 0$ is a fuzzy set where the membership function is as in (6)

$$u(x) = \begin{cases} \frac{1}{\sigma}(x - x_0 + \sigma), & x_0 - \sigma \le x \le x_0 \\ 1, & x \in [x_0, y_0] \\ \frac{1}{\beta}(y_0 - x + \beta), & y_0 \le x \le y_0 + \beta \\ 0, & \text{otherwise} \end{cases} \tag{6}$$

and its parametric for is

$$\underline{u}(r) = x_0 - \sigma + \sigma r, \quad \overline{u}(r) = y_0 + \beta - \beta r$$

For arbitrary fuzzy numbers $u = (\underline{u}, \overline{u})$ and $v = (\underline{v}, \overline{v})$ the function by (7)

$$D_p(u,v) = \left[\int_0^1 |\underline{u}(r) - \underline{v}(r)|^p \, dr + \int_0^1 |\overline{u}(r) - \overline{v}(r)|^p \, dr \right]^{1/p} (p \ge 1) \tag{7}$$

is the distance between u and v. If u_0 is considered as fuzzy origin then left fuzziness σ and right fuzziness β become 0. As a consequence by (8)

TABLE 5. FUZZY SCORES OF ENERGY ALTERNATIVES

Fuzzy scores of energy alternatives.				
Energy alternative	Fuzzy scores			
Nuclear	5,884489	6,381787	6,783292	7,253522
Biomass	5,406096	6,136894	6,470669	7,028442
Hard coal and lignite	5,156448	5,428192	6,209748	6,436327
Oil	5,545003	5,837145	6,151105	6,471428
Hydropower	5,346483	5,714478	6,044497	6,440675
Geothermal	4,538118	4,758326	5,39208	5,640469
Natural Gas	5,364057	5,684451	6,054357	6,402932
Wind	5,370242	5,859401	6,278496	6,795836
Solar	5,243377	5,686771	6,018699	6,490276

$$D_p(u,u_0)=\left[\int_0^1 |\underline{u}(r)|^p\,dr+\int_0^1 |\overline{u}(r)|^p\,dr\right]^{1/p}\quad (p\geq 1) \tag{8}$$

Finally, sign distance is defined as follows:

$$d_p(u,u_0)=\gamma(u)D_p(u,u_0)$$

where $\gamma(u)=\begin{cases}1 & \text{if sign}\left(\int_0^1(\underline{u}+\overline{u})(r)dr\right)\geq 0,\\ -1 & \text{if sign}\left(\int_0^1(\underline{u}+\overline{u})(r)dr\right)<0.\end{cases}$

As a conclusion, for any two trapezoidal fuzzy numbers u and v $\in$ E (E stands the set of fuzzy numbers), it is defined the ranking of u and v by the d_p on E as follows:

$d_p(u,u_0)>d_p(v,u_0)$ if and only if $u \succ v$,

$d_p(u,u_0)<d_p(v,u_0)$ if and only if $u \prec v$,

$d_p(u,u_0)=d_p(v,u_0)$ if and only if $u \approx v$.

Table 6 summarizes calculated sign distances for each energy alternatives and presents their ranking.

Step 5: *Check whether differences between sign distance values of alternatives are enough or not*

Based on Table 6 the "Nuclear Energy Investment" whose $d_p(u,u_0)$ value is greatest is determined as the best energy investment policy alternative for Turkey. The ranking of top three alternatives are evaluated as follows: Nuclear-Biomass and Wind. The threshold (α) value between sing distance value of first three alternative is set to 0,2. In other words, there is not alternative pair that has more than 0,2 difference between their sign distance value so there is no need to execute step 6. Yet, next step is summarized below for sake of discussion.

Step 6: *Execute LLSM to rank first three alternatives*

In this sub-section, previously formed fuzzy group comparison matrixes are used as input for Modified LLSM in order to calculate priorities. LLSM is a constrained nonlinear optimization model, whose constraints is all linear, and can be solved without difficulty by professional optimization software packages such as LINGO or MATLAB. In this research LINGO 8.0 is utilized to solve all given nonlinear models. The optimum solution to the below model directly forms normalized fuzzy weights $\tilde{w}_i=(w_i^L,w_i^M,w_i^U),\ i=1,\ldots,n.$ LLSM is formulated as follows by (9)

$$\begin{aligned}
Min\quad J=&\sum_{i=1}^{n}\sum_{j=1,j\neq i}^{n}\sum_{k=1}^{\delta_{ij}}\left((\ln w_i^L-\ln w_j^U-\ln a_{ijk}^L)^2+(\ln w_i^M-\ln w_j^M-\ln a_{ijk}^M)^2\right.\\
&\left.+(\ln w_i^U-\ln w_j^L-\ln a_{ijk}^U)^2\right)
\end{aligned}$$

$$s.t\quad\begin{cases}w_i^L+\sum_{j=1,j\neq i}^{n}w_j^U\geq 1,\\ w_i^U+\sum_{j=1,j\neq i}^{n}w_j^L\leq 1,\\ \sum_{i=1}^{n}w_i^M=1, & i=1,\ldots,n\\ \sum_{i=1}^{n}(w_i^L+w_i^U)=2,\\ w_i^U\geq w_i^M\geq w_i^L,\\ w_i^L>0,\end{cases} \tag{9}$$

Global fuzzy weights can be obtained by solving two linear programming models and an equation for each decision alternative by (10),(11),(12) $A_k\ (k=1,\ldots,K)$

$$w_{A_k}^L=\underset{W\in\Omega_W}{Min}\sum_{j=1}^{m}w_{kj}^L w_j,\quad k=1,\ldots,K, \tag{10}$$

$$w_{A_k}^U=\underset{W\in\Omega_W}{Max}\sum_{j=1}^{m}w_{kj}^U w_j,\quad k=1,\ldots,K, \tag{11}$$

$$w_{A_k}^M=\sum_{j=1}^{m}w_{kj}^M w_j^M,\quad k=1,\ldots,K, \tag{12}$$

TABLE 6. THE COMPARISONS RESULTS FOR ENERGY POLICY ALTERNATIVES.

Fuzzy scores of energy alternatives.

Energy alternative	Fuzzy scores			
Nuclear	5,884489	6,381787	6,783292	7,253522
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where

$$\Omega_W = \left\{ W = (w_1, \ldots w_m)^T \mid w_j^L \le w_j \le w_j^U, \sum_{j=1}^{m} w_j = 1,\ j = 1, \ldots m \right\}$$ is the space of weights, (w_j^L, w_j^M, w_j^U) is the normalized triangular fuzzy weight of criterion $j\ (j = 1, \ldots, m)$ and $(w_{kj}^L, w_{kj}^M, w_{kj}^U)$ is the normalized triangular fuzzy weight of alternative A_k with respect to criterion $j\ (k = 1, \ldots, K; j = 1, \ldots, m)$. Finally, fuzzy weights of alternatives can be ranked by sign distance method.

IV. SENSITIVITY ANALYSIS

Due to dynamic nature of the decision environment in the real life situation, it is essential to equip the proposed model with the capability to distinguish changes in the problem parameters. Therefore, an important step in many applications of Fuzzy Multi-criteria Decision Making is to perform a sensitivity analysis on the weight of the decision factors. In this section of proposed methodology different scenarios are tested by changing the priority weight of main criteria (Technological, Environmental Social and Economical) to analyze the performance of each energy investment alternatives in non-static settings.

Figure 3 presents the effect of changes in priority vector of environmental factors. It can be noticed that increase in factors' weight positively effects Wind Power energy investment alternative, but on the other hand Nuclear energy investment adversely effected by increasing weight of environmental factors. Indeed this conclusion is consistent with current trend towards environmental awareness and protection of renewable energy resources.

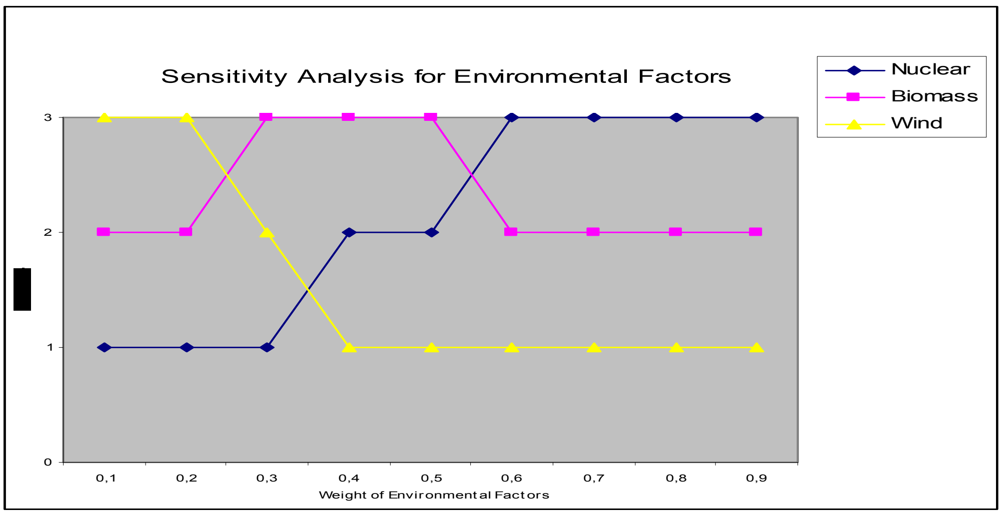

Figure 3. Sensitivity Analysis for Environmental Factors

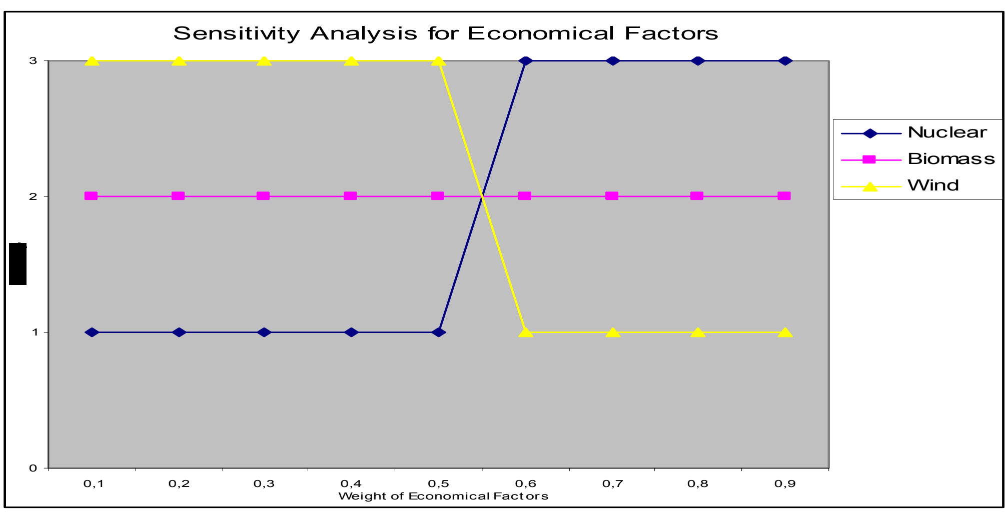

Figure 4. Sensitivity Analysis for Economical Factors

Figure 4 illustrate results of the sensitivity analysis economical factors. It is observed that the ranking of Biomass not affected by change in weight of economical factors. Conversely, Nuclear energy's sign distance value (also its ranking) decreases very rapidly by increment in priority weight vector. Wind energy investment policy is only positively correlated alternatives by increasing weight.

IV. CONCLUSION

In most of the real-world problems like evaluating energy investment alternatives for countries, some of the decision data can be precisely assessed while others cannot. Real numbers are used to represent data which can be precisely measured. For those data which cannot be precisely assessed, fuzzy sets can be used to denote them. The use of fuzzy set theory allows us to incorporate unquantifiable information, incomplete information, non-obtainable information and partially ignorant facts into the decision model.

Selecting the best from various Energy investment projects requires that different groups of decision-makers become involved in the process. The fact that social, economic, technological and environmental factors need to be taken into consideration in decision-making, make the process more complex. Traditional single-criterion decision-making is no longer able to handle these problems properly. However, the presented Fuzzy AHP based methodology significantly contributes to the improvement of evaluation procedure in selection problems. Specifically, the proposed algorithm can assist decision makers by providing the right tools to test various options and make an scientific decisions based on numerical outcomes.

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