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Selection among Renewable Energy Alternatives Using Fuzzy Axiomatic Design: The Case of Turkey

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Abstract: Renewable energy is a source of energy derived from natural resources such as sunlight, wind, water, tides, hot dry rocks, magma, hot water springs, fire wood, animal manure, and crop residues and waste. These renewable energy technologies are called with its source such as solar power, wind power, hydropower, geothermal and biomass. Energy resources are so important in perspective of economics and politics for all countries. Hence, the selection of the best alternative for any country takes an important role for energy investments. In this paper, axiomatic design (AD) methodology is suggested for the selection among renewable energy alternatives under fuzzy environment. AD methodology works under fuzziness which evaluates the alternatives under objective or subjective criteria with respect to the functional requirements obtained from experts. In the application of the proposed methodologies the most appropriate renewable energy alternative is determined for Turkey under fuzziness.

Keywords: Renewable energy, fuzzy, decision making, axiomatic design
Categories: H.0, I.2, I.6, J.6

1 Introduction

Energy has an important role in our daily life. Moreover, energy sources affect the strategies of a county directly. In the world, two kinds of energy are available; non-renewable and renewable. Renewable energy is the energy derived from natural sources. Clean, domestic and renewable energy is commonly accepted as the key for future life. This is primarily because renewable energy resources have some advantages when compared to fossil fuels. Renewable energy sources are also often called alternative sources of energy. Renewable energy resources that use domestic resources have the potential to provide energy services with zero or almost zero emissions of both air pollutants and greenhouse gases. Main renewable energy resources are biomass energy, hydro energy, geothermal energy, solar energy, and wind energy. In the scope of this study, we will focus on selection of an appropriate alternative for Turkey.

The selection among renewable energy alternatives is a multicriteria problem with many conflicting criteria. Moreover, these criteria can be objective and subjective. These kinds of criteria make the evaluation process hard and vague. On the other hand, it is difficult to take the assessments of decision makers on alternatives with respect to related criteria, precisely. In many decision making problems, the decision makers (DM) define their preference in linguistic form since it is relatively difficult to provide exact numerical values during the evaluation of alternatives. Therefore, in many studies, fuzzy logic is successfully used to model this kind of uncertainty. Fuzzy logic, proposed by Zadeh in 1965, is a matter of the fuzzy set theory particularly used to dealing with imprecise information by using a membership function. In a classical set, an element belongs to, or does not belong to, a set whereas an element of a fuzzy set naturally belongs to the set with a membership value from the interval [0, 1]. The fuzzy set theory can be applied to solve group decision-making problems which define a decision problem with several alternatives and experts that try to achieve a common solution taking into account their opinions or preferences. Recently fuzzy linguistic approaches to deal with multi-granular linguistic assessments have been analyzed [Herrera et al., 2008; Mata et al., 2009; Porcel et al., 2009].

In this paper, a fuzzy based multicriteria decision making procedure is suggested to determine the most appropriate renewable energy alternative for Turkey. For this aim, 4 main and 17 sub-main criteria are considered and 5 different renewable energy alternatives are evaluated. As fuzzy based multicriteria decision making procedures, Axiomatic Design (AD) Methodology is used [Suh, 1990].

The rest of this paper is organized as follows: Section 2 includes recent studies about energy investment. Section 3 presents the related criteria to evaluate the alternative renewable energy resources. Then, the methodology is given in Section 4. Section 5 introduces the utilization of AD for the case of Turkey. Finally, concluding remarks are discussed in Section 6.

2 Literature Review

In the literature, many researchers have studied energy investment decisions. Some of these studies are as follows: [Hamalainen and Karjalainen, 1992] used AHP to select the weights of criteria of Finland’s energy policies. [Keeney et al., 1987] presented another application of MCDM methods in national energy policy. [Önüt et al., 2008] used analytic network process (ANP) to evaluate the most suitable energy resources for the manufacturing industry. [Afgan and Carvalho, 2008] used sustainability assessment method for the evaluation of quality of the selected hybrid energy systems. [Patlitzianas et al., 2008] presented an information decision support system, which consists of an expert subsystem, as well as a multi criteria decision making [MCDM) subsystem. [Afgan et al., 2007] performed the multi-criteria sustainability assessment of various options of the energy power system of Bosnia and Herzegovina in order to investigate options for the selection of new capacity building of this complex system. [Burton and Hubacek, 2007] investigated a local case study of different scales of renewable energy provision for local government in the UK. [Patlitzianas et al. 2007] presented an integrated multicriteria decision making approach, ordered weighted average, of qualitative judgments for assessing the environment of renewable energy producers in the fourteen different member states of the European Union accession. [Afgan et al., 2007] presented an evaluation of the potential natural gas utilization in energy sector. [Polatidis et al., 2006] developed a methodological framework to provide insights regarding the suitability of multi-criteria techniques in the context of renewable energy planning. [Uluta□, 2005] analyzed the appropriate energy policy problem which considers as a MCDM problem with interactive criteria and alternatives. She used the ANP to evaluate the alternative energy sources for Turkey's energy resources. [Topcu and Ulengin, 2004] focused on the multi-attribute decision making evaluation of energy resources that enabled the selection of the most suitable electricity generation alternative for Turkey. [Polatidis and Haralambopoulos, 2004] presented the experience from a number of consultations with stakeholders involved in renewable energy projects, the difficulties that have risen and they proposed a new methodological framework of multi-participatory and multi-criteria decision-making. [Goletsis et al., 2003] combined group techniques with multicriteria methods in an integrated methodology so as the prioritization of project proposals in the energy sector of Armenia. [Haralambopoulos and Polatidis, 2003] described an applicable group decision-making framework for assisting with multi-criteria analysis in renewable energy projects, utilizing the PROMETHEE II outranking method to achieve group consensus in renewable energy projects. [Afgan and Carvalho, 2002] presented the selection of criteria and options for the new and renewable energy technologies assessment based on the analysis and synthesis of parameters. [Mavrotas et al., 1999] presented an approach based on a mixed 0-1 Multiple Objective Linear Programming (MOLP) model and applied to the Greek electricity generation sector. [Cavallaro and Ciraolo, 2005] proposed a multicriteria method in order to support the selection and evaluation of one or more of the solutions to make a preliminary assessment regarding the feasibility of installing some wind energy turbines in a site on the island of Salina in Italy. [Beccali et al., 2003] analyzed an application of the multicriteria decision-making methodology used to assess an action plan for the diffusion of renewable energy technologies at regional scale. In recent years some authors have concentrated on renewable energy in Turkey such as [Ediger and Kentel, 1999], [Hepba□lı et al., 2001], [Demirba□2001, 2005], [Kaygusuz 2001, 2002a, 2002b], [Kaygusuz and Sarı, 2003], [Evrendilek and Ertekin, 2003], [Balat, 2004, 2005], [Demirba□and Bakı□, 2004], [Hepba□lı and Ozgener, 2004a, 2004b].

3 Alternatives and Evaluation Criteria

In this section, alternatives and evaluation criteria are briefly explained.

3.1 Alternatives

In this study*, biomass, hydropower, geothermal, solar,* and *wind* energies are focused to select possible energy investment for Turkey. In this section, each renewable energy alternative is briefly explained [Kaygusuz, 2002a; 2003; Uluta□, 2005; Demirba□, 2008].

Biomass: Biomass is biological material derived from living, or recently living organisms. Most commonly, biomass refers to plant matter grown for use as biofuel, but it also includes plant or animal matter used for production of fibres, chemicals or heat, and biodegradable wastes that can be burnt as fuel. It excludes organic material which has been transformed by geological processes into substances such as coal or petroleum.

Hydropower: Hydropower or hydraulic power is the power derived from the force or energy of moving water, which may be harnessed for useful purposes. Hydropower is obtained in the force of the water on the riverbed and banks of a river.

Geothermal energy: Geothermal power is the energy generated by heat stored beneath the Earth's surface or the collection of absorbed heat derived from underground in the atmosphere and oceans.

Solar energy: Solar energy is the energy generated from sunlight by photovoltaic.

Wind energy: Wind energy is the power derived from by wind turbines. They capture the wind's energy with two or three propeller-like blades, which are mounted on a rotor, to generate electricity.

3.2 Criteria

In the scope of this study, four main and 17 sub criteria are determined by taking into account the studies given in Section 2. The considered criteria are presented in Table 1.

Main Criteria	Sub-Criteria
C_1: Technological	C_{11}: Feasibility
	C_{12}: Risk
	C_{13}: Reliability
	C_{14}: The duration of preparation phase
	C_{15}: The duration of implementation phase
	C_{16}: Continuity and predictability of performance
	C_{17}: Local technical know how
C_2: Environmental	C_{21}: Pollutant emission
	C_{22}: Land requirements
	C_{23}: Need of waste disposal
C_3: Economic	C_{31}: Implementation cost
	C_{32}: Availability of funds
	C_{33}: Economic value (PW, IRR, B/C)
C_4: Socio-Political	C_{41}: Compatibility with the national energy policy objectives
	C_{42}: Political acceptance
	C_{43}: Social acceptance
	C_{44}: Labour impact

Table 1: Criteria taken into account to select the most appropriate renewable energy alternative

C_{11}. *Feasibility;* This criterion measures the secure of the possibility for implementation of the renewable energy. The number of times tested successfully can be taken into account as a decision parameter.
C_{12}. *Risk;* The risk criterion evaluates the secure of the possibility for implementation of a renewable energy by measuring the number of problems for failures in a tested case.
C_{13}. *Reliability;* This criterion evaluates the technology of the renewable energy. Technology may have been only tested in laboratory or only performed in pilot plants, or it could be still improved, or it is a consolidated technology.
C_{14}. *The duration of preparation phase;* The criterion measures the availability of the renewable energy alternative to decrease financial assets and reach the minimum cost. The preparation phase is judgment by taking into accounts years or months.
C_{15}. *The duration of implementation phase;* The criterion measures the applicability of the renewable energy alternative to reach the minimum cost. The cost of implementation phase is judgment by taking into accounts years or months of implementation.
C_{16}. *Continuity and predictability of performance;* This criterion evaluates the operation and performance of the technology for renewable energy alternative. It is important to know if the technology operates continuously and confidently.
C_{17}. *Local technical know how;* This criterion includes an evaluation which is based on a qualitative comparison between the complexity of the considered technology and the capacity of local actors to ensure an appropriate operating support for maintenance and installation of technology for renewable energy alternative.
C_{21}. *Pollutant emission;* The criterion measures the equivalent emission of CO_2, air emissions which are the results of combustion process, liquid wastes which are related to secondary products by fumes treatment or with process water, and solid wastes. The evaluation of the criterion includes type and quantity of emissions, and costs associated with wastes treatments. Also the electro-magnetic interferences, bad smells, and microclimatic changes for energy investment are taken into account in the evaluation of this criterion.
C_{22}. *Land requirements;* Land requirement is one of the most critical factors for the energy investment. A strong demand for land can also determine the economic losses.
C_{23}. *Need of waste disposal;* The criterion evaluates the renewable energy's damage on the quality of the environment. The renewable energy alternative can be evaluated to reduce damage on the quality of life and to increase sustainability by taking into account this criterion.
C_{31}. *Implementation cost;* This criterion analyzes the total cost of the energy investment in order to be fully operational.
C_{32}. *Availability of funds;* This criterion evaluates the national and international sources of funds, and economic support of government.
C_{33}. *Economic value (PW, IRR, B/C);* This criterion judges the proposed renewable energy alternative as economically by using one of the engineering economics techniques which are present worth (PW), internal rate of return (IRR), benefit/cost analysis (B/C), and payback period.
C_{41}. *Compatibility with the national energy policy objectives;* The criterion analyzes the integration of the national energy policy and the suggested renewable energy alternative. It measures the degree of objectives' convergence between the

government policy and the suggested policy. The criterion also takes into account the government's support, the tendency of institutional actors, and the policy of public information.

C_{42}. *Political acceptance;* The criterion searches whether or not a consensus among leaders' opinions for proposed renewable energy alternative exists. Also it takes into account avoiding the reactions of the politicians and to satisfying of political leaders.

C_{43}. *Social acceptance;* The criterion enhances consensus among social partners and it takes into account avoiding the reactions from special interest social groups for renewable energy alternatives.

C_{44}. *Labour impact;* Renewable energy alternatives are evaluated by taking into account labour impact which is analyzed taking care of direct and indirect employment and the possible indirect creation of new professional figures are also assessed.

The criteria C_{12}, C_{14}, C_{15}, C_{21}, C_{22}, and C_{23} are of cost criteria whereas the others are of benefit criteria.

4 Multiattribute Selection among Renewable Energy Alternatives

In this paper, AD methodology is applied to the selection problem for renewable energy alternatives under fuzziness. The selection procedure consists of three main steps. At first, alternatives and related criteria are determined from the literature. Second, alternatives are evaluated by experts in linguistic form. In the last step fuzzy aggregation is used to create group decisions, and then AD methodology is applied.

AD was presented about 20 years ago, which is a systematic theoretical model for designers to improve designs or create a new design. The methodology consists of two axioms called as *independence axiom* and *information axiom* which are related to design and decision making, respectively. Especially, information axiom (IA) has been used to give a decision in many problems successfully. Following studies are the good examples of AD in the decision making literature. [Kulak and Kahraman, 2005a] developed IA under fuzzy environment. And then, [Kulak and Kahraman, 2005b] applied the methodology to multi-attribute transportation company selection problem. [Kulak et al., 2005] developed un-weighted and weighted multi attribute axiomatic design approach include both crisp and fuzzy criteria and apply the methodology to equipment selection problem. [Kulak, 2005] developed a decision support system that was utilized for material handling equipment selection under fuzzy environment based on axiomatic design principles. [Coelho and Mourão, 2007] used information axiom to select appropriate technology at a high decision level as required for the subsequent detail design of a mechanical component. [Celik et al., 2009a] used fuzzy information axiom to investigate a systematic evaluation model on docking facilities of shipyards to provide a decision aid for technical ship managers and to perform this responsibility in an efficient manner. [Celik et al., 2009b] proposed a hybrid approach on ensuring the competitiveness requirements for major Turkish container ports by utilizing fuzzy axiomatic design and fuzzy technique for order performance by similarity to ideal solution (TOPSIS) methodologies to manage strategic decision-making with incomplete information. [Celik et al., 2009c] extended the Quality Function Deployment principles towards shipping investment process via originally proposed Ship of Quality framework. [Kahraman and Cebi, 2009] developed fuzzy AD by adding three important tools: The first one was the hierarchy which has the ability of taking the hierarchical structures into account. The second was the crisp tool which has the ability of taking the positive information into consideration under fuzzy environment. The last one was the ranking ability.

4.1 Axiomatic Design and Its Fundamentals

Axiomatic Design (AD) is proposed to compose a scientific and systematic basis that provides structure to design process for engineers. The primarily goal of AD is to provide a thinking process to create a new design and/or to improve the existing design [Suh, 2005]. To improve a design, the axiomatic approach uses two axioms named as 'independence axiom' and 'information axiom'. The first axiom, independence axiom, states that the independence of functional requirements (FRs) must always be maintained, where FRs are defined as the minimum set of independent requirements that characterizes the design goals [Suh, 2001]. Then, the other axiom, information axiom, states that the design having the smallest information content is the best design among those designs that satisfy the independence axiom [Suh, 1990]. The information axiom (IA) is a conventional method and facilitates the selection of proper alternative that has minimum information content.
Information axiom is required to minimize information content of the design. Information axiom is used to select the best alternative when there is more than one design that satisfies independence axiom. In other word, information axiom helps the independence axiom to put forward the best design. The information axiom is symbolized by the information content that is related to probability of satisfying the design goals [Suh, 1990]. The *information content* is given by

$$I_i = \log_x \frac{1}{p_i} \tag{1}$$

where p_i is the probability of achieving a given FR. If there is more than one FR, information content is calculated as follow;

$$I_{system} = -\log_2 p_{(m)} \tag{2}$$

$$I_{system} = -\log_2 (\prod_{i=1}^{m} p_i) \tag{3}$$

$$I_{system} = -\sum_{i=1}^{m} \log_2 p_i = \sum_{i=1}^{m} \log_2 (1/p_i) \tag{4}$$

Figure 1 illustrates the calculation procedures for the probability of achieving the design goal for only one FR.

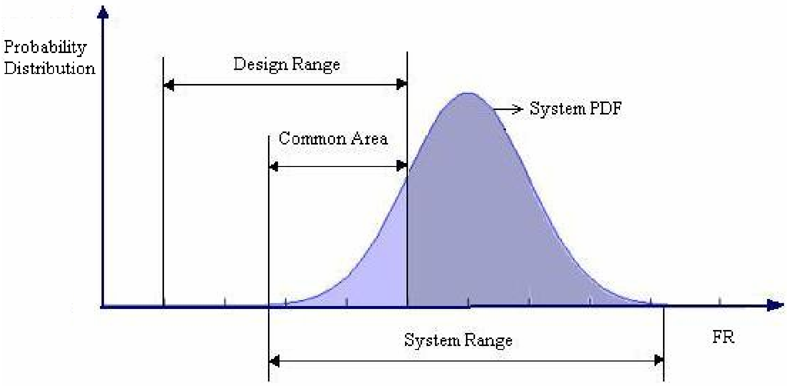

Figure 1: The relationship among design range, common area, and system range [Suh, 1990]

The upper and lower values of the design goal are given by the design range and the property of the system is depicted by a system probability density function (system pdf). The intersection area between system range and design range is named as common area (A_{cr}) or common range (cr). Then the p_i is calculated as follow;

$$P = \int_{cr} p_i dFR \tag{5}$$

In the recent studies, [Kulak and Kahraman, 2005a; 2005b] extended the information axiom under fuzzy environment and the new methodology is used for decision making problems under fuzzy environment. They used triangular fuzzy numbers to depict design goal and properties of the alternatives. Figure 2 illustrates the information content calculation procedure with triangular fuzzy numbers. Both system and design ranges consist of triangular fuzzy numbers. So, information content is calculated by Equation 17

$$I = \log_2 \frac{TFN\ of\ \ System\ Range}{Common\ Area} \tag{6}$$

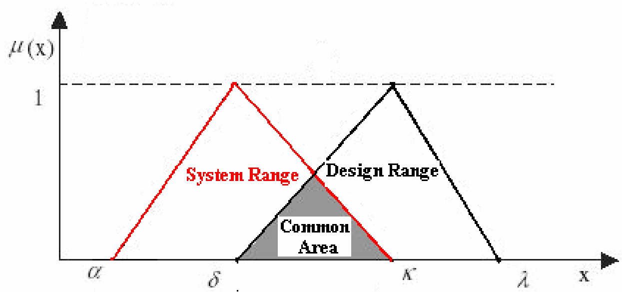

Figure 2: The common area of system and design ranges [Kulak and Kahraman, 2005a; 2005b]

4.2 Proposed Methodology

Step 1: The experts are required to provide their judgements on the basis of their knowledge and expertise for each factor. The experts can provide a precise numerical value, a range of numerical values, a linguistic term or an approximate value.

Step 2: Convert preferences into the standardized trapezoidal fuzzy number (STFN). Since the values of factors provided by experts are crisp, e.g. a numerical value, a range of numerical value, a linguistic term or an approximate value, the STFN is employed to convert experts' crisp 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 $\widetilde{A} = (a, b, c, d)$, where $0 \le a \le b \le c \le d$ as shown in Fig. 3, and its membership function is as follows [Zeng et al., 2007]:

$$\mu_{\widetilde{A}}(x) = \begin{cases} \dfrac{(x-a)}{(b-a)}, & \text{for} \quad a \le x \le b \\ 1 \quad , & \text{for} \quad b \le x \le c \\ \dfrac{(d-x)}{(d-c)}, & \text{for} \quad c \le x \le d \\ 0 \quad , & \text{for} \quad \textit{Otherwise} \end{cases} \tag{7}$$

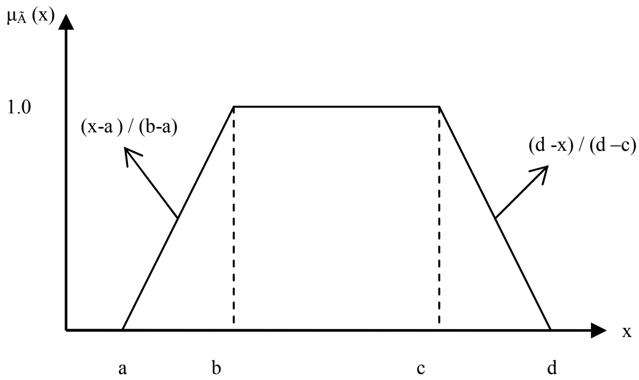

Figure 3:Membership Function of STFN Ã

Step 3: 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

$$\widetilde{S}_i = \widetilde{S}_{i1} \otimes c_1 \oplus \widetilde{S}_{i2} \otimes c_2 \oplus .... \oplus \widetilde{S}_{im} \otimes c_m \tag{8}$$

where $\widetilde{S}_i$ is the fuzzy aggregated score of the i^{th} criterion, $\widetilde{S}_{i1}, \widetilde{S}_{i2}, ..., \widetilde{S}_{im}$ are the STFN scores of each criterion measured by m experts $E_1, E_2, \ldots, E_m$, respectively, $\otimes$ and $\oplus$ denote the fuzzy multiplication and addition operators, respectively, and $c_1, c_2, \ldots, c_m$ are contribution factors allocated to experts, $E_1, E_2, \ldots, E_m$ and $c_1 + c_2 + \ldots + c_m = 1$ [Zeng et al., 2007].

Step 4: Define the FRs, the minimum sets of independent requirements that characterize the design goals for each criteria. Triangular or trapezoidal fuzzy numbers can be used to represent FRs.

Step 5. Calculate Information Contents (*I*). Each alternative is evaluated with respect to decision area of each criterion. Information content is calculated by using system range and common range which is the intersection area between system range and design range (Eq. 6).

Step 6. Select the best alternative. The alternative is the best alternative which has the minimum total information content value. Eq. 9 and Eq. 10 are used for this selection.

$$I_i^t = \sum_{j=1}^{n} I_{ij} \tag{9}$$

$$I^* = \min \begin{Bmatrix} I_1^t \\ I_2^t \\ . \\ . \\ . \\ I_m^t \end{Bmatrix} \tag{10}$$

where i and j represent the number of alternative and criteria, respectively.

5 Application

Energy is a key indicator to show economic and social development and improved quality of life in Turkey, as in other countries. Turkish energy consumption has risen dramatically over the past 20 years due to the combined demands of industrialization and urbanization. The use of energy has been a key in the development of the human society by helping it to control and adapt to the environment. Managing the use of energy is inevitable in any functional society. In the industrialized world the development of energy resources has become essential for agriculture, transportation, waste collection, information technology, communications that have become prerequisites of a developed society.

In this paper, the alternatives and related criteria have been defined in Sections 3. Table 2 presents the expert opinions based on alternatives with respect to the related criteria.

		Biomass				Geothermal				Hydropower				Solar				Wind			
		E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4
C_1	C_{11}	G	7	8	A7	G	7	7	A6	G	7	6~8	A6	P	1	3~4	A4	G	5	7~8	A8
	C_{12}	VL	7	8	8	7	7	6~8	7	7	7	6~8	7	VL	8	8~9	9~10	VL	8	8~9	9~10
	C_{13}	7~8	8	8	7	7~8	8	7~8	7~8	8	8	7~8	7	9	8	8	9	9	8	8	9
	C_{14}	7~8	7	8	7~8	7	7	8~9	7~8	8	6	8~9	7~8	8	7	8	7~9	8	7	8	7~9
	C_{15}	8	7	7	VG	7	7	7	G	7	7	6~7	G	3	2	2~3	G	5	2	2~3	G
	C_{16}	G	7	8~9	7	VG	8	8	8	G	7	5~6	7	VG	8	8~9	8	VG	8	8~9	8
	C_{17}	G	7	8~10	A7	G	9	8	A9	G	6	8~10	A7	P	1	1~2	A4	G	4	4~5	A7
C_2	C_{21}	G	G	8	A8	VH	7	7	A4	L	9	7	A9	VL	9	8~9	A9	VL	9	8~9	A9
	C_{22}	8	7	8~9	8	G	8	7~8	7	G	5	5~7	7	VL	8	9	8	VL	8	9	8
	C_{23}	G	8	G	7~8	VG	8	7~8	7	L	5	6	6~7	VG	8	9	8~9	VG	8	9	8~9
C_3	C_{31}	G	4	7	A8	G	8	8	A6	G	5	6	A6	VH	2	1~2	A2	VH	4	4~5	A5
	C_{32}	G	4	7	8	G	9	8~9	8	VG	8	6	8	VG	8	8~9	8	VG	8	8~9	8
	C_{33}	G	5	8	7	G	8	7~8	7	G	7	6	7~8	VG	8	8~9	7	VG	8	8~9	7~8
C_4	C_{41}	8	8~9	8	8	8	9	8~9	8	8	7	8	8	9	9	9~10	8	9	9	9~10	8
	C_{42}	VH	8	9	G	G	8	8	VG	VG	7	8	G	VH	9	10	VH	VH	9	10	VH
	C_{43}	VH	9	9	7	G	9	9	8	VG	9	9	8	VH	9	10	10	VH	9	10	10
	C_{44}	G	8	G	8	G	8	7	8	G	7	7	8	G	4	9~10	8	G	4	9~10	8

Table 2: Experts' assessments

5.1 Application of Fuzzy AD

Fuzzy axiomatic design is now used to determine the best renewable energy alternative for Turkey. For this aim, four energy experts who are from the Ministry of Energy and Natural Resources, having the same level of experience, evaluate the considered criteria to determine the most appropriate renewable energy alternative.

Step 1. Each criterion of the hierarchy is evaluated by the experts under the defined criteria. A score system for linguistic labels is shown in Figure 4. The representation of these linguistic labels is based on [Zeng et al., 2007]. [Garcia-Cascales and Lamata, 2007] prepared some graphic scales where the left-point, the mid-point and the right-point of the range on which their functions were defined. The semantics of the terms are given by fuzzy numbers defined in the [-10, 10] interval, which are validated by triangular membership functions. Each expert should provide a decision about his/her judgment as a precise numerical value between 0 and 10 (e.g. 7, 8, etc.), a possible range of numerical value between [0, 10] (e.g. 6~7, 7~9), a linguistic term (e.g. VL, VP, etc.), or an approximate value between 0 and 10 (e.g. A6, A8, etc.) (see Table 2).

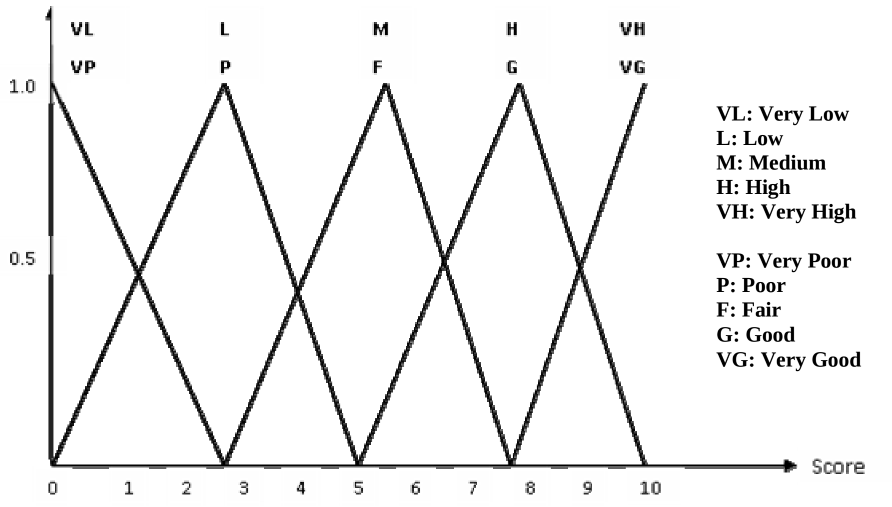

Figure 4: Membership Functions of the Score System

Step 2. Then, to standardize these evaluations, they are converted into STFNs as defined by Eq. (7). The evaluation of cost attributes is transformed based on inverse scoring which means that if a cost criterion takes very low (VL), it is scored as if it were very high (VH).

Step 3. Table 3 provides the aggregation of experts' assessments for Wind Energy. The aggregations of the obtained scores are calculated by Eq. (8). For instance, the aggregation of "Feasibility" under "Technological" section is calculated as follows:

Renewable Energy Evaluation Criteria		Expert-1 (E1)		Expert-2 (E2)		Expert-3 (E3)		Expert-4 (E4)		Aggregated STFN
		Score	STFN	Score	STFN	Score	STFN	Score	STFN	
C_1	C_{11}	G	(5, 7.5, 7.5, 10)	5	(5, 5, 5, 5)	7 8	(7, 7, 8, 8)	About 8	(7, 8, 8, 9)	(6, 6.875, 7.125, 8)
	C_{12}	VL	(7.5, 10, 10, 10)	8	(8, 8, 8, 8)	8 9	(8, 8, 9, 9)	9	(9, 9, 10, 10)	(8.125, 8.75, 9.25, 9.25)
	C_{13}	9	(9, 9, 10, 10)	8	(8, 8, 8, 8)	8 8	(8, 8, 8, 8)	9 9	(9, 9, 9, 9)	(8.5, 8.5, 8.75, 8.75)
	C_{14}	8	(7, 8, 8, 9)	7	(7, 7, 7, 7)	8 8	(8, 8, 8, 8)	7 9	(7, 7, 9, 9)	(7.25, 7.5, 8, 8.25)
	C_{15}	5	(4, 5, 5, 6)	2	(2, 2, 2, 2)	2 3	(2, 2, 3, 3)	G	(5, 7.5, 7.5, 10)	(3.25, 4.125, 4.375, 5.25)
	C_{16}	VG	(7.5, 10, 10, 10)	8	(8, 8, 8, 8)	8 9	(8, 8, 9, 9)	8 8	(8, 8, 8, 8)	(7.875, 8.5, 8.75, 8.75)
	C_{17}	G	(5, 7.5, 7.5, 10)	4	(4, 4, 4, 4)	4 5	(4, 4, 5, 5)	About 7	(6, 7, 7, 8)	(4.75, 5.625, 5.875, 6.75)
C_2	C_{21}	VL	(7.5, 10, 10, 10)	9	(9, 9, 9, 9)	8 9	(8, 8, 9, 9)	A 9	(8, 9, 9, 10)	(8.125, 9, 9.25, 9.5)
	C_{22}	VL	(7.5, 10, 10, 10)	8	(8, 8, 8, 8)	9 9	(9, 9, 9, 9)	8 8	(8, 8, 8, 8)	(8.125, 8.75, 8.75, 8.75)
	C_{23}	VL	(7.5, 10, 10, 10)	8	(8, 8, 8, 8)	9 9	(9, 9, 9, 9)	8 9	(8, 8, 9, 9)	(8.125, 8.75, 9, 9)
C_3	C_{31}	VH	(0, 0, 0, 2.5)	4	(4, 4, 4, 4)	4 5	(4, 4, 5, 5)	About 5	(4, 5, 5, 6)	(3, 3.25, 3.5, 4.375)
	C_{32}	VG	(7.5, 10, 10, 10)	8	(8, 8, 8, 8)	8 9	(8, 8, 9, 9)	8 8	(8, 8, 8, 8)	(7.875, 8.5, 8.75, 8.75)
	C_{33}	VG	(7.5, 10, 10, 10)	8	(8, 8, 8, 8)	8 9	(8, 8, 9, 9)	7 8	(7, 7, 8, 8)	(7.625, 8.25, 8.75, 8.75)
C_4	C_{41}	9	(8, 9, 9, 10)	9	(9, 9, 9, 9)	9 10	(9, 9, 10, 10)	8 8	(8, 8, 8, 8)	(8.5, 8.75, 9, 9.25)
	C_{42}	VH	(7.5, 10, 10, 10)	9	(9, 9, 9, 9)	10	(10, 10, 10, 10)	VH	(7.5, 10, 10, 10)	(8.5, 9.75, 9.75, 9.75)
	C_{43}	VH	(7.5, 10, 10, 10)	9	(9, 9, 9, 9)	10	(10, 10, 10, 10)	10	(10, 10, 10, 10)	(9.125, 9.75, 9.75, 9.75)
	C_{44}	G	(5, 7.5, 7.5, 10)	4	(4, 4, 4, 4)	9 10	(9, 9, 10, 10)	8 8	(8, 8, 8, 8)	(6.5, 7.125, 7.375, 8)

Table 3: Scores and Converted STFN for Wind

$$\tilde{S}_{feasibility} = (6.00,\ 6.88,\ 7.13,\ 8.00)$$

Step 4. In this subsection, the functional requirements for each criterion are determined as follows: The properties of the alternatives must be *at least very good* (AVG) for all criteria except the criteria *duration of implementation phase, technical knowhow*, and *implementation cost*. Moreover, properties of alternatives must be *at least good* (AG) with respect to the criteria *duration of implementation phase* and *technical knowhow* and they must satisfy *implementation cost* criterion at level of *at least fair* (AF). Functional requirements defined for each criterion are given in Figure 5. These recommendations have been determined by us after interviewing with the academicians who are related to energy management.

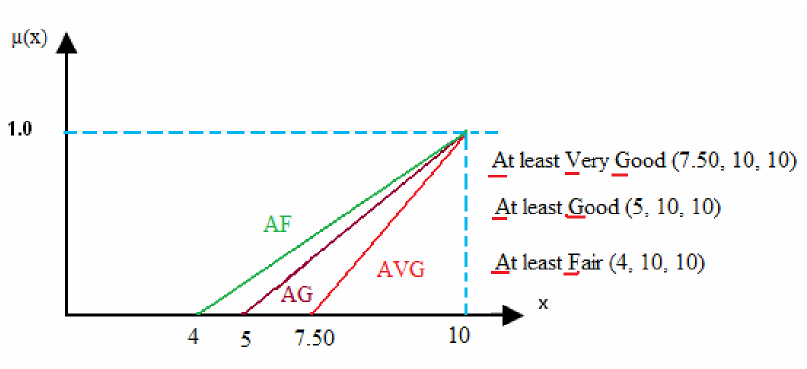

Figure 5: Functional requirements for defined criteria

Step 5. As it is mentioned above, the information content values are computed based on decision-making algorithm with fuzzy information axiom. To illustrate this algorithm, a sample calculation is provided for *biomass* (A_1) with respect to the *risk criterion* as shown in Figure 6.

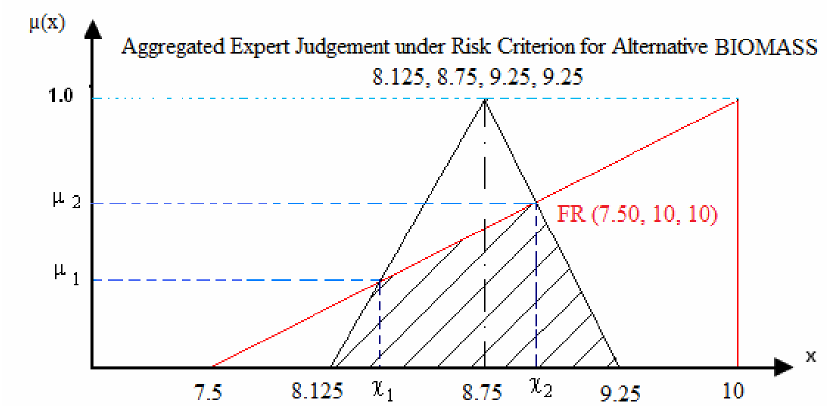

Figure 6: Assessment of aggregated expert judgment for alternative BIOMASS under risk criterion and FR

Using Eq. (6),

$$I_{121} = \log_2 \frac{9.25 - 8.125}{(x_2 - x_1 + (9.25 - 8.125))\mu_1 + (\mu_1 - \mu_2)(x_2 - x_1)} = 2.079$$

is obtained.

Step 6. Finally, Table 4 represents the total information content values for each renewable-energy alternative with respect to the assessments of experts. According to the findings, *wind energy* is selected as the most suitable alternative with respect to the pre-determined FRs. The rest of the alternatives are eliminated since they don't satisfy all criteria *Biomass energy* is eliminated with respect to the criteria *reliability* and *availability of funds.* G*eothermal energy* is eliminated with respect to the criteria *risk* and *pollutant emission*. *Hydropower energy* is eliminated with respect to the criteria *risk, continuity and predictability of performance*, *land requirements*, *need of waste disposal*. *Solar energy* is eliminated with respect to the criteria *feasibility, the duration of implementation phase*, *local technical knowhow* and *implementation cost*. As it is seen in Table 4, there is only one alternative, wind, that satisfies all of the criteria. If r*eliability* and *availability of funds* criteria were not taken into consideration, *biomass* could be selected as the best alternative.

			A_1	A_2	A_3	A_4	A_5
		FR	I	I	I	I	I
C_1	C_{11}	(7.50,10.00,10.00)	4.322	6.129	5.196	∞	4.907
	C_{12}	(7.50,10.00,10.00)	2.079	∞	∞	0.618	0.618
	C_{13}	(7.50,10.00,10.00)	∞	4.322	4.322	1.152	1.152
	C_{14}	(7.50,10.00,10.00)	4.907	4.322	4.907	3.000	3.000
	C_{15}	(5.00,10.00,10.00)	0.333	0.198	0.926	∞	7.492
	C_{16}	(7.50,10.00,10.00)	3.440	0.943	∞	1.197	1.110
	C_{17}	(5.00,10.00,10.00)	0.622	0.147	1.162	∞	2.100
C_2	C_{21}	(7.50,10.00,10.00)	1.441	∞	1.457	0.534	0.534
	C_{22}	(7.50,10.00,10.00)	2.278	0.455	∞	0.669	0.669
	C_{23}	(7.50,10.00,10.00)	2.322	0.326	∞	0.698	0.698
C_3	C_{31}	(4.00,10.00,10.00)	0.531	0.261	1.050	∞	5.852
	C_{32}	(7.50,10.00,10.00)	∞	0.368	2.644	1.197	1.438
	C_{33}	(7.50,10.00,10.00)	6.322	0.202	6.322	1.322	1.284
C_4	C_{41}	(7.50,10.00,10.00)	1.504	0.780	2.322	0.594	0.299
	C_{42}	(7.50,10.00,10.00)	0.956	0.769	1.907	0.041	0.041
	C_{43}	(7.50,10.00,10.00)	2.366	0.769	0.373	0.040	0.040
	C_{44}	(7.50,10.00,10.00)	2.059	2.737	4.544	4.544	4.544
		Total I	∞	∞	∞	∞	35.777

Table 4: Information contents for each renewable-energy

5.2 Validation of the Results

To justify the results, the fuzzy TOPSIS methodology proposed by [Chen, 2000] is used. Fuzzy TOPSIS is the extension of the TOPSIS methodology which is the abbreviation of Technique for Order Preference by Similarity to the Ideal Solution [Kahraman et al., 2009; 2007]. TOPSIS is one of the well known and most used methodologies in the literature. TOPSIS views a multiattribute decision making problem with *m* alternatives as a geometric system with *m* points in the *n* dimensional space. It was developed by [Hwang and Yoon, 1981]. The method is based on the selection of the alternative which has the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution. Fuzzy TOPSIS methodology consists of the following steps; (i) normalization of evaluation values, (ii) construction of weighted decision matrix, (iii) calculation distances of the alternatives to the positive and negative ideal solutions, and (iv) calculation of closeness coefficients [Chen, 2000].

Tables 5 is obtained after applying fuzzy TOPSIS methodology and it gives distances to positive and negative ideal solutions, and closeness coefficients (CC), respectively. According to Table 5, the order of the alternatives are as follow; $A_1=A_2=A_5> A_3> A_4$. The scores of biomass, geothermal, and wind energy alternatives are equal. However, fuzzy AD proposes only wind energy. The reason of this difference is explained as follows.

Fuzzy TOPSIS measures the distance between the ideal solutions and an alternative whereas fuzzy AD methodology does how an alternative satisfies the functional requirements. Hence, in fuzzy AD method, a decision maker defines his/her decision goal using FRs for each criterion while an ideal solution is known as (0, 0, 0) for negative ideal solution and (1, 1, 1) for positive ideal solution in fuzzy TOPSIS method. When an alternative does not satisfy any of FRs, it is out of consideration. So, in the presented study, biomass energy is out of consideration in terms of *Reliability* and *Political acceptance* criteria and geothermal energy is omitted in terms of *Pollutant emission* and *Risk* criteria.

6 Conclusions

Energy is considered one of the most important factors in the generation of wealth and also a key factor to show the economic development. The importance of energy in economic development has been recognized almost universally; the historical data attest to a strong relationship between the availability of energy and economic activity. Renewable energy is commonly accepted as the key investment for future of a country. This is primarily because renewable energy resources have some advantages when compared to other energy alternatives. The selection among renewable energy alternatives is a multicriteria problem with many conflicting criteria. These criteria can be objective and subjective. These kinds of criteria make the evaluation process hard and vague. On the other hand, it is difficult to consider the assessments of decision makers on alternatives with respect to related criteria, precisely. In many decision making problems, the decision makers define their preference in linguistic form since it is relatively difficult to provide exact numerical values during the evaluation of alternatives. It is possible to apply many multicriteria

		C_1							**C_2**			**C_3**			**C_4**						
		C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{21}	C_{22}	C_{23}	C_{31}	C_{32}	C_{33}	C_{41}	C_{42}	C_{43}	C_{44}	**D^***	**D^-**	**CC**
Biomass	d^*	0.16	0.25	0.14	0.09	0.13	0.06	0.12	0.28	0.16	0.12	0.13	0.1	0.15	0.1	0.17	0.15	0.09	2.39	14.87	**0.86**
	d^-	0.86	0.76	0.87	0.93	0.9	0.95	0.91	0.72	0.86	0.89	0.9	0.92	0.87	0.91	0.85	0.86	0.93			
Geothermal	d^*	0.16	0.25	0.14	0.09	0.13	0.06	0.12	0.28	0.16	0.12	0.13	0.1	0.15	0.1	0.17	0.15	0.09	2.39	14.87	**0.86**
	d^-	0.86	0.76	0.87	0.93	0.9	0.95	0.91	0.72	0.86	0.89	0.9	0.92	0.87	0.91	0.85	0.86	0.93			
Hydropower	d^*	0.17	0.25	0.15	0.12	0.17	0.24	0.22	0.16	0.28	0.31	0.27	0.13	0.21	0.16	0.2	0.1	0.12	3.25	13.97	**0.81**
	d^-	0.87	0.76	0.86	0.9	0.85	0.77	0.8	0.86	0.73	0.7	0.75	0.87	0.8	0.84	0.82	0.91	0.9			
Solar	d^*	0.66	0.07	0.02	0.08	0.55	0.05	0.76	0.08	0.04	0.05	0.82	0.07	0.07	0.05	0.06	0.03	0.14	3.6	13.71	**0.79**
	d^-	0.36	0.96	0.99	0.94	0.46	0.97	0.26	0.95	0.98	0.97	0.2	0.94	0.96	0.96	0.97	0.98	0.88			
Wind	d^*	0.15	0.07	0.02	0.08	0.49	0.05	0.39	0.08	0.04	0.05	0.58	0.07	0.07	0.05	0.06	0.03	0.14	2.41	14.9	**0.86**
	d^-	0.88	0.96	0.99	0.94	0.52	0.97	0.63	0.95	0.98	0.97	0.43	0.94	0.96	0.96	0.97	0.98	0.88			

d^* *: Distances to positive ideal solution* D^* *: Total distance to positive ideal solution*

d^- *: Distances to negative ideal solution* D^- *: Total distance tonegative ideal solution*

Table 5: Closeness coefficients

decision making techniques to solve these multicriteria problems in the literature. In this paper a methodology based on fuzzy AD is used to evaluate renewable energy investments for Turkey, which has rich renewable energy sources. The alternative that most satisfies FRs is selected as the best alternative. However, the methodology eliminates the alternative that does not satisfy any criterion. According to experts' assessments; the most appropriate renewable energy alternative is wind energy for Turkey.

In the future research other multicriteria decision making techniques such as AHP, TOPSIS, VIKOR, and ANP can be used and their results can be compared with the ones of our proposed methodology.

The reviewers could also express their assessments in different linguistic scales according to their knowledge about the evaluated alternatives, defining a multi-granular linguistic evaluation framework.

Fuzzy linguistic approaches to deal with multi-granular linguistic assessments can also be used for further research.

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