Journal of Renewable Energy and Environment

Research Article

Journal Homepage: www.jree.ir

# Ranking Locations Based on Hydrogen Production from Geothermal in Iran Using the Fuzzy Moora Hybrid Approach and Expanded Entropy Weighting Method

Ali Mostafaeipour[a*], Mohammad Saidi Mehrabad[b], Mojtaba Qolipour[a], Mohadese Basirati[c], Mostafa Rezaei[a], Amir-Mohammad Golmohammadi[a]

[a] *Department of Industrial Engineering, Yazd University, Yazd, Iran.*
[b] *Department of Industrial Engineering, Iran University of Science and Technology, Tehran, Iran.*
[c] *Department of Industrial Engineering, Sharif University of Technology, Tehran, Iran.*

*PAPER INFO*

*Paper history:*
Received 28 June 2018
Accepted in revised form 06 October 2018

*Keywords*:
Geothermal Energy
Hydrogen Production
Expanded Entropy Weighting Method
Iran

*ABSTRACT*

The present study aimed at ranking and selecting the superior geothermal project for hydrogen production in 14 provinces of Iran using a multi-objective optimization fuzzy hybrid approach through analyzing the ratio (Fuzzy Moora) and expanded entropy weighting method. In this research, the extended entropy weighing method and the Fuzzy-Moora approach were utilized to weigh the criteria and project the ranking, respectively. In this research, 13 criteria for ranking the geothermal projects in Iran have been selected for hydrogen production. At first, the technical-economic feasibility of the projects was carried out in Homer software, and then the ranking process was performed with the proposed hybrid approach. The results showed that among 14 studied provinces using geothermal energy, the provinces of Bushehr, Hormozgan, Isfahan, Mazandaran, East Azarbaijan, Fars, Qazvin, Zanjan, Ardebil, Khorasan Razavi, Kerman, Sistan and Baluchestan, South Khorasan and West Azarbaijan were ranked in that order in terms of hydrogen production.

## 1. INTRODUCTION

Today, the widespread use of fossil fuels has been led to their rapid decline, while they generate enormous amounts of air pollutant material and have environmental impacts. Therefore, the tendency for using the renewable energy resources is of particular interest because of several advantages such as lower prices, availability, less pollution, and most importantly, sustainable economic development [1]. Anyway, many countries in the world have begun a serious effort to replace fossil fuels with renewable energies. One type of renewable energy which is considered as a good alternative instead of fossil fuels is geothermal energy [2]. In fact, after 1913, the geothermal energy was commercially available for electricity production. In the year 2000, the geothermal resources were recognized in more than 80 countries [3]. The geothermal steam generated power in 21 countries, as 5 countries gained 10 % to 22 % of their energy from the geothermal. However, only a small fraction of the geothermal potential has been developed so far, whereas there is a vast space for using the geothermal energy in order to generate the electricity and its direct applications. Moreover, the geothermal energy together with its verified technology and abundant resources have a significant contribution to reduce greenhouse gas emissions [4]. Thus, the geothermal energy is the renewable one that comes from the extractable heat which is initiated from the melt mass heat and decay of the radioactive materials in the depths of the earth. Unlike fossil fuels, this energy is considered as a relatively clean and renewable energy source [5]. It should be mentioned that a variety of the geothermal energy sources are as follows: 1) hydrothermal energy, 2) pressurized layers, 3) dry and hot boulders, and 4) molten masses. In general, given the economic, social, geographic and ecological conditions of each area, using the geothermal energy can be divided into several groups having a variety of applications such as generating the electrical power or any suitable industrial, agriculture or domestic applications [6, 7]. In this study, using the geothermal energy and focusing on the hydrogen production, we selected the best state of the geothermal project. But, what is the important in hydrogen and its production? Regarding Hydrogen and

*Corresponding Author's Email: mostafaei@yazd.ac.ir (A. Mostafaeipour)

its Energy, we believe that the hydrogen energy can be a good alternative for the fossil fuels and it can eliminate their using disadvantages. Because hydrogen has all the properties of a unique energy carrier, it can play an effective role in this condition. However, hydrogen is not found alone in nature, also, much energy is required to separate it. For this purpose, using the geothermal energy sources is the most appropriate and available option due to its relatively low cost and easy access [8]. Iran is one of the potential customers of using hydrogen owing to its various petrochemicals and petroleum industries, so, it has to consider the importance of the domestic production of hydrogen gas. In addition, the hydrogen production by electrolysis requires some electricity which can be generated with much less pollution than the fossil fuels in very low-risk geothermal power plants [9]. This method is continuously utilized in Iran. Therefore, the evaluation and ranking of the regions having the optimal geothermal potential for the hydrogen production can be useful for the future of the high-tech industries in Iran. It is worthy to note that this research wants to answer which of the Iranian provinces have the most priority to produce the hydrogen gas.

Concerning novelty of this research, this is the first time that the hydrogen production using geothermal as a source of energy is evaluated by serving the Fuzzy Moora hybrid approach and expanded entropy weighting method in different provinces in Iran. The utilized criteria include the number of geomorphic springs and fields, distance of nearest geothermal field than main road and provincial capital, total production capacity of geothermal resources, number of water resources in the province, number of related industries to hydrogen in the province, the distance of the provincial capital from the related industries to hydrogen, provincial expert manpower, province population, air pollution rates, rainfall rates, and area of the province.

## 2. AN OVERVIEW ON RELATED RESEARCH WORKS

Geothermal is a Greek word consisting of two words of "geo" and "thermal" which mean "earth" and heat or calorific, respectively [10]. In 1904, for the first time in the world, the power was produced from the geothermal energy source, and then it was considerably expanded so that the power amount generated by the geothermal power stations around the world is numerically estimated to be about 11,000 megawatts [11]. Formal surveys of the geothermal resources were carried out in 1975 by the Ministry of Energy and with the cooperation of an Italian company in north and northeastern of Iran. The studied area was about 260,000 kilometers which over 31,000 square kilometers of it including Sabalan, Damavand, Khoy, Maku and Sahand were recognized as an appropriate place for the construction of the geothermal power plants. Additionally, it should be mentioned that the results of these studies led to the establishment of the Meshgin Shahr geothermal power plant with a production capacity of 55 MW. In 2012, the country had a total power output of 239 billion kilowatt-hours per year which was placed in the second rank in comparison with the entire Middle East with a production rate of 255 billion kilowatt-hours in the year [12].

Hydrogen, as one of the most important fuels of the future, can be generated using either renewable energy sources or fossil fuels. Hydrogen can be obtained from fossil fuels by different ways like gasification [13], partial oxidation [14], steam reforming [15], and autothermal oxidation [16]. On the other hand, hydrogen can be acquired using renewable resources such as solar energy [17], wind energy [18], and Geothermal [19].

In a research work, Mirzayi Ziapour and Eghbali Asl have studied [20] the utilization of the geothermal energy and gas pressure potentials at pressure reduction (Turbo expander) stations to generate the electricity. Gholami Sarrmali et al. [21] have investigated the possibility of using geothermal energy in order to heat several spaces in an area of Ardabil city. The research modeling was performed via the thermal pump system with a vapor compressive cooling cycle for heating a given space using EES software. Their results showed that the ground temperature on the test site remains constant at 12°C at a depth of 4 meters. Moreover, under thermal test conditions, the thermal power was obtained about 1,700 watts from a small plot of land. Safarzadeh and co-workers [1] have studied the geothermal energy potential of Iran and heating systems of the geothermal greenhouses. Their investigation has revealed that Iran has a high potential in this regard which is placed in 14$^{th}$ rank among the countries having the geothermal energy potential. Besides, there is the geothermal energy in most parts of the country in which the northwest and south have the highest potential. Ahmadi Zadeh et al. [22] have identified the geothermal potential by means of a remote thermal evaluation method in South Khorasan through Landsat 7 satellite imagery and +ETM sensor. It was also gained Earth surface temperature anomalies map and identified six susceptible geothermal regions. In a research work conducted by Mohammadzadeh Moghadam et al. [23], the modeling and interpretation of ground-based magnetic data related to the geothermal energy sources have been inspected in the northwest of Delijan. The analysis was accomplished using the Euler method, forward modeling and 3D inversion of the data by the ModelVision software and the Mag3D computer code. The results of this modeling and inversion showed that there is a large magnetic anomaly in the depth of 2500-5000 meters that was interpreted as the region source of the geothermal system. Additionally, Rezaei et al. [24] have examined 7 coastal provinces of Iran based on the location optimization for producing Hydrogen using wind energy. 5 criteria of wind power density, land cost, topographic situation, natural disasters, and population were applied to rank the provinces.

Dabbaghiyan et al. [25] have examined the evaluation of the wind energy potential in the four locations of Bushehr province including Asaluyeh, Bordkhun, Delvar, and Haft-Chah. The analysis utilized the wind speed data measured in 2011 at heights of 10m, 30m and 40m above the ground level and the Weibull probability distribution function was employed to calculate the wind power density and energy for these regions. The results indicated that Bordkhun has better potential for using wind energy than the other three areas. For the winds at a height of 40 m, the annual mean wind power density for this location was found to be about 265 W/m$^2$. Furthermore, comparing the results of the wind turbines indicated that Proven 15 model turbine has the highest capacity factor and was the best choice economically for all of the considered locations. Moreover, Balta et al. [26] have studied the thermodynamic aspects of the geothermal energy for hydrogen production. Using geothermal energy, Kanoglu et al. [27] have analyzed the utilized thermodynamic model to generate hydrogen. Ouali et al. [28] have also examined the technical-economic status of produced hydrodynamics in several areas with the geothermal energy potential. Using geothermal energy, Yilmaz et al. [29] have assessed the hydrogen production economy. The performance of an integrated geothermal system for generating the electricity, hydrogen, and heat has been evaluated through an investigation carried out by Al-Zahrani et al. [30]. Furthermore, Rahmouni and colleagues [31] have carried out a technical, economic and environmental analysis of the carbon-energy-geothermal energy system for the hydrogen production. Yilmaz et al. [32] have scrutinized the hydrogen production costs using a geothermal power plant. Ramezankhouni et al. [19] have studied the feasibility of hydrogen production via the geothermal energy in Iran. Yuksel and Ozterk [33] have also analyzed the thermodynamic and thermo-economy on an integrated geothermal energy system for hydrogen production. Gaebi et al. [34] have examined the economy of energy and exergy of the hydrogen production using the low-energy geothermal resources.

In order to investigate the different applications of geothermal energy, El Haj Assad et al. [35] have surveyed this sustainable and environmentally friendly energy as a heat source to drive vapor absorption chillers. Likewise, Abdelkareem et al. [36] have studied another application of geothermal energy as a power source of desalinating water. In an investigation conducted by El Haj Assad et al. [37], three different types of the geothermal power plants including single and dual flash, and binary were compared in terms of the generated power amount and their performance. There are few related research work in the literature [38-50] which different renewable sources were investigated in order to combat air pollution, climate change, and global warming in different parts of the world especially in Iran.

The present research focuses on ranking and selecting the yop project for the hydrogen production from the geothermal energy using the fuzzy Moora hybrid approach and the entropy weighing method developed in 14 provinces of Iran.

## 3. GEOGRAPHIC FEATURE

This paper wants to evaluate the potential for hydrogen production from the geothermal energy, so, it attempts to assess the capability of the suitable provinces. The location of each province is illustrated in Fig. 1. The latitude and longitude of the selected provinces are also shown in Table 1.

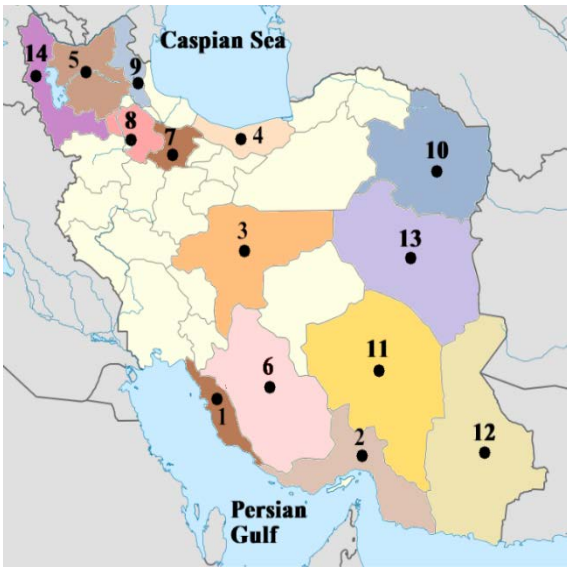


**Figure 1**. Location of the studied provinces.

## 4. METHODOLOGY

According to the previous research works, in the geothermal projects for the power generation and hydrogen, there are several criteria that can be used for ranking. In this research, based on the investigation of Ramazankhani et al. [19], 13 criteria for ranking the geothermal projects in Iran have been selected for hydrogen. The selected criteria include the numbers of geomorphic springs and fields, distance from the nearest ground to the main road and from the nearest land area to the provincial capital, total production capacity of the geothermal resources, number of water resources belong to the province, number of industries related to hydrogen in the province, province center distance from the industries related to hydrogen, provincial expert force, province population, air pollution, rainfall and area of each province. According to the proposed combination method in this research, the criteria are, then, divided into two groups of desirable and undesirable. According to Table 2, 8 and 5 of these 13 criteria are favorable and unfavorable, respectively. In Table 2, a list of the desirable and undesirable criteria, the Abbreviation assigned to each criterion and their units are presented separately.

After determining the type of the criteria, the method of obtaining the values of each criterion should be introduced. In this research, the criteria values are extracted from the investigation of Ramazankhani et al. [19]. Then, using the proposed combination method, the project rankings are addressed. The suggested combination method is now described.

**Table 1.** Geographical coordinates of the studied regions [51].

| No. | Location | longitude | Latitude |
|---|---|---|---|
| 1 | Bushehr | 50°50'E | 28°58'N |
| 2 | Hormozgan | 56°16'E | 27°11'N |
| 3 | Isfahan | 51°39'E | 32°38'N |
| 4 | Mazandaran | 53°03'E | 36°33'N |
| 5 | East Azarbaijan | 46°16'E | 38°04'N |
| 6 | Fars | 52°32'E | 29°37'N |
| 7 | Qazvin | 50°00'E | 36°16'N |
| 8 | Zanjan | 48°29'E | 36°40'N |
| 9 | Ardebil | 48°17'E | 38°15'N |
| 10 | Khorasan Razavi | 59°36'E | 36°17'N |
| 11 | Kerman | 57°05'E | 30°17'N |
| 12 | Sistan and Baluchestan | 60°52'E | 29°29'N |
| 13 | South Khorasan | 59°12'E | 32°51'N |
| 14 | West Azarbaijan | 45°04'E | 37°33'N |

**Table 2.** Desirable and undesirable criteria.

| Symbol | Criterion | Unit | Desirable benchmark | Undesirable benchmark |
|---|---|---|---|---|
| C1 | Number of geothermal springs | number | * | |
| C2 | Number of geostationary fields | number | * | |
| C3 | Distance from the nearest square to the main road | Km | | * |
| C4 | Distance from the nearest square to the center of the province | Km | | * |
| C5 | Total production capacity of resources | Power (kJ) | * | |
| C6 | Number of water resources of the province | number | * | |
| C7 | Number of industries related to hydrogen in the province | number | * | |
| C8 | The provincial capital's distance from the hydrogen-related industries | Km | | * |
| C9 | Provincial expert | number | * | |
| C10 | Provincial population | number | | * |
| C11 | Air pollution | Kt | * | |
| C12 | The rainfall | mm | * | |
| C13 | Area of the province | $Km^2$ | | * |

### 4.1. Fuzzy Moora hybrid method (F-MOORA[2])

Based on Herbert Simon's theory, the pure rationality is used in single-objective and single criterion world, but, none of the existing options will provide all the goals in the real world. Given the diversity of the criteria in real decisions, it requires a method having the rationality, also, it can provide a "satisfactory" decision instead of an "optimal response". The introduction of multi-objective decision making in this field can help the process of selection and decision making. The logic of this approach is to provide an optimal solution and to choose from a set of available options according to the diverse purposes. Therefore, this method was proposed to solve the multi-objective decision problems [52]. This algorithm is based on four basic steps:

1. Choose the problem (selecting the best option);
2. Classify the problem (To classify options into relatively homogeneous groups);
3. Rank the problem (ranking options from the best to the worst one);
4. Describe the problem (describing the options in terms of their characteristics).

It should be noted that some scholars have defined three broad categories of the multi-objective decision-making methods including Measuring models, Target models, aspirations and reference levels, and Superior models [53].

Based on the assumptions of the problem, each of the proposed models has both disadvantages and advantages, so, the Moora method is expanded in this study. The Moora method was first proposed in 2006 based on the previous researches [54]. Such as the other

[2] Fuzzy multi-objective optimization by ratio analysis

multipurpose optimization approaches, the Moora method has an effective application in solving the various problems in complex decision making. This method has recently been used in a variety of scientific fields such as smart production project ranking, prioritization of eco-friendly power generation technologies, selection of production materials and etc. The starting point for the Moora method is a decision matrix that examines the performance of different options established upon the various criteria. MooraThis method has 7 steps which are as follows [53- 55]:

Step 1: Identify related options and criteria.

Step 2: Create a decision matrix for displaying variables: In a decision matrix, all the required information about the criteria is shown. In Eq. (1), the matrix $X_{m\times n}$ is a decision one in which the size elements of the function are the ith and jth which refer to the option and criterion (m and n are the number of options and criteria, correspondingly). Hence, the initial expansion of the decision matrix X is given by Eq. (1):

$$X = [x_{ij}]_{m\times n} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

After expressing the decision matrix, it must be normalized so that all matrices are unmatched and comparable. To normalize this matrix, the ratio technique was used. Table 3 provides much information about the options, criteria, weight of each benchmark, and performance rate of each option. The task of the decision maker is related to the classification and selection of the best option among the available ones through providing information in the decision Table and adopting a decision method.

**Table 3.** Multi-criteria decision matrix.

| | Criteria | | | | |
|---|---|---|---|---|---|
| | Weight of each criterion | | | | |
| Options | $B_1$ $(w_1)$ | $B_2$ $(w_2)$ | $B_3$ $(w_3)$ | $\cdots$ $(...)$ | $B_n$ $(w_n)$ |
| $A_1$ | $x_{11}$ | $x_{12}$ | $x_{13}$ | $\cdots$ | $x_{1n}$ |
| $A_2$ | $x_{21}$ | $x_{22}$ | $x_{23}$ | $\cdots$ | $x_{2n}$ |
| $A_3$ | $x_{31}$ | $x_{32}$ | $x_{33}$ | $\cdots$ | $x_{3n}$ |
| $\cdots$ | $\cdots$ | $\cdots$ | $\cdots$ | $\cdots$ | $\cdots$ |
| $A_m$ | $x_{41}$ | $x_{42}$ | $x_{43}$ | $\cdots$ | $x_{44}$ |

Of course, the criteria nature in a multi-objective decision making may be aligned or contradictory. Hence, the real world decision maker encounters two types of criteria:

A) Desirable benchmark: This means that maximizing the number of options is desirable.
B) Undesirable criteria: This means that minimizing the number of options is desirable.

Step 3: Normalizing the decision matrix: The decision matrix regardless of the benchmark type, which is desirable or undesirable, should be normalized. So, the dimensionless number $x_{ij}$ belongs to the interval [0 , 1] and the function operator of the i^th option and j^th criterion. To denote this fraction. This ratio is mathematically shown in Equation (2):

$$x_{ij}^{*} = \frac{x_{ij}}{[\sum_{i=1}^{m} x_{ij}^{2}]^{1/2}} \qquad [j = 1, 2, 3, \ldots, n] \qquad (2)$$

Step 4: Calculation of the objective function: To optimize the multi-objective function in the maximization state, the desired and undesired criteria are combined and subtracted respectively for the minimization mode. Thus, the optimization problem is formed as Eq. (3):

$$y_i = \sum_{j=1}^{g} x_{ij}^{*} - \sum_{j=g+1}^{n} x_{ij}^{*} \qquad (3)$$

where g and n-g denote the number of criteria that must be maximized and minimized respectively and yi is the normal estimated value of i-th choice with counting all criteria. In some cases, it can be seen that some criteria are more valuable or more important than the other ones. Therefore, in order to make this important for some criteria, we can multiply the weight corresponding to each criterion. Now, according to the weight of each criterion, Eq. (3) changes as Eq. (4):

$$y_i = \sum_{j=1}^{g} w_j x_{ij}^{*} - \sum_{j=g+1}^{n} w_j x_{ij}^{*} \qquad [j = 1, 2, 3, \ldots, n] \quad (4)$$

where wj is the j-th criterion which describes how these weights are calculated.

Step 5: Determine the final priorities: yj may be either positive or negative depending on the total maximum (desirable criteria) and minimum (undesirable criteria) values in the decision matrix. When yi is arranged in descending order, the final ranking is determined. As a result, the best option has the highest yi, while the worst one has the lowest yi.

Step 6: Define a Virtual Option: This option is defined based on the most ideal and desirable mode, so that its desirable and undesirable criteria take the most and least amount, respectively.

Step 7: Determining the distance of each option by the virtual one: According to the aforementioned assumptions, the virtual option has the highest value. In this case, its value is defined as $y_{max}$, so, consistent with Eq. (5) and via determining the value k, the distance between each option and the ideal state is measured.

$$k_i = \frac{y_i - y_{\min}}{y_{\max} - y_{\min}} \times 100 \quad [j = 1, 2, 3, \ldots, n] \qquad (5)$$

In Eq. (5), the lowest value of $y_i$ is shown with $y_{min}$. In simpler terms, the most unfavorable option is displayed among the possible ones with $y_{min}$ too.

## 4.2. Entropy method

According to the fourth step of the Moora method, if the criteria are of special relative importance to each other, then the weight of the criteria should be identified. Now, we discuss which decision makers use one of the three suggested methods based on the problem type [56]:

3-1) Based on the decision matrix and the different options characteristic: In this case, according to the decision matrix and the characteristics of the various options, the decision maker calculates the weights via different ways such as analyzing the hierarchy of fuzzy, the entropy method and etc. To calculate the weights, we should consider the sum of all weights is equal to one ($\sum_{j=1}^{m} w_j = 1$). Considering that the entropy method uses the decision matrix values to compute the weights of the criteria, it was served in this study.

3-2) Based on the subjective preferences of the criteria: in this case, the decision maker exactly knows which weights should be assigned to the criteria. This knowledge is related to either the result of evidence and information about the issue or the actions of the decision maker.

3-3) based on the combination of 3-1 and 3-2 which is called "integrated weight allocation". This mode is divided into two parts:

A) When the decision maker exactly knows the importance of the criteria and tends to apply them in a particular way. In this case, the weights $w_j^O$ and $w_j^S$ are the objective (scientific) and subjective weights, respectively.

$$w_j^I = W^O w_j^O + W^S w_j^S \qquad (6)$$

$$W^O + W^S = 1 \qquad (7)$$

where $W^O$ and $W^S$ are the assignment of the objective and subjective weights to criteria, respectively. Moreover, $w_j^S$ is the assignment that allocated by the decision maker because of comparison with the criteria, while the entropy method is used to calculate $w_j^O$.

B) When the decision maker does not distinguish the importance of the criteria, he uses Eq. (11) to weigh. $w_j^{I*}$ is also defined as follows:

$$w_j^{I*} = \frac{w_j^O * w_j^S}{\sum_{k=1}^{m} w_k^O * w_k^S} \qquad (8)$$

Therefore, for weighting the criteria, it is assumed that the decision maker does not have complete information about the significance of the criteria, so, the criteria weight is calculated based on Eq. (8).

### 1- Extending the scoring scale of 11 fuzzy points

One of the scoring methods of the criteria is the utilization of the 11-point fuzzy scoring scale approach. This method has been presented as a corrective approach for the previous fuzzy ranking ones. The fuzzy function of the score, which is assigned to the verbal variables such as M, is calculated as follows [56]:

$$\mu_{\max}(x) = \begin{cases} x & 0 \le x \le 1 \\ 0 & otherwise \end{cases} \qquad (9)$$

$$\mu_{\min}(x) = \begin{cases} 1-x & 0 \le x \le 1 \\ 0 & otherwise \end{cases} \qquad (10)$$

The maximum and minimum fuzzy numbers are defined in such a way that the absolute position of the fuzzy numbers is automatically included between spaces. The numerical value of the left of each fuzzy number $M_i$ is calculated according to Eq. 11 [56]:

$$\mu_L(M_i) = Supx[\mu_{\min}(x) \wedge \mu_{M_1}(x)] \qquad (11)$$

where $\mu_L(M_i)$ denotes a unique real number between the interval (0, 1) which refers to the maximum value of the intersection of the fuzzy number $M_i$ and the minimal fuzzy number. Similarly, the numerical value of the right side is calculated by Eq. (12) [56]:

$$\mu_R(M_i) = Supx[\mu_{\max}(x) \wedge \mu_{M_i}(x)] \qquad (12)$$

where $\mu_R(M_i)$ denotes a unique real number between the interval (0, 1). Having the left and right values of any fuzzy number $M_i$, its exact value is calculated using Eq. (13) [56]:

$$\mu_T(M_i) = \frac{\mu_R(M_i) + 1 - \mu_L(M_i)}{2} \qquad (13)$$

These values are for the fuzzy number of $M_i$ [56]:

$$\mu_L(M_i) = Supx[\mu_{\min}(x) \wedge \mu_{M_1}(x)] = 0.0909 \tag{14}$$

$$\mu_R(M_i) = Supx[\mu_{\max}(x) \wedge \mu_{M_i}(x)] = 1 \tag{15}$$

$$\mu_T(M_i) = \frac{\mu_R(M_i) + 1 - \mu_L(M_i)}{2} = 0.0455 \tag{16}$$

As can be seen in Fig. 2 and Table 4, the comparison of the 11th point of the linguistic terminology with the definite numbers, i.e. the assigned functions, as well as the computed values of the left and right of each fuzzy number was carried out.

The comparison of 11 points of the linguistic expressions to definite the numbers and calculated values of the left and right of each fuzzy number is shown in Fig. 2.

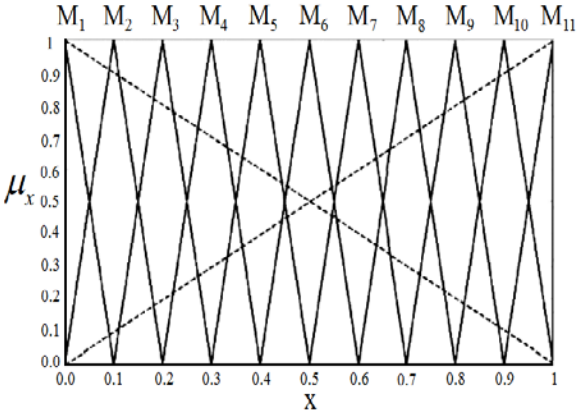


**Figure 2.** Changes of linguistic to fuzzy for 11-points.

**Table 4.** Fuzzy numbers [56].

| $\mu_R(M_i)$ | $\mu_L(M_i)$ | Fuzzy Function | $\mu_T(M_i)$ | Fuzzy Number | Qualitative value |
|---|---|---|---|---|---|
| 0.0909 | 1.0000 | $M_1(x) = \begin{cases} 1 & x = 0 \\ (0.1 - x)/0.1 & 0 \le x \le 0.1 \end{cases}$ | 0.0455 | $M_1$ | Extra-Low |
| 0.1818 | 0.9091 | $M_2(x) = \begin{cases} (x - 0.1)/0.1 & 0 \le x \le 0.1 \\ (0.2 - x)/0.1 & 0.1 \le x \le 0.2 \end{cases}$ | 0.1364 | $M_2$ | Severely Low |
| 0.2727 | 0.8182 | $M_3(x) = \begin{cases} (x - 0.1)/0.1 & 0.1 \le x \le 0.2 \\ (0.3 - x)/0.1 & 0.2 \le x \le 0.3 \end{cases}$ | 0.2273 | $M_3$ | Very Low |
| 0.3636 | 0.7273 | $M_4(x) = \begin{cases} (x - 0.2)/0.1 & 0.3 \le x \le 0.2 \\ (0.4 - x)/0.1 & 0.3 \le x \le 0.4 \end{cases}$ | 0.3182 | $M_4$ | Low |
| 0.4545 | 0.6364 | $M_5(x) = \begin{cases} (x - 0.3)/0.1 & 0.3 \le x \le 0.4 \\ (0.5 - x)/0.1 & 0.4 \le x \le 0.5 \end{cases}$ | 0.4091 | $M_5$ | Under Moderate |
| 0.5455 | 0.5455 | $M_6(x) = \begin{cases} (x - 0.4)/0.1 & 0.4 \le x \le 0.5 \\ (0.6 - x)/0.1 & 0.5 \le x \le 0.6 \end{cases}$ | 0.5000 | $M_6$ | Moderate |
| 0.6364 | 0.4545 | $M_7(x) = \begin{cases} (x - 0.5)/0.1 & 0.5 \le x \le 0.6 \\ (0.7 - x)/0.1 & 0.6 \le x \le 0.7 \end{cases}$ | 0.5909 | $M_7$ | Above Moderate |
| 0.7273 | 0.3636 | $M_8(x) = \begin{cases} (x - 0.6)/0.1 & 0.6 \le x \le 0.7 \\ (0.8 - x)/0.1 & 0.7 \le x \le 0.8 \end{cases}$ | 0.6818 | $M_8$ | High |
| 0.8182 | 0.2727 | $M_9(x) = \begin{cases} (x - 0.7)/0.1 & 0.7 \le x \le 0.8 \\ (0.9 - x)/0.1 & 0.8 \le x \le 0.9 \end{cases}$ | 0.7727 | $M_9$ | Very High |
| 0.9091 | 0.1818 | $M_{10}(x) = \begin{cases} (x - 0.8)/0.1 & 0.8 \le x \le 0.9 \\ (1.0 - x)/0.1 & 0.9 \le x \le 1.0 \end{cases}$ | 0.8636 | $M_{10}$ | Severely High |
| 1.0000 | 0.0909 | $M_{11}(x) = \begin{cases} (x - 0.9)/0.1 & 0.9 \le x \le 1.0 \\ 1 & x = 1 \end{cases}$ | 0.9545 | $M_{11}$ | Extra-High |

Consequently, the research is completed in five steps:

1. Identify and determine the criteria for ranking the project.

2. Collecting the values of each criterion for each project.

3. Objective (by researchers/experts) and scientific (using entropy approach) weighing and calculating the significance coefficient of each criterion.
4. Performing ranking and designing a superior project using the Fuzzy Moora method.
5. Analysis of the findings.

## 5. ANALYSIS

According to Table 2, thirteen criteria were selected for ranking the renewable geothermal projects, as eight and five of them were desirable and undesirable, respectively. Table 5 shows the values of 13 criteria for each province. In fact, Table 5 is the same decision matrix in the Moora method.

In the decision matrix of the Moora method, in addition to the options ahead, a virtual option (virtual P) is provided by researchers/experts. This option is the most ideal and desirable one that the reasons for its selection and entrance into the calculation are to have an optimal measure in order to evaluate the values of the selected criteria.

**Table 5.** Decision matrix.

| Project | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $P_1$ | 7 | 2 | 12.2 | 37.2 | 51.8 | 9 | 3 | 13 | 10 | 3724260 | 28977.5 | 307.46 | 45650 |
| $P_2$ | 10 | 2 | 58.9 | 181 | 74.1 | 12 | 1 | 30 | 3 | 3080576 | 23966.8 | 389.61 | 37411 |
| $P_3$ | 6 | 3 | 7.8 | 34 | 44.4 | 7 | 0 | 188 | 2 | 1248488 | 9713.2 | 338.3 | 17800 |
| $P_4$ | 4 | 2 | 9 | 208 | 29.6 | 5 | 3 | 22 | 16 | 4879312 | 37961.04 | 156.27 | 107029 |
| $P_5$ | 3 | 1 | 0 | 0 | 22.2 | 6 | 10 | 46 | 1 | 1030386 | 8016.4 | 95.75 | 22743 |
| $P_6$ | 1 | 2 | 2 | 199 | 7.4 | 1 | 0 | 547 | 1 | 662489 | 5154.1 | 136.2 | 151193 |
| $P_7$ | 3 | 1 | 0 | 228 | 22.2 | 6 | 0 | 233 | 8 | 5993615 | 46630.03 | 168.346 | 118854 |
| $P_8$ | 3 | 1 | 0 | 0 | 22.2 | 2 | 0 | 257 | 1 | 1015734 | 79024.4 | 243.55 | 21773 |
| $P_9$ | 5 | 2 | 0 | 118 | 37 | 4 | 0 | 523 | 2 | 2531239 | 19693.03 | 71.46 | 180726 |
| $P_{10}$ | 3 | 1 | 0 | 141 | 22.2 | 16 | 1 | 36 | 7 | 4822082 | 36648.59 | 223.266 | 122608 |
| $P_{11}$ | 4 | 1 | 0 | 117 | 29.6 | 7 | 0 | 153 | 1 | 1201028 | 9343.99 | 229.6 | 15567 |
| $P_{12}$ | 9 | 1 | 0 | 159 | 59.2 | 4 | 0 | 356 | 4 | 2932186 | 22812.4 | 136.25 | 181785 |
| $P_{13}$ | 5 | 3 | 0 | 71.2 | 37 | 11 | 0 | 186 | 6 | 3073938 | 23915.2 | 890.756 | 23842 |
| $P_{14}$ | 14 | 2 | 0 | 111 | 113.6 | 8 | 2 | 6 | 3 | 1574850 | 12252.2 | 63.95 | 70697 |
| $P_V$ | 15 | 5 | 60 | 240 | 150 | 20 | 14 | 550 | 20 | 6000000 | 50000 | 900 | 181758 |

After determining the values of each criterion, they must be converted into definite numbers through the data of Table 4. At first, the values of each criterion, which are large numbers too, are converted to numbers between zero and one using the values of the virtual option (virtual P). Then, in keeping with the information in Table 4, the definite values corresponding to each number are extracted and presented in a new Table called "quantitative decision matrix". Table 6 shows the quantitative decision matrix values for each criterion and project. The conversion of the 11-point fuzzy scale (Table 4) was used to derive the definitive values of all the criteria. In the first row of Table 6, the importance coefficient (weight) of each criterion was calculated using Eq. (11), then we decided to use them in the steps of the merged Moora-Entropy method in the matrix. Furthermore, in Table 6, the last row of the matrix ($\sum_{i=1}^{m} x_{ij}^2$ values) is utilized in the next calculation step (normalizing the quantized decision matrix).

After quantifying the decision matrix in the Moora method, it should be normalized. The purpose of normalizing the decision matrix is to convert the values of each component of each criterion to a number without any dimension and belong to the interval [0, 1]. In accordance with step 3 and using Eq. (2), the quantitative decision matrix (Table 6) is normalized, as its results are presented in Table 7. It is worthy to mention that Table 7 shows the normalized decision matrix.

**Table 6.** Quantitative decision matrix.

| Project | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Weights | 0.032 | 0.015 | 0.294 | 0.052 | 0.032 | 0.03 | 0.224 | 0.083 | 0.068 | 0.034 | 0.033 | 0.049 | 0.054 |
| $P_1$ | 0.4091 | 0.3182 | 0.2273 | 0.1364 | 0.3182 | 0.4091 | 0.2273 | 0.0455 | 0.4091 | 0.5909 | 0.5 | 0.3182 | 0.2273 |
| $P_2$ | 0.5909 | 0.3182 | 0.8636 | 0.6818 | 0.4091 | 0.0455 | 0.0455 | 0.0455 | 0.1364 | 0.5 | 0.4091 | 0.4091 | 0.2273 |
| $P_3$ | 0.3182 | 0.5 | 0.1364 | 0.1364 | 0.2273 | 0.3182 | 0.0455 | 0.3182 | 0.0455 | 0.2273 | 0.1364 | 0.3182 | 0.0455 |
| $P_4$ | 0.2273 | 0.3182 | 0.1364 | 0.7227 | 0.1364 | 0.2273 | 0.2273 | 0.0455 | 0.6818 | 0.2273 | 0.6818 | 0.1364 | 0.5 |
| $P_5$ | 0.1364 | 0.1364 | 0.0455 | 0.0455 | 0.1364 | 0.2273 | 0.6818 | 0.0455 | 0.0455 | 0.1364 | 0.1364 | 0.1364 | 0.1364 |
| $P_6$ | 0.0455 | 0.3182 | 0.0455 | 0.7227 | 0.0455 | 0.0455 | 0.0455 | 0.8636 | 0.0455 | 0.1364 | 0.1364 | 0.1364 | 0.7227 |
| $P_7$ | 0.1364 | 0.1364 | 0.0455 | 0.8636 | 0.1364 | 0.2273 | 0.0455 | 0.4091 | 0.3182 | 0.8636 | 0.8636 | 0.1364 | 0.59.9 |
| $P_8$ | 0.1364 | 0.1364 | 0.0455 | 0.0455 | 0.1364 | 0.0455 | 0.0455 | 0.4091 | 0.0455 | 0.1364 | 0.1364 | 0.2273 | 0.1364 |
| $P_9$ | 0.3182 | 0.3182 | 0.0455 | 0.4091 | 0.2273 | 0.1364 | 0.0455 | 0.8636 | 0.0455 | 0.4091 | 0.3182 | 0.0455 | 0.8636 |
| $P_{10}$ | 0.1364 | 0.1364 | 0.0455 | 0.5 | 0.1364 | 0.6818 | 0.0455 | 0.0455 | 0.3182 | 0.6818 | 0.6818 | 0.2273 | 0.5909 |
| $P_{11}$ | 0.2273 | 0.1364 | 0.0455 | 0.4091 | 0.1364 | 0.3182 | 0.0455 | 0.2273 | 0.0455 | 0.2273 | 0.1364 | 0.2273 | 0.0455 |
| $P_{12}$ | 0.5 | 0.1364 | 0.0455 | 0.5909 | 0.3182 | 0.1364 | 0.0455 | 0.5909 | 0.1364 | 0.4091 | 0.4091 | 0.1364 | 1 |
| $P_{13}$ | 0.3182 | 0.5 | 0.0455 | 0.2273 | 0.2273 | 0.5 | 0.0455 | 0.3182 | 0.2273 | 0.5 | 0.4091 | 0.8636 | 0.1364 |
| $P_{14}$ | 0.8636 | 0.3182 | 0.0455 | 0.4091 | 0.5909 | 0.3182 | 0.1364 | 0.0455 | 0.1364 | 0.2273 | 0.2273 | 0.0455 | 0.3182 |
| $P_V$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $\sum_{i=1}^{m} x_{ij}^2$ | 1.9959 | 1.2191 | 0.8553 | 3.4495 | 0.9877 | 1.6323 | 0.6074 | 2.4421 | 0.9546 | 3.1276 | 2.6736 | 1.3678 | 3.4810 |

**Table 7.** Normalized decision matrix.

| Project | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Weights | 0.032 | 0.015 | 0.294 | 0.052 | 0.032 | 0.03 | 0.224 | 0.083 | 0.068 | 0.034 | 0.033 | 0.049 | 0.054 |
| $P_1$ | 0.2896 | 0.2882 | 0.2458 | 0.0734 | 0.3202 | 0.3202 | 0.2916 | 0.0291 | 0.4187 | 0.3341 | 0.3058 | 0.2719 | 0.1218 |
| $P_2$ | 0.4182 | 0.2882 | 0.9338 | 0.3671 | 0.4116 | 0.3914 | 0.0584 | 0.0291 | 0.1396 | 0.2827 | 0.2502 | 0.3495 | 0.1218 |
| $P_3$ | 0.2252 | 0.4528 | 0.1475 | 0.0734 | 0.2287 | 0.2490 | 0.0584 | 0.2036 | 0.0466 | 0.1285 | 0.0834 | 0.2719 | 0.2719 |
| $P_4$ | 0.1609 | 0.2882 | 0.1475 | 0.3891 | 0.1372 | 0.1779 | 0.2916 | 0.0291 | 0.6978 | 0.4086 | 0.4170 | 0.1165 | 0.2680 |
| $P_5$ | 0.0965 | 0.1235 | 0.0492 | 0.0245 | 0.1372 | 0.1779 | 0.8748 | 0.0291 | 0.0466 | 0.0771 | 0.0834 | 0.1165 | 0.0731 |
| $P_6$ | 0.0322 | 0.2882 | 0.0492 | 0.3891 | 0.0458 | 0.0356 | 0.0584 | 0.5526 | 0.0466 | 0.0771 | 0.0834 | 0.1165 | 0.3874 |
| $P_7$ | 0.0965 | 0.1235 | 0.0492 | 0.4650 | 0.1372 | 0.1779 | 0.0584 | 0.2618 | 0.3257 | 0.4883 | 0.5282 | 0.1165 | 0.3167 |
| $P_8$ | 0.0965 | 0.1235 | 0.0492 | 0.0245 | 0.1372 | 0.0356 | 0.0584 | 0.2618 | 0.0466 | 0.0771 | 0.0834 | 0.1942 | 0.0731 |
| $P_9$ | 0.2252 | 0.2882 | 0.0492 | 0.2203 | 0.2287 | 0.1068 | 0.0584 | 0.5526 | 0.0466 | 0.2312 | 0.1946 | 0.0389 | 0.4629 |
| $P_{10}$ | 0.0965 | 0.1235 | 0.0492 | 0.2692 | 0.1372 | 0.5336 | 0.0584 | 0.0291 | 0.3257 | 0.3855 | 0.4170 | 0.1942 | 0.3167 |
| $P_{11}$ | 0.1609 | 0.1235 | 0.0492 | 0.2203 | 0.1372 | 0.2490 | 0.0584 | 0.1454 | 0.0466 | 0.1285 | 0.0834 | 0.1942 | 0.0244 |
| $P_{12}$ | 0.3539 | 0.1235 | 0.0492 | 0.3182 | 0.3202 | 0.1068 | 0.0584 | 0.3718 | 0.1396 | 0.2313 | 0.2505 | 0.1165 | 0.5360 |
| $P_{13}$ | 0.2253 | 0.4528 | 0.0492 | 0.1224 | 0.2287 | 0.3914 | 0.0584 | 0.2036 | 0.2326 | 0.2827 | 0.2505 | 0.7379 | 0.0731 |
| $P_{14}$ | 0.6112 | 0.2882 | 0.0492 | 0.2203 | 0.5946 | 0.2490 | 0.1750 | 0.0291 | 0.1396 | 0.1285 | 0.1390 | 0.0389 | 0.8705 |
| $P_V$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

After normalizing the decision matrix in step 3, the importance coefficient (weight) of each criterion is multiplied by components of the column related to the criterion in step 4 in order to make the balance between the components. It is due to that each criterion has significant importance. Additionally, it is necessary that the importance level (weight) of each criterion is multiplied by the corresponding value related to that criterion for each area to concentrate on their importance. Therefore, the weights (obtained from Eq. 8 which appear in the first row of Tables 6 and 7) are multiplied by the normalized components, so, the matrix of the weighted normalized decision is obtained. Table 8 shows the values of the weighted normalized decision matrix.

**Table 8.** Weighted Normalized Decision Matrix.

| Project | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $P_1$ | 0.0093 | 0.0043 | 0.0722 | 0.0038 | 0.0102 | 0.0096 | 0.0653 | 0.0024 | 0.0285 | 0.0114 | 0.0101 | 0.0133 | 0.0066 |
| $P_2$ | 0.0134 | 0.0043 | 0.2745 | 0.0191 | 0.0132 | 0.0117 | 0.0131 | 0.0024 | 0.0095 | 0.0096 | 0.0083 | 0.0171 | 0.0066 |
| $P_3$ | 0.0072 | 0.0067 | 0.0434 | 0.0038 | 0.0073 | 0.0075 | 0.0073 | 0.0169 | 0.0032 | 0.0044 | 0.0028 | 0.0133 | 0.0013 |
| $P_4$ | 0.0051 | 0.0043 | 0.0434 | 0.0202 | 0.0044 | 0.0053 | 0.0044 | 0.0024 | 0.0474 | 0.0139 | 0.0138 | 0.0057 | 0.0145 |
| $P_5$ | 0.0031 | 0.0018 | 0.0145 | 0.0013 | 0.0044 | 0.0053 | 0.1959 | 0.0024 | 0.0032 | 0.0026 | 0.0028 | 0.0057 | 0.0039 |
| $P_6$ | 0.0010 | 0.0043 | 0.0145 | 0.0202 | 0.0015 | 0.001 | 0.0131 | 0.0459 | 0.0032 | 0.0026 | 0.0028 | 0.0057 | 0.0209 |
| $P_7$ | 0.0031 | 0.0018 | 0.0145 | 0.0242 | 0.0044 | 0.0053 | 0.0131 | 0.0217 | 0.0221 | 0.0166 | 0.0174 | 0.0057 | 0.0171 |
| $P_8$ | 0.0031 | 0.0018 | 0.0145 | 0.0013 | 0.0044 | 0.0011 | 0.0131 | 0.0217 | 0.0032 | 0.0026 | 0.0028 | 0.0095 | 0.0039 |
| $P_9$ | 0.0071 | 0.0043 | 0.0145 | 0.0114 | 0.0073 | 0.0032 | 0.0131 | 0.0459 | 0.0032 | 0.0079 | 0.0064 | 0.0019 | 0.0250 |
| $P_{10}$ | 0.0031 | 0.0018 | 0.0145 | 0.0140 | 0.0044 | 0.0160 | 0.0131 | 0.0024 | 0.0221 | 0.0131 | 0.0138 | 0.0095 | 0.0171 |
| $P_{11}$ | 0.0051 | 0.0018 | 0.0145 | 0.0114 | 0.0044 | 0.0075 | 0.0131 | 0.0121 | 0.0032 | 0.0044 | 0.0028 | 0.0095 | 0.0013 |
| $P_{12}$ | 0.0113 | 0.0018 | 0.0145 | 0.0165 | 0.0102 | 0.0032 | 0.0131 | 0.0314 | 0.0095 | 0.0079 | 0.0083 | 0.0057 | 0.0289 |
| $P_{13}$ | 0.0072 | 0.0068 | 0.0145 | 0.0064 | 0.0073 | 0.0117 | 0.0131 | 0.0169 | 0.0158 | 0.0096 | 0.0083 | 0.0362 | 0.0039 |
| $P_{14}$ | 0.0196 | 0.0043 | 0.0145 | 0.0114 | 0.0190 | 0.0075 | 0.0392 | 0.0024 | 0.0095 | 0.0044 | 0.0046 | 0.0019 | 0.0092 |
| $P_V$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

After calculating the normalized rational decision matrix, the values of the target function for each project are calculated using Eq. 4. To compute the target function values, the criteria ones (the values of each row) should be summed together. Hence, to determine the values of the objective function regarding each project, the desirable and undesirable criteria are considered as positive and negative values, correspondingly. Now, $k_i$ values for all projects are computed by Eq. 5. After computing the target function and $k_i$ values for each project, the values of the objective function are arranged from the highest to the lowest value, therefore, the final ranking is obtained. The values of the target function and ranking all seven studied projects are separately presented in Table 9.

**Table 9.** The target function values and ranking of the projects.

| Project | Function value | (%) $K_i$ | Rank |
|---|---|---|---|
| Virtual | $Y_v = 1$ | 100 | * |
| Bushehr | $Y_5 = 0.1975$ | 34.31 | 1 |
| Hormozgan | $Y_{14} = 0.0639$ | 23.38 | 2 |
| Isfahan | $Y_4 = 0.0570$ | 22.82 | 3 |
| Mazandaran | $Y_{13} = 0.0550$ | 22.65 | 4 |
| East Azarbaijan | $Y_1 = 0.0542$ | 22.58 | 5 |
| Fars | $Y_{10} = 0.0228$ | 20.00 | 6 |
| Qazvin | $Y_{11} = 0.0040$ | 18.47 | 7 |
| Zanjan | $Y_8 = - 0.0051$ | 17.72 | 8 |
| Ardebil | $Y_3 = - 0.0084$ | 17.46 | 9 |
| Khorasan Razavi | $Y_7 = - 0.0210$ | 16.42 | 10 |
| Kerman | $Y_{12} = - 0.0360$ | 15.19 | 11 |
| Sistan and Baluchestan | $Y_9 = - 0.0581$ | 13.38 | 12 |
| South Khorasan | $Y_6 = - 0.0715$ | 12.29 | 13 |
| West Azarbaijan | $Y_2 = - 0.2216$ | 00.00 | 14 |

Thus, according to the data of Table 9 and the objective function values shown in Fig. 3, the provinces of Bushehr, Hormozgan, Isfahan, Mazandaran, East Azarbaijan, Fars, Qazvin, Zanjan, Ardebil, Khorasan Razavi, Kerman, Sistan and Baluchestan, South Khorasan and West Azarbaijan are ranked first to fourteenth, respectively, in terms of hydrogen production using the geothermal energy source. The province of Bushehr with the objective function value of + 0.1975 is the best location for producing hydrogen from the geothermal energy.

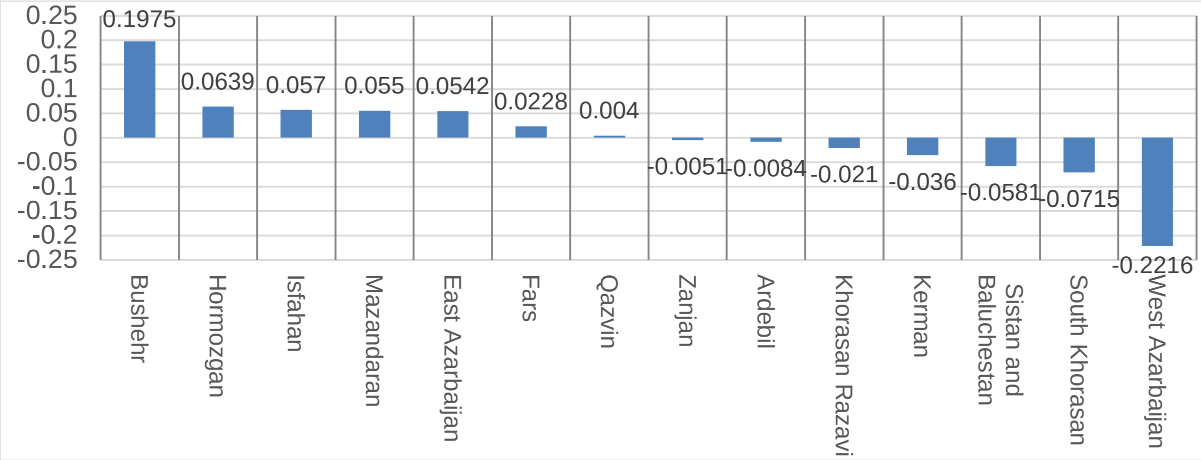


**Figure 3.** The objective function of different sites.

## 6. CONCLUSIONS

This study was carried out with the aim of ranking and selecting the best geothermal project for the hydrogen production in 14 provinces of Iran using a multi-objective optimization fuzzy hybrid approach through expanded proportional analysis (fuzzy Moora) and entropy weighting method. Since there are several criteria in the geothermal projects for the power and hydrogen generation that can be used for ranking, based on the previous researches, 13 criteria for ranking of the geothermal projects in Iran were selected. Selected criteria are as follows: the numbers of geomorphic springs and fields, the distance from the nearest geothermal field to the main road and provincial capital, the total production capacity of the geothermal resources, the number of water resources in the province, the number of related industries to hydrogen in the province, the distance of the provincial capital from the related industries to hydrogen, provincial expert manpower, province population, air pollution and rainfall rates, and area of the province. Then, considering the nature of the proposed hybrid method in this study, the criteria were divided into two categories: desirable and undesirable. Therefore, 8 desirable and 5 undesirable criteria of 13 selected ones were determined. At that time, using the entropy weighing method extended to weighing the criteria and Fuzzy-Moora integrated approach, the ranking of the projects was carried out. Regarding novelty of this research, it is worthy to note this is the first time that the hydrogen production using the geothermal as a source of energy is evaluated through the Fuzzy Moora hybrid approach and expanded entropy weighting method in different provinces in Iran. The results showed that among the selected case studies, the provinces of Bushehr, Hormozgan, Isfahan, Mazandaran, East Azarbaijan, Fars, Qazvin, Zanjan, Ardebil, Khorasan Razavi, Kerman, Sistan and Baluchestan, South Khorasan and West Azarbaijan were ranked first to fourteenth, respectively, in terms of the hydrogen production using the geothermal energy source. Moreover, the objective function values are respectively as follows: 0.1975, 0.0639, 0.0570, 0.0550, 0.0542, 0.0228, 0.0040, 0.0051, 0.0084, 0.0210, 0.0360, -0.0581, -0.0715 and -0.2216.

The province of Bushehr with the objective function value of + 0.1975 is the best location for producing hydrogen from the geothermal energy.

## 7. ACKNOWLEDGEMENT

Authors would like to thank all the organizations in Iran, also, Mr. Ramezankhani who provided data for this research work.

## REFERENCES

1. Safarzadeh, A.A., Abdi, R. and Shirichi Scuba,Y., "Geothermal energy potential of Iran and its applicability in greenhouse heating system", Master's Thesis, State Department- Ministry of Science, Research, Technology- Tabriz University, College of Agriculture, (2013).
2. Razzaghi, A., "Geothermal energy and its applications", ***Journal of Neshae Elm***, Vol. 1, (2012), 30-41.
3. Asadi, F., Karim, M.H. and Fasharif, M., "Competitiveness of geothermal electricity in comparison with conventional power generation in Iran", ***Journal of Energy Economy of Iran***, Vol. 18, (2016), 1-13.

4. Rezaei, M. and Torabi, H., "Geothermal energy for human use", Thirty-first Earth Sciences Conference, Geological Survey and Mineral Exploration of Iran, (2012).

5. Zare, M., "Perspective on the use of geothermal energy", ***Journal of Energy***, Vol. 32, (2016), 72-81.

6. Haj Aghababai, N., "Development of geothermal energy in architecture", ***Journal of Building and Day Equipment***, Vol. 41, (2016), 67-78.

7. Hashemi Nasab, M.R., Attarzadeh, P., Karimi, M. and Azadi M.H. "Geothermal energy, its applications and environmental effects", Thirty-first Earth Sciences Conference, Geological Survey and Mineral Exploration of Iran, (2012).

8. Farhudi, F. and Khalil Aria, S.H., "Thermodynamic analysis of hydrogen production methods", Master's Thesis, State-Ministry of Science, Research, and Technology- Orumieh University-College of Engineering, (2013).

9. Nuralini, J., "The geothermal energy and its environmental benefits", ***Journal of Eksie Novin***, Vol. 5, (2017), 192-199.

10. Hossein Zadeh, M.M. and Afshar, R., "Geothermal energy, its uses and its advantages in Iran", ***Journal of Growth in Geological Education***, Vol. 45, (2006), 35-39.

11. Sarrami, H. and Nazaripoor, H., "Geothermal energy as an alternative and renewable energy in the energy basket", ***Journal of Energy Economy***, Vol. 90, (2007), 26-33.

12. U.S. Energy Information Administration Total Electricity Net Generation, (2015).

13. Gonga, M., Nanda, S., Hunter, H.N., Zhud, W., Dalai, A.K. and Kozinski, J.A., "Lewis acid catalyzed gasification of humic acid in supercritical water", ***Catal Today***, Vol. 291, (2017), 13-23.

14. Sheikhbahaei, V., Baniasadi, E. and Naterer, G.F., "Experimental investigation of solar assisted hydrogen production from water and aluminum", ***International Journal of Hydrogen Energy***, Vol. 43, No. 19, (2018), 9181-9191.

15. Abdalla, A.M., Hossain, S., Nisfindy, O.B., Azad, A.T., Dawood, M. and Azad, A.K., "Hydrogen production, storage, transportation and key challenges with applications: A review", ***Energy Conversion and Management***, Vol. 165, (2018), 602-627.

16. Rau, F., Herrmann, A., Krause, H., Fino, D. and Trimis, D., "Production of hydrogen by autothermal reforming of biogas", ***Energy Procedia***, Vol. 120, (2017), 294-301.

17. Badea, G., Naghiu, G.S., Giurca, I., Aşchilean, I. and Megyesi, E., "Hydrogen production using solar energy- Technical analysis", ***Sustainable Solutions for Energy and Environment, EENVIRO 2016***, (26-28 October 2016), Bucharest, Romania.

18. Rezaei, M., Mostafaeipour, A., Qolipour, M. and Tavakkoli-Moghaddam. R., "Investigation of the optimal location design of a hybrid wind-solar plant: A case study", ***International Journal of Hydrogen Energy***, Vol. 43, (2018), 100-114.

19. Ramazankhani, M.E., Mostafaeipour, A., Hosseininasab, H. and Fakhrzad, M.B., "Feasibility of geothermal power assisted hydrogen production in Iran", ***International Journal of Hydrogen Energy***, Vol. 41, (2016), 18351-18369.

20. Mirzayi Ziapor, B. and Eghbali Asl, E., "Geothermal energy and gas pressure potential at pressure reduction stations for generation of electricity", Thesis, Government- Ministry of Science, Research, Technology- Mohaghegh Ardabili University- College of Engineering, (2011).

21. Gholami Sarmali, H., Rahimi, M. and Zakawe, S.J., "Investigating the possibility of using geothermal energy in the heating of spaces in Ardebil province", Bachelor's Thesis, State-Ministry of Science, Research and Technology- University of Mohaghegh Ardabili- Faculty of Engineering, (2012).

22. Ahmadi Zadeh, S.R., Arasteh, F., Fanaie Kheirabad, G.H.A. and Ashrafi, A., “"Identification of geothermal potentials, using Thermal Remote Sensing method in southern Khorasan", ***Journal of Environmental Research,*** Vol. 10, (2014), 135-143.

23. Mohammadzadeh Moghadam, M., Mirzai, S., Mirzai, M., Skoee, B. and Heidarian Dehkordi N., "Modeling and interpreting ground magnetic data related to geothermal resources, northwest of Delijan", ***Geological Quarterly of Iran***, Vol. 34, (2015), 103-114.

24. Rezaei, M., Mostafaeipour, A., Qolipour, M. and Arabnia, H.R., "Hydrogen production using wind energy from sea water: A case study on Southern and Northern coasts of Iran", ***Energy & Environment***, Vol. 29, (2018), 333-357.

25. Dabbaghiyan, A., Fazelpour, F., Dehghan-Abnavi, M.A. and Rosen, M., "Evaluation of wind energy potential in province of Bushehr, Iran", ***Renewable and Sustainable Energy Reviews***, Vol. 55, (2016), 455-466.

26. Balta, M.T., Dincer, I. and Hepbasli, A., "Thermodynamic assessment of geothermal energy use in hydrogen production", ***International Journal of Hydrogen Energy***, Vol. 34, (2009), 2925-2939.

27. Kanoglu, M., Bolatturk, A. and Yilmaz, C., "Thermodynamic analysis of models used in hydrogen production by geothermal energy", ***International Journal of Hydrogen Energy***, Vol. 35, (2010), 8783-8791.

28. Ouali, S., Chader, S., Belhamel, M. and Benziada, M., "The exploitation of hydrogen sulfide for hydrogen production in geothermal areas", ***International Journal of Hydrogen Energy***, Vol. 36, (2011), 4103-4109.

29. Yilmaz, C., Kanoglu, M., Bolatturk, A. and Gadalla, M., "Economics of hydrogen production and liquefaction by geothermal energy", ***International Journal of Hydrogen Energy***, Vol. 37, (2012), 2058-2069.

30. Al-Zaharani, A., Dincer, I. and Naterer, G.F., "Performance evaluation of a geothermal based integrated system for power, hydrogen and heat generation", ***International Journal of Hydrogen Energy***, Vol. 38, (2013), 14505-14511.

31. Rahmouni, S., Settou, N., Chennouf, N., Negrou, B. and Houari, M., "A Technical, economic and environmental analysis of combining geothermal energy with carbon sequestration for hydrogen production", ***Energy Procedia***, Vol. 50, (2014), 263-269.

32. Yilmaz, C., Kanoglu, M. and Abusoglu, A., "Thermoeconomic cost evaluation of hydrogen production driven by binary geothermal power plant", ***Geothermics***, Vol. 57, (2015), 18-25.

33. Yuksel, Y.E. and Ozturk, M., "Thermodynamic and thermo economic analyses of a geothermal energy based integrated system for hydrogen production", ***International Journal of Hydrogen Energy***, Vol. 42, (2017), 2530-2546.

34. Gaebi, H., Farhang, B., Parikhani, T. and Rostamzadeh, H., "Energy, exergy and exergoeconomic analysis of a cogeneration system for power and hydrogen production purpose based on TRR method and using low grade geothermal source", ***Geothermics***, Vol. 71, (2018), 132-145.

35. Assad, El., Tawalbeh, M., Salameh, T. and Al-Othman, A., "Thermodynamic analysis of lithium bromide absorption chiller driven by geothermal energy", ***International Conference on Renewable Energy Generation and Applications***, (2018 February 26-28), 2018 UAEU Al Ain, UAE.

36. Abdelkareem, M.A., El Haj Assad, M., Taha Sayed, E. and Soudan, B., "Recent progress in the use of renewable energy sources to power water desalination plants", ***Desalination***, Vol. 435, (2018), 97-113.

37. El Haj Assad, M., Bani-Hani, E. and Khalil, M., "Performance of geothermal power plants (single, dual, and binary) to compensate for LHC-CERN power consumption: comparative study", ***Geothermal Energy***, Vol. 5, No. 1 (2017), 1-17.

38. Mostafaeipour, A. and Abesi, S., "Wind turbine productivity and development in Iran", ***Biosciences (Biosciences World)***, International Conference Bari, Italy. (2010), 112-118.

39. Sen, A., "Should Indians pay more for renewable energy based electricity?- The need for evidence based consumer tariffs for electricity in India", ***Journal of Renewable Energy and Environment***, Vol. 4, No. 2&3, (2017), 23-32.

40. Mostafaeipour, A., Saidi-Mehrabad, M., Rezaei, M. and Qolipour, M., "The ranking of southern ports and islands of Iran for seawater plants using ELECTRE III method", ***Journal of Renewable Energy and Environment***, Vol. 4, No. 2&3, (2017), 10-22.

41. Al-Khazar, A.A.A. and Khaled, A.J., "A comparative study of the available measured global solar radiation in Iraq", ***Journal of Renewable Energy and Environment***, Vol. 4, No. 2&3, (2017), 47-53.

42. Mostafaeipour, A., "Productivity and development issues of global wind turbine industry", ***Renewable and Sustainable Energy Reviews***, Vol. 14, No. 3, (2010), 1048-1058.

43. Mostafaeipour, A., Jadidi, M., Mohammadi, K. and Sedaghat, A., "An analysis of wind energy potential and economic evaluation in Zahedan, Iran", ***Renewable and Sustainable Energy Reviews,*** Vol. 30, (2014), 641-650.

44. Keshavarz, M. and Mostajeran Goortani, B., "Solar heat utilization in separation column reboilers case study: Amine regenerator in South Pars Gas Complex, Assalouyeh", ***Journal of Renewable Energy and Environment***, Vol. 4, No. 2&3, (2017), 56-67.

45. Mostafaeipour, A., Qolipour, M. and Mohammadi, K., "Evaluation of installing photovoltaic plants using a hybrid approach for Khuzestan province, Iran", ***Renewable and Sustainable Energy Reviews,*** Vol. 60, (2016), 60-74.

46. Mostafaeipour, A., Qolipour, M. and Goudarzi, H., "Feasibility of using wind turbines for renewable hydrogen production in Firuzkuh, Iran", ***Frontiers in Energy***, (2018), 1-12.

47. Qolipour, M., Mostafaeipour, A., Shamshirband, S., Alavi, O., Goudarzi, H. and Petković, D., "Evaluation of wind power generation potential using a three hybrid approach for households in Ardebil Province, Iran", ***Energy Conversion and Management***, Vol. 118, (2016), 295-305.

48. Goudarzi, H. and Mostafaeipour, A., "Energy saving evaluation of passive systems for residential buildings in hot and dry regions", ***Renewable and Sustainable Energy Reviews***, Vol. 68, (2017), 432-446.

49. Sedaghat, A., Hassanzadeh, A., Jamali, J., Mostafaeipour, A. and Chen, W.H., "Determination of rated wind speed for maximum annual energy production of variable speed wind turbines", ***Applied Energy***, Vol. 205, (2017), 781-789.

50. Mohammadi, K., Mostafaeipour, A., Dinpashoh, Y. and Pouya, N., "Electricity generation and energy cost estimation of large-scale wind turbines in Jarandagh, Iran", ***Journal of Energy,*** (2014).

51. https://www.bahesab.ir/map/geographic [accessed on 25 May 2018].

52. Rezaei-Shouroki, M., Mostafaeipour, A. and Qolipour, M., "Prioritizing of wind farm locations for hydrogen production: A case study", ***International Journal of Hydrogen Energy***, Vol. 42, (2017), 9500-9510.

53. Karande, P. and Chakraborty, S., "Application of multi objective optimization on the basis of ratio analysis (MOORA) method for materials selection", ***Materials and Design***, Vol. 37, (2012), 317-324.

54. Brauers, W.K.M. and Zavadskas, E.K., "The MOORA method and its application to privatization in a transition economy control and cybernetics", ***Systems Research Institute of the Polish Academy of Sciences***, Vol. 35, (2006), 445-469.

55. Balezentis, T., Balezentis, A., Streimikiene, D. and Krisciukaitie, I., "Prioritizing sustainable electricity production technologies: MCDM approach", ***Renewable and Sustainable Energy Reviews***, Vol. 16, (2012), 3302-3311.

56. Amerizadeh Gheisari, B. and Sheikh, R., "Prioritization and selection of project using the fuzzy Moora hybrid approach and expanded entropy weights", ***Journal of Engineering and Management of Sharif,*** Vol. 32, (2016), 87-96.