

EVALUATION OF TURKEY'S INTERNATIONAL ENERGY PROJECTS BY USING FUZZY MULTI-CRITERIA DECISION MAKING METHODS

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Abstract

Energy improves the standard of living of the people and it is an essential input to the production of goods. Due to Turkey's geopolitical location, i.e. neighbor to energy resource-rich countries, Turkey plays a significant key role in all "East-West" and "South-West" corridor energy projects to EU. Turkey completed many international energy projects and planned international energy projects, i.e. "East-West" and "North-South" energy corridor projects are; Samsun-Ceyhan Transit Crude Oil Pipeline & NGPL, Eastern Mediterranean Sea-Offshore NGPL, Turkmenistan NGPL, Kazakh Crude Oil Pipeline Project, Azerbaijan-Turkey (Shah Deniz II) NGPL, Iraq-Turkey Crude Oil Pipeline-II Project, Iraq-Turkey NGPL, Egypt NGPL, New LNG Terminals, Marmara Ereğlisi LNG Terminal's capacity increase project, New Floating Storage and Regasification Unit (FSRU) projects (Saros, Mersin, Ceyhan, İzmir...), capacity increase of North Marmara and Degirmenköy Natural Gas Storage Facilities, Salt Lake Underground Natural Gas Storage Project, Crude Oil Storage Project (Kırıkkale), Ceyhan Refinery Plant Project... Solving of such a difficult problem, i.e. evaluation of energy projects, the use of the fuzzy decision-making approach, which enables an assessment under uncertain circumstances, emerges as an effective problem-solving tool to evaluate and result in ranking of alternatives. In the study Fuzzy Multicriteria Decision-Making (FMCDM) methods, i.e. fuzzy AHP, fuzzy TOPSIS and fuzzy PROMETHEE methods, are used to evaluate Turkey's international energy projects. The surveys/interviews were conducted with the energy managers & engineers (DM) working in public and private sectors about Turkey's energy (fossil, renewable, pipeline, storage etc) projects. In the study, 6 main criteria and 26 sub-criteria have been determined for the selection of international energy projects planned to be constructed in Turkey. The weights of the energy projects are determined by fuzzy AHP and fuzzy TOPSIS & fuzzy PROMETHEE methods are used for the rankings of the international energy projects of Turkey. As a result of evaluation, Turkey's international energy projects are evaluated/ranked and the most suitable project is selected, i.e. Salt Lake underground natural gas storage project considering energy security/aim/target parameters of EU and Turkey. Construction of Turkey's international energy projects, especially natural gas storage projects, will significantly contribute to EU & Turkey's energy supply security and will make Turkey an indispensable actor/country in EU energy security system, within this scope Turkey will become a strong EU candidate country.

Keywords: Energy Projects, Energy Planning, fuzzy AHP, fuzzy TOPSIS, fuzzy PROMETHEE, Fuzzy Multi-Criteria Decision Making Method, Turkey.

1. INTRODUCTION

In recent years, multicriteria decision analysis has been used in a wide variety of fields by decision makers, due to the flexibility of such techniques to find solutions to energy management problems. With these tools, a better understanding of decision-making problems is achieved by promoting the role of participants in decision-making, facilitating collective decisions, providing a platform for model perception and allowing for analysis of realistic scenarios.

The number of publications on energy planning problems and multi-criteria scenarios has increased widely in recent years. In energy planning problems, projects are usually carried out prioritizing the technical-economic criteria in order to maximize the amount of energy produced, as well as the

profits, without taking into account the social and environmental aspects that guarantee the participation of local communities. In addition, there are problems with the communities that do not generate the economic resources for the costs of maintenance and replacement of equipment. This shows a need for local knowledge in the communities to perform preventive maintenance and repair of equipment.

Energy projects are taken into account the communities, their socioeconomic and political environment, long-term project profits and losses. In the study Fuzzy Multi Criteria Decision Making (FMCDM) model is used to evaluate/select Turkey's international energy projects. FMCDM model is based on fuzzy AHP, TOPSIS and PROMETHEE methods. The weights of the energy projects are determined by fuzzy AHP and then fuzzy TOPSIS & fuzzy PROMETHEE methods are used for the rankings of the international energy projects of Turkey. The methods are used to prioritize criteria, subcriteria and alternatives of Turkey's international energy projects, presenting the integration of technical, economical, social, socio-political, political, environmental, and risk criteria as its main novelty, which require a coherent planning to guarantee permanence.

2. FUZZY MULTI CRITERIA DECISION MAKING METHODS (FMCDM)

Evaluation and selection of best energy project is not easy, relative and hard to measure, the use of Fuzzy decision-making methods presents an efficient solution in this regard. Additively, Fuzzy decision-making methods enable the ability to carry out the decision process in cases involving uncertainty. In this context, the aim of this study is to evaluate/select Turkey's international energy projects by using FMCDM methods. For this aim, an integrated Fuzzy AHP- Fuzzy TOPSIS-Fuzzy PROMETHEE approaches are used to assess/evaluate Turkey's international energy projects and select the best energy project of Turkey.

In literature Fuzzy AHP, Fuzzy TOPSIS, Fuzzy PROMETHEE are used in different fields by many researchers, i.e. to select best project, performance evaluation of national R&D companies, to evaluate intelligent timetable, to evaluate the criteria for human resource for science and technology, for analyzing customer preferences, to evaluate risk analysis in green supply chain (Mangla et al., 2015), and to select machine tools (Nguyen et al., 2015).

2.1. AHP Method

The Analytic Hierarchy Process (AHP) method was developed by Thomas Saaty in early 70s of the last century. This is one of the most important decision methods which finds its application in solving complex problems consisting of the objective, criteria and alternatives. AHP is a decision-making tool used to solve problems with multiple criteria. In this method a hierarchy is performed in which the problem to solve is located at the top and at the base are the solution alternatives. At the intermediate levels are the criteria that are the basis of decision-making (Saaty and Vargas, 2012).

2.2. Fuzzy AHP Method

Since the standard AHP method does not include the possibility of situations with ambiguity in the estimation, it is possible to upgrade this method with fuzzy approach. This approach is called the Fuzzy AHP method. Instead of one defined value, in the Fuzzy AHP method full range of values that include unsafe attitudes of decision maker should be generated. For that process it is possible to use triangular fuzzy numbers, trapezoidal or Gaussian fuzzy numbers. The Fuzzy AHP method suggests their application directly in criteria pairs comparison matrix. Triangular fuzzy numbers are used in most cases/problems by many researchers in literature because of this reason in the study triangular fuzzy numbers method is used in Fuzzy AHP method.

In AHP, weight measurement is calculated by pairwise comparison of the relative importance of two factors. However when assessing a problem, AHP method cannot take into account uncertainty influentially because of the usage of human thoughts with exact numerical values (Lee et al., 2010). Generally, indefinite and incomplete data information is introduced to decision making problems and explains why it is more logical to present the data by fuzzy numbers instead of crisp numbers (Gu and Zhu, 2006). A triangular fuzzy number that is defined in R set can be described as $\tilde{N} = (l, n, u)$ where l is the minimum, n is the most possible and u is the maximum value of a fuzzy case. Its triangular membership function is characterized below (Deng, 1999) which is presented in Figure 1 and in equation (1).

$$\mu_{\tilde{N}}(x) = \begin{cases} (x-l)/(n-l), & l \leq x \leq n \\ (x-u)/(n-u), & n \leq x \leq u \\ 0, & x < l \text{ or } x > u \end{cases} \quad (1)$$

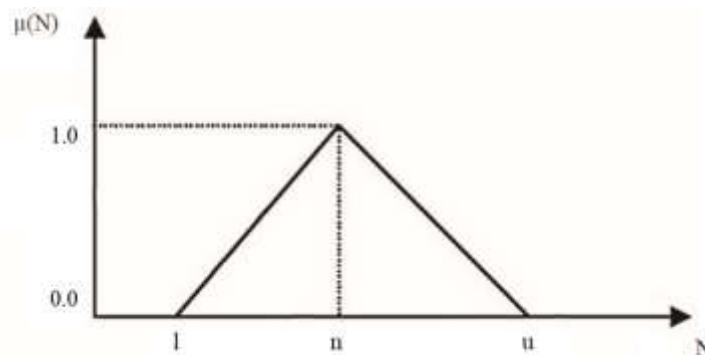


Figure 1. Triangular fuzzy number

Triangular fuzzy number $\tilde{N}$ (Figure 1) can be described as an interval of real numbers where each of them has a degree of belonging to the interval between 0 and 1. Triangular fuzzy number is defined with three real numbers, expressed as l , n and u . Basic operations of two triangular fuzzy numbers are summarized in Table 1.

Table 1. Basic Operations with Fuzzy Numbers

Operation	Notation	Function
Addition	$\tilde{A}_1(+) \tilde{A}_2$	$(l_1, n_1, u_1) (+) (l_2, n_2, u_2) = (l_1+l_2, n_1+n_2, u_1+u_2)$
Subtraction	$\tilde{A}_1(-) \tilde{A}_2$	$(l_1, n_1, u_1) (-) (l_2, n_2, u_2) = (l_1-u_2, n_1-n_2, u_1-l_2)$
Multiplication	$\tilde{A}_1(x) \tilde{A}_2$	$(l_1, n_1, u_1) (x) (l_2, n_2, u_2) = (l_1 \times l_2, n_1 \times n_2, u_1 \times u_2) \quad l_i > 0, n_i > 0, u_i > 0$
Division	$\tilde{A}_1(/) \tilde{A}_2$	$(l_1, n_1, u_1) (/) (l_2, n_2, u_2) = (l_1/l_2, n_1/n_2, u_1/u_2) \quad l_i > 0, n_i > 0, u_i > 0$

The Fuzzy AHP weights used in this study are calculated based on Chang (1996)'s extent analysis method. The following section outlines the extent analysis method (Incekara, 2019; 2017). The first step in solving problem by Fuzzy AHP method is replacing numerical values from Saaty's scale with triangular fuzzy numbers in the pairwise comparison matrix of the study which is presented in Table 3. After forming a matrix of fuzzy criteria comparison it should be defined vector of criteria weights W . For that purpose, the following equations/steps were used in the study.

Let $X = \{x_1, x_2, \dots, x_m\}$ be an object set, and $G = \{g_1, g_2, \dots, g_n\}$ be a goal set. N extent analysis values for each object can be obtained as $N_{gi}^1, N_{gi}^2, \dots, N_{gi}^n \quad i = 1, 2, \dots, n$

Step 1: The values of fuzzy extensions for the i -th object are given in Expression (2);

$$S_i = \sum_{j=1}^n N_{gi}^j \otimes [\sum_{i=1}^m \sum_{j=1}^n N_{gi}^j]^{-1} \quad (2)$$

In order to obtain the expression $[\sum_{i=1}^m \sum_{j=1}^n N_{gi}^j]$ it is necessary to perform additional fuzzy operations with n values of the extent analysis, which is represented in Equation (3) and (4);

$$\sum_{j=1}^n N_{gi}^j = (\sum_{j=1}^n l_j, \sum_{j=1}^n n_j, \sum_{j=1}^n u_j) \quad (3)$$

$$[\sum_{i=1}^m \sum_{j=1}^n N_{gi}^j] = (\sum_{i=1}^m l_i, \sum_{i=1}^m n_i, \sum_{i=1}^m u_i) \quad (4)$$

And it is required to calculate the inverse vector above by using Expression (5);

$$[\sum_{i=1}^m \sum_{j=1}^n N_{gi}^j]^{-1} = \left(\frac{1}{\sum_{i=1}^m u_i}, \frac{1}{\sum_{i=1}^m n_i}, \frac{1}{\sum_{i=1}^m l_i} \right) \quad (5)$$

Step 2: While N_1 and N_2 are triangular fuzzy numbers, the degree of possibility for $N_2 \geq N_1$ is defined as:

$$V(N_2 \geq N_1) = \sup_{y \geq x} (\min(\mu_{N_1}(x), \mu_{N_2}(y))) \quad (6)$$

It can be represented in the following manner by Expression (7):

$$V(N_2 \geq N_1) = \text{hgt}(N_2 \cap N_1) \mu_{N_2}(d) \quad (7)$$

$$= \begin{cases} 1, & \text{if } n_2 \geq n_1 \\ 0, & \text{if } l_1 \geq l_2 \\ \frac{(l_1 - u_2)}{(n_2 - u_2)(m_1 - l_1)}, & \text{otherwise} \end{cases}$$

Where d is the ordinate of the highest intersection point D between μ_{N_1} and μ_{N_2} .

To compare μ_{N_1} and μ_{N_2} , values of both, $V(N_2 \geq N_1)$ and $V(N_1 \geq N_2)$ are needed.

Step 3: The degree of possibility for a convex fuzzy number to be greater than k convex numbers N_i ($i=1,2,...,k$) can be defined by expression (8);

$$V(N \geq N_1, N_2, \dots, N_k) = V[(N \geq N_1), (N \geq N_2), \dots, (N \geq N_k)] \quad (8)$$

$$= \min V(N \geq N_i, i=1,2,3,\dots,k)$$

Assume that Expression (9) is;

$$d'(A_i) = \min V(S_i \geq S_k) \quad (9)$$

for $k=1,2,\dots,n$; $k \neq i$. So the weight vector is obtained by Expression (10);

$$W' = (d'(A_1), d'(A_2), \dots, d'(A_m))^T \quad (10)$$

where, A_i ($i=1,2,\dots,n$) consists of n elements.

Step 4: Through normalization, the weight vectors are reduced to Expression (11);

$$W = (d(A_1), d(A_2), \dots, d(A_n))^T \quad (11)$$

where W represents an absolute number.

2.3. TOPSIS Method

TOPSIS, which is developed by Hwang and Yoon (1981), is a multi-attribute decision making method to identify solutions from a finite set of alternatives. In the classical TOPSIS method, the ratings of alternatives are presented by real values. However, it is difficult to determine the values of ratings of the alternatives with respect to local criteria, these ratings are presented by fuzzy values.

2.4. Fuzzy TOPSIS Method

In TOPSIS, it is important to define positive ideal solution (PIS) and negative ideal solution (NIS). The ideal solution composed of best attribute values, whereas the negative ideal solution is comprised of all worst attribute values. The alternatives are compared with these PIS and NIS, to find out the distance. The PIS is the solution that maximizes the benefit criteria and minimizes the cost criteria; whereas the NIS maximizes the cost criteria and minimizes the benefit criteria. The best alternative should have the shortest distance from the PIS and the farthest distance from NIS.

In TOPSIS method the ratings of alternatives are crisp values, however due to vagueness of the decision data, crisp data are ineligible to model real life decision problems (Lee et al., 2010). In this paper, we adopt the extension of TOPSIS method introduced by Chen (2001), to achieve the ranking of the alternatives in fuzzy environment. The fuzzy TOPSIS calculation most important step is given in Equation (12) (Song et.al., 2013), i.e. Creating the Decision Matrix; aggregated ratings are calculated by using Equation (12):

$$\tilde{V}_{ij} = \frac{1}{2} [\tilde{v}_{ij}^1 \oplus \tilde{v}_{ij}^2 \oplus \dots \oplus \tilde{v}_{ij}^s] \quad (12)$$

where $\tilde{v}_{ij}^s$ is the performance rating value obtained from s-th decision maker.

2.5. PROMETHEE Method

The PROMETHEE method is one of the newer methods in the field of multi criteria analyses. The PROMETHEE (The Preference Ranking Organization Method for Enrichment Evaluation) is a multi-criteria decision making method developed by Jean-Pierre Brans (1982). Other authors of the PROMETHEE method are Ph. Vincke and B. Mareschal. The PROMETHEE method performs comparison and ranking of various alternatives simultaneously valued on more quantitative or qualitative criteria.

For solving the mentioned problem by this method, both quantitative values of criteria for each alternative as well as weights of criteria preference function should be defined. The preference function represents preference intensity of alternative a in relation to alternative b. There are six different preference functions. In this case linear preference function with indifference area was chosen. For each of these preference functions some parameters should be defined. These parameters are: q–indifference threshold, defines the area within the difference of two alternative values according to some criteria is negligible for the decision maker, p–preference threshold, defines the area of strict preference. Decision maker's preference increases linearly in indifference area to strict preference area i.e. the area between thresholds q and p (presented in Figure 2).

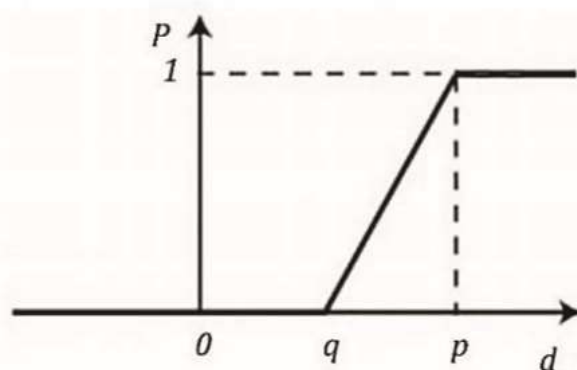


Figure 2. V shape preference function with indifference area

2.6. Fuzzy PROMETHEE (F-PROMETHEE) Method

In F-PROMETHEE method the performance of each scenario to each criterion is introduced as a fuzzy number. In the study the ratings of qualitative criteria are considered as linguistic variables. These linguistic variables can be expressed in positive triangular fuzzy numbers as described in Table 2.

Table 2. Linguistic Variables for the Alternatives

Linguistic Terms-Abbreviation	Linguistic Variables	Triangular Fuzzy Numbers
SDA	Strongly Disagree	(0, 0, 0.15)
DA	Disagree	(0.15, 0.15, 0.15)
LDA	Little Disagree	(0.30, 0.15, 0.20)
NC	No Comment	(0.50, 0.20, 0.15)
LA	Little Agree	(0.65, 0.15, 0.15)
A	Agree	(0.80, 0.15, 0.20)
SA	Strongly Agree	(1, 0.20, 0)

While F-PROMETHEE method is applied in the study, the fifth preference function was used. It is represented as follows:

$$\Omega_j(\alpha, \beta) = \Omega_j(d_j) = \begin{cases} 0, & d_j < q \\ \frac{(d_j - q)}{(p - q)}, & q \leq d_j \leq p \\ 1, & d_j > p \end{cases} \quad (13)$$

If d_j is expressed as a fuzzy number (m, α, β) , then the preference function equation is defined below:

$$\tilde{A} = \begin{cases} 0, & m - \alpha \leq 0 \\ \frac{(m, \alpha, \beta) - q}{(p - q)}, & q \leq m - \alpha \text{ and } m + \beta \leq p \\ 1, & m + \beta \geq p \end{cases} \quad (14)$$

The degree of preference comparison of the alternatives a and b , with the criterion f , can be defined as:

$$\begin{aligned} A_j(f(a) - f(b)) &= A_j(d) \\ &= A_j(n), (A_j(n) - A_j(n - \alpha)), (A_j(n + \beta) - A_j(n)) \end{aligned} \quad (15)$$

The multi criteria preference index is expressed as:

$$\Pi(a, b) = \frac{\sum_{i=1}^k w_i A_i(a, b)}{\sum_{i=1}^k w_i} \quad (16)$$

The preference index is calculated as a fuzzy number. By using the yager index, which is seen below, it should be transformed into an absolute number.

$$f(n, \alpha, \beta) = 1/3 (3n - \alpha + \beta) \quad (17)$$

After transformation of all fuzzy numbers to absolute numbers, they can be ranked by the PROMETHEE II method.

3. EVALUATION OF TURKEY'S INTERNATIONAL ENERGY PROJECTS

Turkey's international energy projects is evaluated in the study, the level of significance (importance weights) of energy project's dimensions is determined by Fuzzy AHP approach as a result of the surveys/interviews, which are obtained from the energy managers & engineers (DM) working in public and private sectors about Turkey's energy (fossil, renewable, pipeline, storage etc) projects. With the help of the survey/interviews data obtained from DM, i.e. the questionnaire was answered

by 49 energy experts/DMs (that filled the questionnaire out of 55 candidate). In the study, 6 main criteria, i.e. technical (energy "Demand & Supply" of Turkey and EU, EU's 4th energy corridor projects (EU's Southern Gas Corridor projects)), economical (Energy Returned on Energy Invested Rate...), social, socio-political, environmental and risk criteria related with energy security/aim/target parameters of EU and Turkey; and 26 related sub-criteria have been determined for the selection of international energy projects planned to be constructed in Turkey. Turkey's international energy projects are assessed by an integrated Fuzzy AHP- Fuzzy TOPSIS-Fuzzy PROMETHEE approach which is used to assess/evaluate Turkey's international energy projects and select the best energy project of Turkey. At the end, the ranking of Turkey's international energy projects is acquired according to their performance. In the study below mentioned Turkey's international energy projects are examined/assessed in detail:

- Samsun-Ceyhan Transit Crude Oil Pipeline & Natural Gas Pipeline Project (NGPL),
- Eastern Mediterranean Sea-Offshore NGPL,
- Turkmenistan NGPL,
- Kazakh Crude Oil Pipeline Project,
- Kazakh NGPL,
- Azerbaijan-Turkey (Shah Deniz II) NGPL,
- Iraq-Turkey Crude Oil Pipeline-II Project,
- Iraq-Turkey NGPL,
- Blue Stream-II NGPL,
- Cyprus-Turkey Offshore NGPL,
- Egypt NGPL,
- New LNG Terminals (Mersin, izmir),
- Marmara Ereğlisi LNG Terminal's capacity increase project,
- New Floating Storage and Regasification Unit (FSRU) projects (Saros),
- New Floating Storage and Regasification Unit (FSRU) projects (Mersin),
- New Floating Storage and Regasification Unit (FSRU) projects (Ceyhan),
- New Floating Storage and Regasification Unit (FSRU) projects (İzmir),
- Capacity increase of North Marmara and Degirmenkoy Natural Gas Storage Facilities,
- Salt Lake Underground Natural Gas Storage Project,
- Mersin Underground Salt Caverna Natural Gas Storage Project,
- Kırşehir Salt Cave Natural Gas Storage Project,
- New Crude Oil Storage Project (Kırıkkale),
- Crude Oil Storage Project (Mardin),
- Crude Oil Storage Project (Ceyhan),
- Crude Oil Storage Project (Dörtyol),
- Crude Oil Storage Project (Marmara),
- Ceyhan Refinery Plant Project,
- Mersin Refinery Plant Project,

- İzmir-III Refinery Plant Project,
- Aegean Sea Offshore Wind Farm
- 5000 MW Solar Project-II in Konya Region
- 1000 MW Wind Farm in Toros Mountain

Multiple software products and add-ins have been developed with the aim to facilitate the decision-making and calculation processes which are; MS Excel, Visual PROMETHEE, TOPSIS programs. For the solution Excel's macros are written also.

3.1. Determining the evaluation criteria weights with Fuzzy AHP Approach

Firstly, each DM practiced pair-wise comparisons of energy project's dimensions and evaluation factors by using Saaty's 1-9 scale. Using the survey data acquired from these experts, integrated pair-wise comparison matrices are formed by combining all expert opinions. Thus, the pair-wise comparison values are converted to triangular fuzzy numbers and fuzzy pair-wise comparison matrices are created which is presented in Table 3.

Table 3. Fuzzy mutual criteria comparison

	C1	C2	C3	C4	C5	C6
C1	(1, 1, 1)	(1, 3, 5)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(7, 9, 11)
C2	(1/5, 1/3, 1)	(1, 1, 1)	(5, 7, 9)	(1, 3, 5)	(7, 9, 11)	(5, 7, 9)
C3	(1/9, 1/7, 1/5)	(1/9, 1/7, 1/5)	(1, 1, 1)	(3, 5, 7)	(7, 9, 11)	(5, 7, 9)
C4	(1/9, 1/7, 1/5)	(1/5, 1/3, 1)	(1/7, 1/5, 1/3)	(1, 1, 1)	(1, 7, 9)	(1, 3, 5)
C5	(1/9, 1/7, 1/5)	(1/11, 1/9, 1/7)	(1/11, 1/9, 1/7)	(1/9, 1/7, 1)	(1, 1, 1)	(1, 7, 9)
C6	(1/11, 1/9, 1/7)	(1/9, 1/7, 1/5)	(1/9, 1/7, 1/5)	(1/5, 1/3, 1)	(1/6, 1/7, 1)	(1, 1, 1)

The weight vector is obtained and after the normalization, the weight vector for the criteria are obtained. After acquiring the fuzzy comparison matrices, importance weights of energy projects dimensions and evaluation criteria are calculated by the FAHP method.

3.2. Ranking the alternatives by Fuzzy TOPSIS and Fuzzy PROMETHEE methods

For the evaluation of Turkey's international energy project, Fuzzy TOPSIS and Fuzzy PROMETHEE approach is conducted with the collected data of DM's surveys/interviews. Primarily, the linguistic variables of the alternatives are created. By the help of criteria weights, Fuzzy TOPSIS and Fuzzy PROMETHEE method's steps are completed and Turkey's international energy projects are ranked from the best to the worse.

In Fuzzy PROMETHEE method when the obtained Turkey's international energy projects performance scores (Φ_{net}) are examined, ranking of the alternatives is as follows: "Salt Lake Underground Natural Gas Storage Project-SNGSP" is the best energy project, and "North Marmara and Degirmenkoy Natural Gas Storage project-NDNGPS" is the second ranked energy project. "New Floating Storage and Regasification Unit (FSRU) projects (Saros)" is the third ranked energy project of Turkey.

In Fuzzy TOPSIS method when the obtained Turkey's international energy projects performance scores are examined, ranking of the alternatives is as follows: "Salt Lake Underground Natural Gas Storage Project-SNGSP" is the best energy project, and "North Marmara and Degirmenkoy Natural Gas Storage project-NDNGPS" is the second ranked energy project of Turkey. "Mersin Underground

Salt Caverna Natural Gas Storage Project” is the third ranked energy project of Turkey which is different than Fuzzy PROMETHEE method’s result.

4. CONCLUSION AND DISCUSSIONS

In general, energy policy and decision making problems include several conflicting criteria and it causes to more complexity in these problems. These problems can be evaluated in multi-dimensional space of different parameters and objectives in order to cope with complexity. To make this evaluation, multi-criteria decision making (MCDM) is one of the most suitable ways. Use of MCDM methods for these problems provides a reliable compromising solution by assessing energy sources, technologies and projects by regarding various objectives, aspects, and criteria. On the other hand, the collected data in these problems include vagueness and uncertainties. To deal with vagueness and uncertainties, fuzzy sets are used with MCDM methods in the decision-making process. Uncertainties are unavoidable due to increasing complexity of energy policy and decision making problems. Therefore, fuzzy MCDM methods are applied as analytic and effective approaches for solving these problems.

Fuzzy MCDM methods have successfully facilitated in identifying the importance of various energy alternatives, scenario analysis, energy project plans, and investment decisions. One of the results is that these fuzzy MCDM methods are appropriate tools for energy policy and decision making problems. As a result of this literature analysis, we determined that a large number of fuzzy MCDM methods exist and many of these methods are applicable for the solution of energy policy and decision making problems such as selecting energy alternative, evaluating energy supply technologies, and determining energy policy. On the other hand, energy demand in all over the world increases, which is driven by industrialization and population growth, as a result the number of energy project investigation will increase and it is an important study area for researchers.

In this study Turkey’s international energy projects are evaluated with FMCDM method. In line with this purpose, an integrated Fuzzy AHP, Fuzzy TOPSIS and Fuzzy PROMETHEE approach is conducted for evaluating the energy projects of Turkey. In the AHP method the overall priorities of alternatives are calculated by summing local priorities of each alternative multiplied by weights of criteria. And also, in the Fuzzy AHP method the overall priorities of alternatives are calculated in exactly the same way. Ranking of alternatives of Turkey’s international energy projects are examined with FMCDM method, i.e. an integrated Fuzzy AHP- Fuzzy TOPSIS-Fuzzy PROMETHEE approach which is used to assess/evaluate Turkey’s international energy projects and select the best energy project of Turkey. Fuzzy AHP method is located in pairwise comparison approach. The method is applied to calculate relative importance values of criteria and alternatives by using pairwise comparison matrices. And fuzzy TOPSIS method is classified as distance based methods. Alternatives are evaluated according to their distance to ideal solutions in these methods. Another method, i.e. fuzzy PROMETHEE method, used in the study is outranking method used for partial and complete ranking of several alternatives. This method is also extended under fuzziness in order to get more sensitive results.

Multiple software products and add-ins have been developed with the aim to facilitate the decision-making and calculation processes which are; MS Excel, Visual PROMETHEE, TOPSIS programs. The method uses weights and preference functions that allow proper decision-making particularly for too large optimization criteria.

The integrated Fuzzy AHP-Fuzzy TOPSIS-Fuzzy PROMETHEE approaches/methodologies, in fact, enabled us to understand the decision variants more specifically with regard to common criteria, thereby synthesizing the qualitative criteria into numerical values and thus providing results with adequate clarity. The weights of the energy projects are determined by fuzzy AHP and then fuzzy TOPSIS & fuzzy PROMETHEE methods are used for the rankings of the international energy projects of Turkey. In the study, 6 main criteria, i.e. technical (energy "Demand & Supply" of Turkey



and EU, EU's 4th energy corridor projects (EU's Southern Gas Corridor projects)), economical (Energy Returned on Energy Invested Rate...), social, socio-political, political, environmental and risk criteria related with energy security/aim/target parameters of EU and Turkey; and 26 related sub-criteria have been determined for the selection of international energy projects planned to be constructed in Turkey. An interview/survey was developed and answered by 49 of the 55 energy experts consulted. From the responses obtained from the survey; study's 6 criteria and 26 subcriteria were defined.

In Fuzzy PROMETHEE method when the obtained Turkey's international energy projects performance scores (Φ_{net}) are examined, ranking of the alternatives is as follows: "Salt Lake Underground Natural Gas Storage Project-SNGSP" is the best energy project, and "North Marmara and Degirmenkoy Natural Gas Storage project-NDNGPS" is the second ranked energy project. "New Floating Storage and Regasification Unit (FSRU) projects (Saros)" is the third ranked energy project of Turkey. In Fuzzy TOPSIS method when the obtained Turkey's international energy projects performance scores are examined, ranking of the alternatives is as follows: "Salt Lake Underground Natural Gas Storage Project-SNGSP" is the best energy project, and "North Marmara and Degirmenkoy Natural Gas Storage project-NDNGPS" is the second ranked energy project of Turkey. "Mersin Underground Salt Caverna Natural Gas Storage Project" is the third ranked energy project of Turkey which is different than Fuzzy PROMETHEE method's result. The main reason of the subject selection/ranking is the strategic geographical position of Turkey between oil and gas producer countries, i.e. more than 70% of the World's proven fossil fuel reserves, and consumer countries, i.e. EU, provide safe and sustainable route for transporting resources from the Caspian Basin, Middle East and Southern/Eastern Mediterranean and Central Asia countries to World and EU's energy markets. Construction of Turkey's international energy projects, especially natural gas storage projects, will significantly contribute to EU & Turkey's energy supply security and will make Turkey an indispensable actor/country in EU energy security system, within this scope Turkey will become a strong EU candidate country.

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