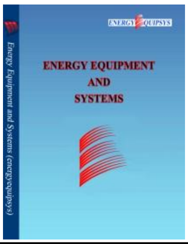
Energy Equip. Sys./ Vol. 5/No.2/ June 2017/165-187

ENERGY QUIPSYS

Energy Equipment and Systems

http://energyequipsys.ut.ac.ir
www.energyequipsys.com



The location optimization of wind turbine sites with using the MCDM approach: A case study

Author

Mostafa Rezaei-Shouroki [a*]

[a] Industrial Engineering Department, Yazd University, Yazd, Iran

ABSTRACT

The many advantages of renewable energies—especially wind—such as abundance, permanence, and lack of pollution, have encouraged many industrialized and developing countries to focus more on these clean sources of energy. The purpose of this study is to prioritize and rank 13 cities of the Fars province in Iran in terms of their suitability for the construction of a wind farm. Six important criteria are used to prioritize and rank these cities. Among these, wind power density—the most important criterion—was calculated by obtaining the three-hourly wind speed data at the height of 10 m above ground level related to the time period between 2004 and 2013 and then extrapolating these data to acquire wind speed related to the height of 40 m. The Data Envelopment Analysis (DEA) method was used for prioritizing and ranking the cities, after which Analytical Hierarchy Process (AHP) and Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (FTOPSIS) methods were used to assess the validity of the results. According to the results obtained from these three methods, the city of Izadkhast is recommended as the best location for the construction of a wind farm.

Article history:

Received : 20 September 2016
Accepted : 5 February 2017

Keywords: Wind Farm; Prioritizing; Optimization; Fars Province; Data Envelopment Analysis (DEA).

1. Introduction

Nowadays, ozone depletion, increasing global average temperature, climate change, different types of pollution, and high dependence on fossil fuels are some the major issues facing humanity. It is obvious that sources of coal, oil, and gas will eventually dry up in the foreseeable future. Thus, the increased use of clean and renewable energies is one of the measures that many developed countries have taken in recent decades to tackle these problems to some extent. The development of renewable energy technology and its accompanying benefits—such as reduced pollution, abundance, and permanence—have caused this type of energy, especially wind energy, to become economically viable [1] and to be viewed favourably by all experts on this subject. Wind, like other renewable energy sources, is geographically widespread and is almost always available; however, it is also dispersed and decentralized and has a fluctuating and intermittent nature [2].

Hence, it is obviously necessary to perform extensive research on this type of energy sources. In this paper, we aim to prioritize and rank the cities of the Fars province in terms of their suitability for the construction of a wind farm. All factors influencing the issue must be considered for minimizing the costs and choosing the right location. Therefore, after conducting some initial research about wind energy and the factors influencing it, six criteria—wind conditions, topographical conditions, population, and distance from distribution grid, land price, and probability of natural disasters—were selected as effective factors [3–5].

*Corresponding author: Mostafa Rezaei-Shouroki
Address: Industrial Engineering Department, Yazd University, Yazd, Iran
E-mail address: mm.sr6870@yahoo.com

The criterion of the probability of natural disasters itself includes three sub-criteria—namely floods, earthquakes, and dust storms, the probability of which must be calculated using long-term data. Wind power—the most important criterion in this study—is calculated by Weibull distribution function and three-hourly wind speed data related to the height of 10 m above ground level, recorded in the time period between 2004 and 2013 and collected from the national meteorological organization. This data is related to the height of 10 m above ground level; thus, the wind speed at the height of 40 m above ground level will be calculated by extrapolation. We will use aerial photographs and expert suggestions to calculate and obtain proper values for the criteria of topographical conditions and distance from distribution grid. Suitable topographical conditions for the construction of wind farm include flat and smooth land surfaces where there are no tree cover, mountains, hills, or tall buildings. These areas must also be within a 7.5 km radius, because meteorological data are only valid within this limit [5].

To calculate the criterion of distance from distribution grid, 20 sites that are considered suitable in terms of topography will be selected and then the average distance between these sites and the centre of the city (since the distribution grids are usually located in the centre of the city) will be calculated. The statistics gathered from the Statistical Centre of Iran will be used for the population criterion. To determine the land price criterion, we will follow the advice of the experts in this field in different cities of the Fars province. After the calculation of values representing each criterion, the DEA model will be used to rank and prioritize the cities. The DEA method assumes that decision-making units (DMUs) employ the same inputs to produce similar outputs [6, 7]. This method uses the ratio of the sum of weighted outputs to the sum of weighted inputs; its objective is to maximize the relative efficiency score of each unit by changing the weights of outputs and inputs. One of the applications of this method is the ranking and prioritization of units that do similar tasks. After the implementation of the DEA model, DMUs will be ranked according to their efficiency score, which means that DMUs with higher efficiency score will be ranked higher. If more than one DMU acquire a full efficiency score (maximum efficiency score is 1), then they cannot be compared by this score alone; they will have to be reassessed by Andersen–Petersen model (also called AP model) because in this model, efficiency scores can have values greater than 1. In this study, three criteria of wind conditions, topographical conditions, and population are considered as the DEA model outputs, while three criteria of distance from distribution grid, land price, and probability of natural disasters are considered as the DEA model inputs. Once cities are ranked by the DEA model, two techniques of AHP and FTOPSIS will be used to assess the validity of the results by comparing the results of these three methods. The AHP method consists of three important steps [8]: 1. Creating a hierarchical structure; 2. Creating pairwise comparison matrix for criteria and options; and 3. Performing the necessary calculations to determine the final weights and ranking of the options. The first step in the FTOPSIS method is to assign verbal variables to each of the problem criteria and then to acquire their equivalent fuzzy numbers [9]. After performing the necessary mathematical calculations, the next step is to determine the positive and negative ideal solutions and finally to obtain the closeness coefficient [10]. The best option should have the shortest distance from the positive ideal solution and largest distance from the negative ideal solution [11].

The rest of this paper is organized as follows: In Section 2, the literature review is presented, including some research about wind energy and prioritization of places for wind energy harnessing. In Section 3, the geographic description of Fars province in Iran is given. In Section 4, wind energy in the world and in Iran is discussed. Section 5 discusses the methodology of the paper. Statistical analyses and discussion are presented in Sections 6 and 7 respectively. Finally, the conclusion is drawn in Section 8.

2. Review of the literature

A good deal of research has been conducted on the use of renewable energy in the world and in Iran. Renewable energies include solar, wind, geothermal, biomass, and marine energy, all of which have attracted increasing attention in almost all countries, including Iran. In 1994, Iran became one of the countries that use wind energy to generate electricity [12]. Therefore, conducting research on the potential of renewable energies in different regions of Iran is essential. Some of the research and studies related to wind energy are mentioned and reviewed below.

The most important criterion to be considered in wind turbine installation is wind power, because persistent wind is very essential. Mohammadi and Mostafaeipour [13] have studied about the economic feasibility of electricity generation using wind turbines in the city of Aligoodarz situated in the west part of Iran. The wind energy potential and its characteristics were assessed through diurnal, monthly, and annual analysis using three-hourly measured wind speed data from 2005 to 2009 at 10 m elevation and the Weibull distribution. The analysis showed a nearly stable wind pattern in different hours and months of the year; therefore, this area was deemed suitable for wind energy harnessing. Then, the economic feasibility of six different wind turbines with rated powers ranging from 20–150 kW was evaluated. Finally, among all the turbines examined, the E-3120 wind turbine was identified as the most attractive option for installation. Mostafaeipour et al. [14] have investigated wind power potential of the city of Shahrbabak in the Kerman province of Iran using Weibull distribution and three-hourly wind speed data at 10 m height from 1997 to 2005. Numerical values of the dimensionless Weibull shape parameter (k) and Weibull scale parameter (c) were determined with a yearly mean value of 1.504 and 5.314 (m/s) respectively. With an average wind power density of 100W/m^2, the city is considered suitable for the employment of small turbines with 10 kW power.

Mohammdai et al. [15] have investigated the feasibility of harnessing wind power at three free-economic and industrial zones of Chabahar, Kish, and Salafchegan in Iran. Weibull distribution function and three-hourly long-term data of wind speed were used for analysing the wind potentials at different heights. It was found that Chabahar was not suitable for wind energy development, but Kish and Salafchegan—with yearly wind powers of 111.28 W/m^2 and 114.34 W/m^2 respectively—ranked in Class 2, which is considered marginal for wind power development.

Mostafaeipour et al. [3] have assessed wind energy potential for Zahedan city in southeast part of Iran. For the calculation of the wind power, density and energy are taken from the Weibull density function and five-year (2003–2007) wind speed data. Yearly mean Weibull parameters k and c were computed to be 1.155 and 3.401 (m/s) respectively. The finally obtained values for wind power and energy density are 89.148 W/m^2 and 781.252 kWh/m^2 respectively. Based on the economic evaluation and analysis of four wind turbines, it is recommended to install the 2.5kW model wind turbine, which is proved to be the most cost-efficient option.

In a research by Mirhosseini et al. [28], the Semnan province of Iran was statistically analysed to determine the potential of wind power generation. Extrapolation of the 10m data through the power law was used to determine the wind data at heights of 30 m and 40 m Damghan city was found to have the best potential for using wind energy in the province.

Mostafaeipour et al. [12] have statistically analysed the hourly measured wind speed data recorded between2007 and 2010 at 10 m, 30 m, and 40 m height to determine the potential of wind power in the Binalood region of Iran. For calculating wind power, energy and density are taken from Weibull distribution. The yearly values of k at 40 m elevation range from 2.165 to 2.211, with a mean value of 2.186, while c values are in the range of 7.683–8.016 with a mean value of 7.834. The yearly mean wind speed, mean wind power, and mean power density at 40 m height are calculated as 5.923 m/s, 305.514 W/m^2, and 2676.30 (kWh/m^2) respectively. The final results show that Binalood has great wind energy potential available, due to which a 600kW wind turbine is recommended.

Azadeh et al. [16] have ranked 25 cities in Iran for wind turbine installation and divided each city into five regions: the area at a distance of 5 km or less from the city centre is the first region, the area at a distance of 5–20 km is the second region, at a distance of 20–40 km is the third region, at a distance of 40–60 km is the fourth region, and area more than 60 km away from the city centre is the fifth region. For this purpose, a two-step DEA model was used. In the first step, the best region among the five regions of each city was determined. In this step, the criteria of population, distance to distribution net were the outputs and land cost was the input of DEA. In the second step, the 25 cities were compared with each other and the best city was identified. In this step, the criteria of wind speed and geology situation were the outputs and earthquake disaster was the input of the model. The results showed that Manjil is the best city for wind energy harnessing. The last-mentioned paper has two significant problems. First, it considers wind speed as output criterion even though steadiness and frequency of wind are more important than speed of. Second, it divides each city into five regions, though it is possible that some cities do not have all five regions. So, for solving the first problem, the current paper uses yearly wind power instead of wind speed.

3. Geographical Profile

Fars province is located in the southern and southwestern part of Iran, at E50°36'–E55°35' longitude and W27°03–W31°40' latitude. The area of this province is 122,000 km^2, which constitutes about 12.5 per cent of Iran's total area; it is the fourth largest province in the country [17]. Neighbours of Fars province are Yazd in the northwest, Kerman in the west, Esfahan in the north, Hormozgan in the south, and Bushehr in west. Figure 1 shows the map of Iran and the location of the province and its cities.

The Fars province has various climates. Cities in the northern and north-western parts of Fars have very cold winters and moderate summers because of mountains. Cities located in the central region of this province have Mediterranean climate, while cities located in the southern and southwestern regions have moderate winters and very hot summers [17,19].

In this research, we selected 13 different cities of the Fars province, including Izadkhast, Estahban, Eghlid, Shiraz, Fasa, Safashahr, Bavanat, Abadeh, Arsanjan, Kazerun, Neyriz, Sepidan, and Firuzabad to rank them in terms of their suitability for wind turbine installation. Table 1 shows the geographical profile of these cities.

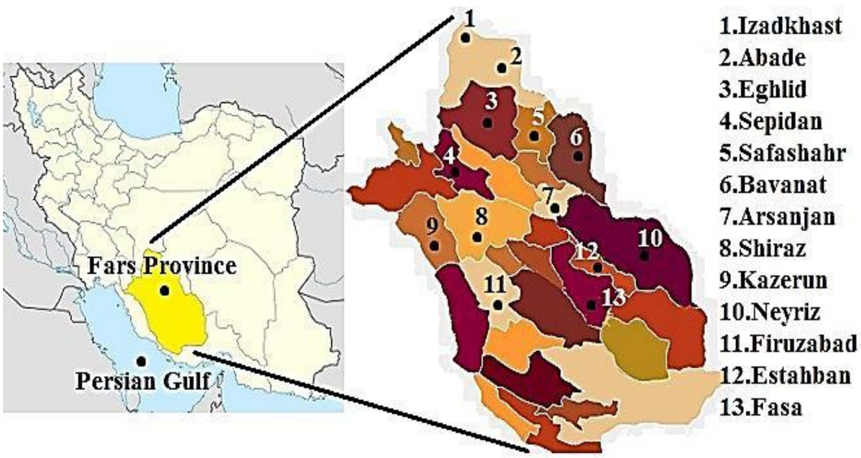


Fig.1. Map of Iran and cities of Fars province [18]

Table 1. Geographical profile of 13 cities in Fars province [20].

Row	City	Longitude	Latitude
1	Izadkhast	52°40'E	31°08'N
2	Estahban	54°03'E	29°12'N
3	Safashahr	53°11'E	30°36'N
4	Firuzabad	52°55'E	28°81'N
5	Eghlid	52°41'E	30°53'N
6	Neyriz	54°19'E	29°15'N
7	Sepidan	52°5'E	30°20'N
8	Arsanjan	53°32'E	29°92'N
9	Bavanat	53°27'E	30°28'N
10	Abadeh	52°40'E	31°08'N
11	Fasa	53°39'E	29°00'N
12	Kazerun	51°40'E	29°38'N
13	Shiraz	52°54'E	29°61'N

4. Wind energy

Nowadays, population growth and increasing demand for energy have encouraged many industrialized and developing countries to make more use these clean and economical sources of energy. Wind is a free source of energy, which—considering the excessive pollution of fossil energy and its diminishing sources—has been favourably viewed as an alternative solution for the last few decades; thus, the use of this type of energy has seen a growing trend like other renewable energies.

4.1. Wind energy in the world

According to the predictions of researchers and the International Energy Agency, the energy demands in the future will have a rapid and worryingly increasing trend. It is worth mentioning that from 1998 to 2013, the global demand for electricity increased by 30 per cent to 20,582 TWh [21, 22]. In recent years, the wind industry has grown in terms of turbine installation capacity; it has created about 300,000 new jobs and has reached an annual trade worth about forty billion dollars worldwide [23]. The share of wind power in the global electricity generation is expected to reach 8 per cent by 2018 and 12 per cent by 2020, which indicates the rapid movement of countries towards further utilization of this energy [24]. The importance and urgency of the problem of generating electricity through renewable energy sources has led to many comprehensive and broad research works on this issue, many of which have predicted the wind energy status in the next few years. It is predicted that by the end of 2020, the installed capacity will reach 2.1 Gigawatts. A number of American states are seeking to supply about 25 to 30 per cent of their electricity demand through renewable energy by the end of 2020. For China, this value is 10 per cent by the end of 2020 [25]. Wind energy supplies 20 per cent of energy demand in Denmark, 9 per cent in Spain, and 7 per cent in Germany [22]. Figure 2 shows the growing trend of using wind power in the world by the end of 2013 [26].

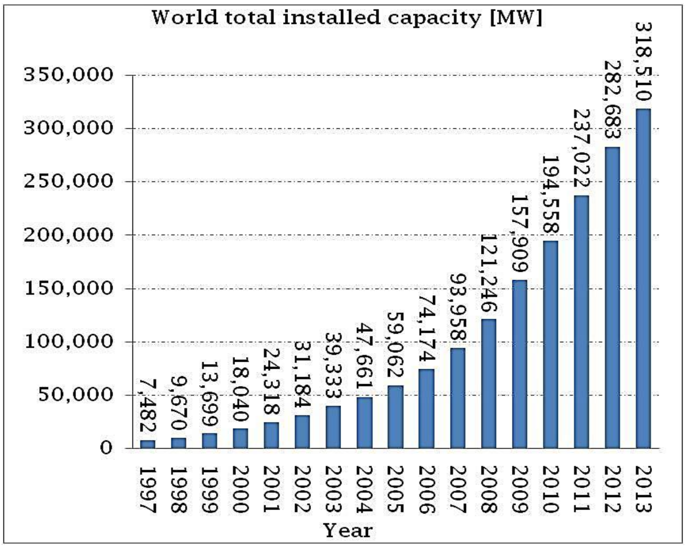


Fig. 2. The growing trend of using wind power in the world by the end of 2013 [26]

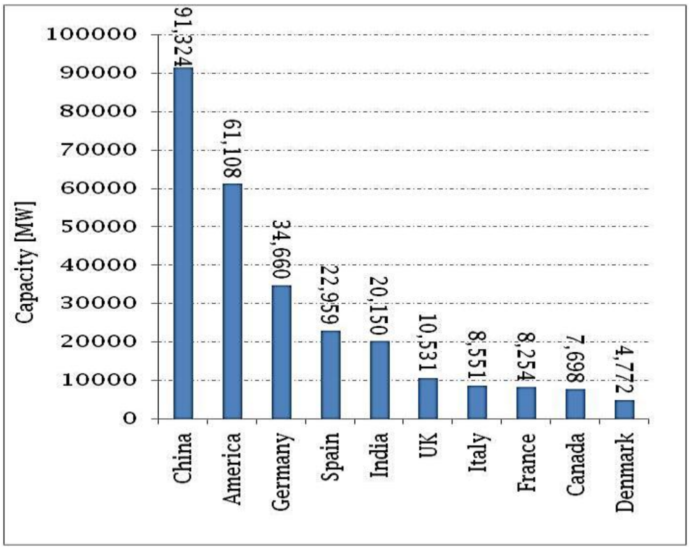


Fig. 3. The top 10 countries in terms of installed wind power capacity by the end of 2013 [26]

China, America, and Germany—with wind power capacity of 91,324, 61,108, and 34,660 megawatts respectively (by the end of 2013)—hold the top three ranks in this regard. Figure 3 lists the top 10 countries in terms of installed wind power capacity by the end of 2013 [26].

4.2. Wind energy in Iran

Due to the special geographical situation of Iran, its location in low-pressure area, and also strong-flowing air in the summer and winter in some locations, this country has very good wind energy potential in many zones. The country is influenced by two main winds [3]:

(1) Winds from the Atlantic Ocean, Mediterranean Sea, and central Asia in the winter.
(2) Winds from the Indian Ocean and the Atlantic Ocean in the summer.

A study by the Renewable Energy Organization of Iran (SUNA) illustrates that in 26 zones of the country—including 45 sites—the wind energy potential is estimated to be about 6,500 MW [27]. The amount of electricity power accessible from the wind energy in the whole country is estimated about 20,000 MW [3]. The first experience of Iran in installing wind turbines took place in 1994—two wind power plants of 500 kW were installed in cities of Manjil and Roodbar in Gilan province in the northern part of Iran [28]. Their annual production of wind power is more than 1.8 million kW; the average wind speed values in Roodbar and Manjil areas are 15 m/s and 13 m/s respectively [12]. Other locations of Iran that harness wind energy and have wind turbines are Binalood in Khorasan-E Razavi province with 43 turbines of 38,380 kW and Kahak in Qazvin province with eight turbines of 20,000kW. In all, Iran had nine wind farms at the end of 2013. Figure 4 shows development of wind turbine installation capacity in Iran from the beginning up to 2013 [26].

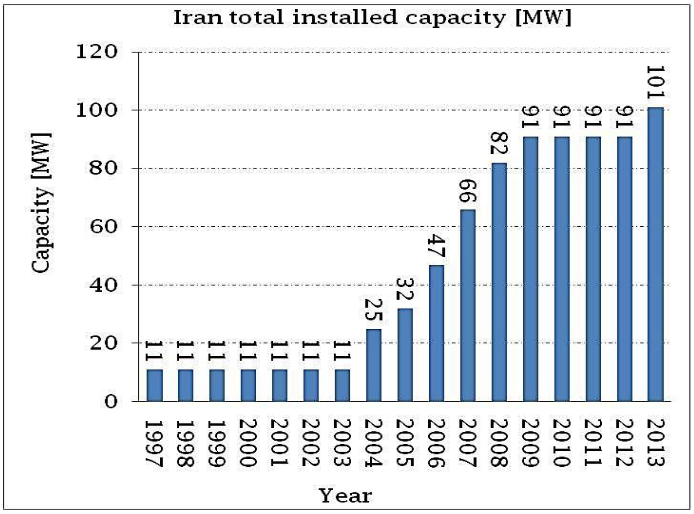


Fig. 4. Development of wind turbine installation capacity in Iran from the beginning up to 2013 [26]

Many research works and studies about wind energy have been done in some provinces of Iran, such as Lorestan [13], Kerman [14], Sistan and Baluchestan, Qom [15], Semnan [28], and Khorasan-E Razavi [12]. In the present study, wind energy potential of 13 cities of the Fars province are analysed and five more criteria are investigated for ranking the cities in terms of suitability of development of wind turbine installation in Iran. Wind speed data for this study were obtained from the Iranian Meteorological Organization. The main purpose of this research work is to assess wind energy potential for 13 cities and then rank them.

5. Methodology

In this study, the DEA method and a set of economic, technical, and geological factors are used to prioritize and rank 13 cities of the Fars province in terms of their suitability for the construction of a wind farm. AHP and FTOPSIS are also used to assess the validity of the obtained results.

5.1. DEA method

There are various definitions of efficiency in terms of attempting to decrease inputs or increase outputs [6]. In a simple definition, it can be stated that efficiency is the ratio of outputs to inputs in a system. Each system usually has a number of inputs and outputs—the ratio of the sum of weighted outputs to the sum of weighted inputs should be used to calculate efficiency [29]. The DEA model also uses this ratio to calculate the efficiency of each DMU.

The original idea of DEA was first presented by Farrell in 1957 [30] and the model known as CCR was presented later by Charnes et al. [31]. This is an effective tool to measure the relative efficiency of DMUs with regard to relevant criteria; these criteria are divided into two groups—inputs and outputs. This model is one of the most important nonparametric methods and is based on linear programming method, and is designed with the aim of measuring the efficiency of DMUs that do similar tasks. Nonparametric methods are based on a series of mathematical optimization that are used to calculate the relative efficiency of DMUs. The efficiency values obtained from this type of methods result from comparing DMUs with one another; thus, a change in the number of DMUs can change their efficiency [32, 33]. In the last two decades, the DEA method has found many applications in different areas such as education [31], health [34], and environmental issues [35].

An important application of this method is the prioritization and ranking of DMUs that do similar tasks, which is done by comparing the efficiency value obtained for each DMU. In this study, the relative efficiency values of 13 cities in Fars province will be compared by considering three inputs and three outputs, and then these cities (DMUs) will be ranked in terms of their potential and suitability for the construction of wind farms.

Experiences have shown that when the total number of DMUs is close to the total number of inputs and outputs, most DMUs will be identified as efficient. This result will be unrealistic and such ranking will be unreliable. It has been shown that the number of DMUs and criteria must comply with either Eq.(1) or Eq.(2) [7, 36].

Number of DMUs ≤3 × (number of inputs + number of outputs) (1)

Number of DMUs≤2 × (number of inputs) ×(number of outputs) (2)

There are 13 DMUs (cities) and six criteria in this study; neither of these two equations applies on these values. To resolve this problem, the dual form of DEA method is formulated as follows [7, 29]:

$$\begin{aligned}
&\text{Minimize } Z_p = \theta\\
&\text{Subject to: } \textstyle\sum_{j=1}^{n} l_j y_{rj} \geq y_{rp}\\
&\theta x_{ip} - \sum_{j=1}^{n} l_j x_{ij} \geq 0\\
&l_j \geq 0\\
&\quad r = 1, 2, \ldots, S\\
&\quad i = 1, 2, \ldots, K\\
&\quad j = 1, 2, \ldots, n
\end{aligned} \tag{3}$$

In this model, Z_p is the efficiency of unit p, θ is the variable that should be minimized, Y_{rj} is the r^{th} output (r = 1 to s) of j^{th} DMU(j=1 to n), X_{ij} is the i^{th} input (i = 1 to k) of j^{th} DMU, and $l_j s$ are the coefficients that should be calculated for constraints. In the cases where this model yields several efficient DMUs (several DMUs with the score of 1), comparing these efficient DMUs will be impossible. The Andersen–Petersen (AP) model can be used to tackle this problem. In the AP model, the efficiency values of efficient DMUs are allowed to be greater than 1. This is done by eliminating the p^{th} constraint in the initial model or eliminating the p^{th} variable (weight) from the constraints of dual model in each cycle of model. This model can be used for both the basic and the dual form of DEA. Since we have used the dual form of the DEA for initial prioritization, we should also use the dual form of the AP model to rank the efficient DMUs. The following minor changes will modify the dual model mentioned above by AP method [32, 36]:

$$\begin{aligned}
&\text{Minimize } Z_p = \theta\\
&\text{Subject to: } \textstyle\sum_{\substack{j=1\\ j\neq p}}^{n} l_j y_{rj} \geq y_{rp}\\
&\theta x_{ip} - \sum_{\substack{j=1\\ j\neq p}}^{n} l_j x_{ij} \geq 0\\
&l_j \geq 0\\
&\quad r = 1, 2, \ldots, S\\
&\quad i = 1, 2, \ldots, K\\
&\quad j = 1, 2, \ldots, n
\end{aligned} \tag{4}$$

The only difference between this model and the previous model is that the p^{th} term will be removed from the constraints in each cycle of this model.

5.2. AHP method

When the discussed issue has several competing options (DMUs) and decision criteria, the Analytical Hierarchy Process (AHP) can be used to rank these options. This method of decision-making is based on pairwise comparisons.

A separate matrix (as shown in Table 2) will be formed for each criterion. In this matrix, options will be compared two by two with each other in respect to the evaluated criterion [37].

Table 2. Pairwise comparisons matrix between alternatives for each criterion.

	1st option	2nd option	...	Last option
1st option	1	Amount of criterion of 1st option divided to Amount of criterion of 2nd option	...	Amount of criterion of 1st option divided to Amount of criterion of last option
2nd option	Amount of criterion of 2nd option divided to Amount of criterion of 1st option	1	...	Amount of criterion of 2nd option divided to Amount of criterion of last option
⋮	...	...	1	⋮
Last option	Amount of criterion of last option divided to Amount of criterion of 1st option	Amount of criterion of last option divided to Amount of criterion of 2nd option	...	1

Once the matrix is formed separately for each criterion, it should be normalized. To do this, first the sum of each column of the matrix will be calculated, and then each member of the matrix will be divided by this value. The resulting matrix will be the normalized pairwise comparison matrix for the options with respect to one criterion [37, 38]. After that, the values of each row of the normalized pairwise comparison matrix will be averaged and the resulting values will be the relative weight of that criterion for the options [39]. This process should be repeated for each criterion. Equation 5 shows the matrix, where n is number of criteria and m the number of options.

$$\begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix} \tag{5}$$

The most important step in this method is the formation of a pairwise comparison matrix for different criteria with respect to each other. So, the pairwise comparisons between the problem criteria will be done through verbal preferential values, which will indicate the preference or priority of the two decision elements [8]. This step will be performed through a survey to collect the opinions of experts on the subject. Then, the verbal variables will be converted to quantitative values using a nine-item Saaty scale [38] (Table 3); finally the obtained values will be averaged.

Table 4 shows the pairwise comparison matrix for different criteria with respect to each other after conducting the survey and averaging the results.

Table 3. Saaty's nine-point scale [38, 39]

Explanation	Definition	Intensity of importance
Two factors contribute equally to the objective	Equal importance	1
Experience and judgment slightly favour one over the other	Somewhat more important	3
Experience and judgment strongly favour one over the other	Much more important	5
Experience and judgment very strongly favour one over the other	Very much more important	7
The evidence favoring one over the other is of the highest possible validity	Absolutely more important	9
When compromise is needed	Intermediate values	2, 4, 6, 8

Table 4. Pairwise comparison matrix of criteria

Criteria	1st criterion	2nd criterion	...	Last criterion
1st criterion	1	Preference value of 1st criterion toward Preference value of 2nd criterion	...	Preference value of 1st criterion toward Preference value of last criterion
2nd criterion	Preference value of 2nd criterion toward Preference value of 1st criterion	1	...	Preference value of 2nd criterion toward Preference value of last criterion
⋮	...	...	1	⋮
Last criterion	Preference value of last criterion toward Preference value of 1st criterion	Preference value of last criterion toward Preference value of 2nd criterion	...	1

Once the aforementioned matrix is formed, it should also be normalized; this normalization has a process similar to that used in the previous pairwise comparison matrix. The resulting matrix will be the pairwise comparison matrix for the criteria [37, 38]. After that, the values of each row of the normalized pairwise comparison matrix will be averaged and resulting values will be the relative weight of that criterion [39]. The resulting matrix will be in the form of:

$$[w_1, w_2, \dots, w_n] \,. \tag{6}$$

In the final step, the relative weight of each criterion should be multiplied by the relative weight of a particular option and the sum of the products of these values should be calculated to obtain the final weight of that option [37] (as shown in Eq.(7)). This process should be repeated for each option to obtain their final weight in order to be able to rank these options:

$$\text{Final weight of } i^{th} \text{ option} = (a_{i1}\times w_1)+ \dots + (a_{in}\times w_n). \tag{7}$$

5.3. FTOPSIS method

TOPSIS is a practical and useful technique for the ranking and selection of a number of externally determined alternatives through distance measures [40]. The basic concept of this method is that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution [9]. The positive ideal solution is a solution that simultaneously maximizes the benefit criteria and minimizes cost criteria, whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria. The TOPSIS method assumes that each criterion has a tendency to monotonically increase or decrease the utility. Therefore, it is easy to define the positive and negative solutions.

Fuzzy logic is a powerful mathematical tool for handling the existing uncertainty in decision-making. Overcoming the uncertainty of qualitative data, the ranking process may be accomplished by the fuzzy TOPSIS (FTOPSIS) method. The mathematical concept of FTOPSIS has been proposed by Chen [9].

In this method, a decision matrix will be created with respect to the number of criteria, number of options, and evaluation of all options for different criteria. This matrix will be in the form [9–11] given by:

$$\widetilde{D}=\begin{bmatrix} \tilde{x}_{11} & \cdots & \tilde{x}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \cdots & \tilde{x}_{mn} \end{bmatrix}, \tag{8}$$

Here, m is the number of options and n is the number of criteria.

In assessing the options for the different criteria, all values are quantitative, so the decision matrix should be normalized in the form of numbers between 0 and 10.

X_{ij} is a triangular fuzzy number, so the performance of options i (i=1,2,…,m) in criteria j (j=1,2,…,m) will be ij=(aij,bij,cij) [10,41,42]. In the next step, the important factor of different decision-making criteria will be defined in the form of [41]:

$$\widetilde{w}=[\widetilde{w}_1,\widetilde{w}_2,\dots,\widetilde{w}_n]. \tag{9}$$

The fuzzy numbers are triangular, so the weight of each component w_j will be defined as$\widetilde{w}$j= (w_{1j}, w_{2j}, w_{3j}). Assessment of different criteria are qualitative and in the form a verbal variable, so experts' opinions should be used. The verbal variables of all decision-makers should then be converted to their equivalent fuzzy numbers (a_i, b_i, c_i) with accordance with Table 5. The final weight of each criterion, which is a triangular fuzzy number, will be obtained by assigning the minimum of a_i's, the average of b_i's, and the maximum of c_i's to first, second, and third parameters of this fuzzy number respectively [9].

Table 5. Verbal variables and equivalent of these with triangle fuzzy number [42].

Fuzzy triangle number	Verbal variables for evaluation options	Fuzzy triangle number	Verbal variables of criteria
(0, 0, 0.1)	Very low momentous	(0, 0, 1)	Very low
(0, 0.1, 0.3)	Low momentous	(0, 1, 3)	Low
(0.1, 0.3, 0.3)	Some deal low momentous	(1, 3, 5)	Almost low
(0.3, 0.5, 0.7)	Indifferent	(3, 5, 7)	Medium
(0.5, 0.7, 0.9)	Some deal momentous	(5, 7, 9)	Almost high
(0.7, 0.9, 1)	Momentous	(7, 9, 10)	High
(0.9, 0.9, 1)	Very momentous	(9, 10, 10)	Very high

To acquire scale-less values, instead of performing complex calculations, the linear scaling will be used to convert the scale of different criteria to a comparable scale. Given that the fuzzy numbers are triangular, elements of scale-less decision matrix for the positive and negative criteria can be obtained from [9,11]:

$$\tilde{r}_{ij}=\left(\frac{a_{ij}}{c_j^*},\frac{b_{ij}}{c_j^*},\frac{c_{ij}}{c_j^*}\right) \tag{10}$$

and

$$\tilde{r}_{ij}=\left(\frac{a_j^-}{c_{ij}},\frac{a_j^-}{b_{ij}},\frac{a_j^-}{a_{ij}}\right), \tag{11}$$

respectively. In the above equations, $c^*_j=\max c_{ij}$ and $a^-_j=\min a_{ij}$, so scale-less fuzzy decision matrix can be obtained from [10, 41, 42]:

$$\tilde{R}=\begin{bmatrix} \widetilde{r_{11}} & \cdots & \widetilde{r_{1n}} \\ \vdots & \ddots & \vdots \\ \widetilde{r_{m1}} & \cdots & \widetilde{r_{mn}} \end{bmatrix} \tag{12}$$

In the next step, given the weights of different criteria, the weighted fuzzy decision matrix can be obtained in the form of Eq.(13) by multiplying the importance factor of each criterion by the scale-less fuzzy matrix given by ([42]):

$$\tilde{v}=\begin{bmatrix} \tilde{v}_{11} & \cdots & \tilde{v}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{v}_{m1} & \cdots & \tilde{v}_{mn} \end{bmatrix}. \tag{13}$$

Thus, the weighted fuzzy decision matrix will be in the form of [11].

$$\tilde{v}_{ij}=\tilde{r}_{ij}\times\tilde{w}_j \tag{14}$$

Here, $\widetilde{w_j}$ represent the importance factor of criterion c_j.

In the next step, we must obtain the ideal and anti-ideal fuzzy solutions, which are defined as [41, 42].

$$A^*=\{\widetilde{v_1^*},\widetilde{v_2^*},\widetilde{v_3^*}\} \tag{15}$$

and

$$A^-=\{\widetilde{v_1^-},\widetilde{v_2^-},\widetilde{v_3^-}\}, \tag{16}$$

respectively; where $\tilde{v}_i^*$ is the best value of criterion i and $\tilde{v}_i^-$ is the worst value of criterion i among all options. Then, the distance between the two triangular fuzzy numbers can be obtained from [11, 43].

$$d(\widetilde{m}_1,\widetilde{m}_2)=\sqrt[2]{\frac{1}{3}[(a_1-a_2)^2+(b_1-b_2)^2+(c_1-c_2)^2]}. \tag{17}$$

In the above equation, $\widetilde{m_1}=(a_1,b_1,c_1)$ and $\widetilde{m_2}=(a_2,b_2,c_2)$.Distance of each option from the ideal and anti-ideal fuzzy solutions and the closeness coefficient can be obtained from Eqs. (18), (19) and (20) respectively [9]. Options that have a shorter distance from the ideal fuzzy solution and a longer distance from the anti-ideal fuzzy solution will have a higher ranking:

$$s_i^*=\sum_{j=1}^{n} d(\widetilde{v_{ij}},\widetilde{v_j^*}) \quad , \quad i=1,2,\dots,m \tag{18}$$

$$s_i^-=\sum_{j=1}^{n} d(\widetilde{v_{ij}},\widetilde{v_j^-}), \quad i=1,2,\dots,m \tag{19}$$

and

$$c_i=\frac{s_i^-}{s_i^*+s_i^-} \tag{20}$$

In the final step of the FTOPSIS model, options will be ranked in respect to their closeness coefficient; this means that options with higher closeness coefficient will have a higher ranking.

6. Analysis

To analyse the data, first the values representing each effective criterion must be calculated. To calculate the most important criterion, i.e. wind power, long-term data related to time period of 2004–2013 obtained from the Iran Meteorological Organization database will be used. Since this data is related to the height of 10 m above the ground, we should use extrapolation to calculate the data pertaining to the height of 40 m. To obtain a value that can represent the topographical conditions, the area of suitable sites within a circle with a radius of 7.5 km will be calculated. To calculate the distance from the distribution grid, first the sites that are suitable in terms of topography will be selected and then the average distance of these sites from the centre of the city will be calculated. To estimate the probability of natural disasters, the probability of floods, earthquakes, and dust storms will be calculated. The data gathered from the Statistical Centre of Iran will be used for the population criterion, and the real estate experts' opinions will be used for land price criterion. These six criteria and three sub criteria will be calculated in the next sections.

6.1. Effective criteria

The wind farm should be built in a suitable location that can lead to the maximization of generated electricity and minimization of construction costs. Various economic, technical, and topographical criteria should be determined to locate this most suitable site, of which the available wind power is the most important criterion. This means that a region that has higher wind energy is more suitable for the installation of wind turbine. Another criterion is the distance of the wind farm from the distribution grid—a lower distance is more preferable. Another criterion is the topography of the area—lower degrees of tree cover, mountains, hills, and tall buildings are more suitable for the construction of the wind farm. This is because buildings and mountains reduce the wind speed and tree cover increases the risk of damage to the turbines. Economic criterion is also considered for site selection—the sites that have a lower land price are more preferable. Another criterion that should be taken into account is the probability of natural disasters such as floods, earthquakes, and dust storms, which must be minimum, because they impose the risk of damaging or even destroying wind turbines. Another measure that can have an important role in the ranking of each region is its population; a higher population in an area indicates that it is more preferable for the construction of wind farm [3–5].

6.1.1. Wind power

The first and foremost condition that a candidate site for the construction of a wind farm must satisfy is the high degree of continuous and persistent windiness. Another important issue is the statistical distribution of wind speed; suitable wind speed alone is not enough to produce wind energy—its frequency and duration is also important. Wind energy also depends on air pressure and temperature as well as wind speed. Therefore, in this study, we try to calculate the wind power density, because it is the best criterion to assess the wind resource in an area. In fact, this criterion shows how much wind energy in an area can be converted into electricity.

Long-term meteorological data [14] and some statistical calculations must be used to calculate the wind power density of a region. An important point to be considered is that the wind speed in the four warm months of June, July, August, and September is more important than the other months of the year, because the data related to electric energy consumption in all studied cities in a five-year period (2009 to 2013) show that the amount of electricity consumed in these four months is 50 per cent higher than that in the other months of the year [44], mainly due to the increased use of air conditioners. Therefore, to bring the study results closer to reality, in the course of calculating the annual mean wind power for cities, we apply a weight coefficient of 1.5 on the wind speeds related to these four months to emphasize their higher importance. In this study, three-hourly wind speed data, temperature, and air pressure for a period of 10 years (2004–2013) were collected from the national meteorological organization, and then Eq.(21) was used to extrapolate these data for the height of 40 m [13]:

$$V_2 = V_1(\frac{h_2}{h_1})^{\alpha} \tag{21}$$

Wind power density in each area can be calculated by [13–15]

$$\frac{P}{A} = \int_0^{\infty} \frac{1}{2}\rho v^3 f(v) dv = \frac{1}{2}\Gamma \rho c^3 \left(1 + \frac{3}{k}\right). \tag{22}$$

Two parameters of ρ(air density) and Γ(gamma) can be calculated by [14]

$$\rho = \frac{\overline{P}}{R_d \overline{T}} \tag{23}$$

$$\Gamma\,(x) = \int_0^{\infty} e^{-u} u^{x-1} du \tag{24}$$

respectively. In Eq.(22), two parameters of c and k are scale factor and shape factor, which can be calculated by [28]

$$c = \frac{v}{\Gamma * (1 + \frac{1}{k})} \tag{25}$$

$$k = 0.83 v^{0.5} \tag{26}$$

respectively. Ultimately, the mean wind power for each of the cities was calculated by Excel software, the results of which are presented in Table 6.

6.1.2. Topographical conditions

Wind data collected from the meteorological organization is only valid within a radius of 7.5 km, centred at the weather station [4]; therefore, suitable areas for each city should be selected within this valid area. Urban regions, residential and industrial areas, and areas with tree cover should also be removed. The area of suitable regions for the

Table 6. Average of 10-year wind power values of the 13 cities

City	Wind power (W/m^2)
Izadkhast	166.64
Estahban	84.00
Safashahr	126.63
Firuzabad	60.40
Eghlid	74.72
Neyriz	56.06
Sepidan	65.26
Arsanjan	126.23
Bavanat	130.60
Abadeh	63.24
Fasa	27.86
Kazerun	45.64
Shiraz	26.40

construction of wind farm was calculated with the help of experts on this subject. These regions and the area calculated for each city are presented in Table 7. In the best topographical conditions, i.e. an area without any tree cover, buildings, or mountains and hills, the maximum value in Table 7 can be the area of a circle with a radius of 7.5 km, i.e. 176.7 sq. km. Among all the cities investigated in the research, the city of Eghlid has the most appropriate places with 171 km2, while the worst city is Shiraz with 117 km2.

6.1.3. Distance from power distribution grid

Table 8 shows the average distance of topographically suitable locations (at least 20 sites for each city) from 20kV substations within each city. For each city, first the topographically suitable locations are selected and then the average distances of these locations from the centre of the city are considered as the values representing the criterion of distance from power distribution grid.

Table 7. Suitable topographical area

City	Topographic situation (km^2)
Izadkhast	165
Estahban	155
Safashahr	168
Firuzabad	142
Eghlid	171
Neyriz	159
Sepidan	112
Arsanjan	132
Bavanat	141
Abadeh	165
Fasa	147
Kazerun	137
Shiraz	117

Table 8. Average of distances to distribution net.

City	Distance to distribution net (km)
Izadkhast	6.61
Estahban	6.73
Safashahr	6.77
Firuzabad	6.10
Eghlid	6.83
Neyriz	6.85
Sepidan	4.35
Arsanjan	5.17
Bavanat	5.22
Abadeh	6.52
Fasa	6.53
Kazerun	4.95
Shiraz	4.40

6.1.4. Land price

Regions suitable for wind farms are located outside residential areas; therefore, the average price of agricultural land is considered for this criterion. These values are presented in Table 9.

6.1.5. Natural Disasters

The probability of three types of natural disasters—flood, earthquake, and dust storm—are considered for this criterion, because they impose the risk of damaging or even destroying wind turbines. Wind farm should be constructed in a location that has the minimum probability of such events. The number of recorded floods at the end of 2013 for a period of about 62 years is considered for calculating the flood sub-criteria (more data are not available). Poisson distribution was used to calculate the probability of at least one flood in the 25-year lifespan of a turbine [5]. Table 10 shows the flood statistics for each city and the calculations performed to obtain the probability of flooding.

According to the statistics related to earthquakes, the number of recorded earthquakes in different cities of the Fars province belongs to a 100-year period. In this case, there was no record of destructive earthquakes that can damage wind turbines (8

Table 9. Land cost

City	Land cost (Rial/m^2)
Izadkhast	650000
Estahban	650000
Safashahr	1100000
Firuzabad	1900000
Eghlid	950000
Neyriz	1750000
Sepidan	1050000
Arsanjan	700000
Bavanat	800000
Abadeh	1000000
Fasa	900000
Kazerun	1300000
Shiraz	4500000

Table 10. Number of floods, Landa Poisson, and Poisson distribution

City	Number of floods (for 62 years)	Landa Poisoon (for 25 years)	Poisson distribution of floods
Izadkhast	5	2.016	0.816
Estahban	6	2.419	0.911
Safashahr	5	2.016	0.867
Firuzabad	7	2.823	0.941
Eghlid	5	2.016	0.867
Neyriz	6	2.419	0.911
Sepidan	6	2.419	0.911
Arsanjan	3	1.210	0.702
Bavanat	2	0.806	0.554
Abadeh	5	2.016	0.867
Fasa	4	1.613	0.801
Kazerun	4	1.613	0.801
Shiraz	4	1.613	0.801

or higher on the Richter scale [5]) in any of these areas, so the probability of destructive earthquake was considered zero for all these cities.

The number of events related to dust storms category is too high for Poisson distribution to be used. In this case, given the high number of trials (number of studied days), we used binomial distribution with normal approximation. This approximation involves calculating the probability of success (p) and the number of trials (n) for binomial distribution, and then calculating the mean (μ) and standard deviation (σ) of normal distribution by Eqs. (27) and (28) and ultimately calculating the probability of at least one event by normal distribution using

$$\mu = np \tag{27}$$

$$\sigma^2 = np(1-p) \tag{28}$$

Here, n is the number of days in the normal lifespan of a turbine (25 years), i.e. 9131 days. Then, the probability of at least one dust storm in a period of 25 years must be calculated. Table 11 shows the statistics of this event for each city and calculations of variables p (the probability of dust storm in a day in binomial distribution), and n (the number of studied days or number of trials in binomial distribution), normal μ and σ, and ultimately the probability of at least one such event.

Table 11. Binomial distribution parameters and probability of dust storm occurrence

City	p	n=9131 (25×365+6)	μ=np	σ	Probability of at least once dust storm and normal distribution
Izadkhast	0.08	9131	750.49	26.245	0.86
Estahban	0.11	9131	1000.66	29.85	0.87
Safashahr	0.07	9131	675.44	25	0.86
Firuzabad	0.06	9131	525.35	22.25	0.86
Eghlid	0.14	9131	1250.82	32.85	0.88
Neyriz	0.15	9131	1325.87	33.66	0.88
Sepidan	0.03	9131	300.20	17.04	0.85
Arsanjan	0.003	9131	25.02	4.99	0.84
Bavanat	0.07	9131	625.41	24.14	0.86
Abadeh	0.11	9131	1000.66	29.85	0.87
Fasa	0.09	9131	825.54	27.4	0.86
Kazerun	0.06	9131	525.35	22.25	0.86
Shiraz	0.21	9131	1951.28	39.17	0.90

The final step is to combine the probabilities of these three natural disasters, so that we can obtain a value that can represent this criterion in the model. Thus, according to expert opinion, weight coefficients of 0.25, 0.25, and 0.5 were considered for flood, earthquake, and dust storm respectively, and the results are presented in Table 12.

6.1.6. Population

Another important criterion for the location of wind farm is population. It is obvious that this factor should be considered as an output of the DEA model, because higher population means that the area is more preferable for the installation of wind turbine. Table 13 shows the population of the cities.

7. Discussion

Given the high number of constraints, LINDO software is used to solve the linear programming problem. The result obtained from the model shows that five cities—Firouzabad, Neyriz, Arsanjan, Sepidan, and

Table 12. Probability of occurrence of natural disasters once in 25 years

City	Earthquake	Flood	Dust storm	Probability of natural disaster (at least one time in 25 years)
Izadkhast	0	0.816	0.86	0.647
Estahban	0	0.911	0.87	0.663
Safashahr	0	0.867	0.86	0.647
Firuzabad	0	0.941	0.86	0.665
Eghlid	0	0.867	0.88	0.657
Neyriz	0	0.911	0.88	0.668
Sepidan	0	0.911	0.85	0.653
Arsanjan	0	0.702	0.84	0.596
Bavanat	0	0.554	0.86	0.569
Abadeh	0	0.867	0.87	0.652
Fasa	0	0.801	0.86	0.630
Kazerun	0	0.801	0.86	0.630
Shiraz	0	0.801	0.90	0.650

Table 13. Population of the cities [18]

City	Population (person)
Izadkhast	27800
Estahban	66172
Safashahr	50252
Firuzabad	119721
Eghlid	98188
Neyriz	113750
Sepidan	89398
Arsanjan	41476
Bavanat	48416
Abadeh	93975
Fasa	200000
Kazerun	320792
Shiraz	1700678

Abade—have attained efficiency scores of less than 1, so they can be easily ranked. But eight cities—Izadkhast, Estahban, Safashahr, Eghlid, Bavanat, Fasa, Kazeroon, and Shiraz—have attained the maximum efficiency score (1); therefore, they cannot be ranked at this stage. The AP dual model is used to revaluate the ranking of these eight cities. In this model, the efficiency score cap is removed by eliminating the p^{th} variables. The result of the AP model shows that Shiraz—with a score of 5.9641—is in the first place. The results for the other cities are presented in Table 14. After using AP model on efficient DMUs (cities), the final rankings of the cities in terms of their suitability for the installation of wind turbines to harness wind energy are as follows:

In this study, two methods—AHP and FTOPSIS—are used to assess the validity of results obtained from the DEA model.

7.1 Validating by AHP model

To assess the validity using the AHP model, the procedures listed in Section 5.2 are followed step by step. The mean values of results obtained from the survey of experts' opinions on the related subjects are used to assign appropriate weights to the criteria with respect to their importance; the values of criteria in comparison with one another (comparison matrix) are presented in Table 15. The results of this model show that the city of Izadkhast—with a final weight of 0.1143—is in the first place. This city is ranked first because its wind power is higher than all other cities and the wind power criterion has much more influence compared to the other criteria. Similarly, Fasa was ranked 13th because of its low wind power. Table 16 shows the final weights of the options after AHP model analysis.

Table 14. Efficiency scores of DEA and AP and ranks of the 13 cities

City	Efficiency scores of DEA	Efficiency scores of AP	Rank
Izadkhast	1	1.4217	2
Estahban	1	1.0523	5
Safashahr	1	1.009	8
Firuzabad	0.8687	-	13
Eghlid	1	1.0251	7
Neyriz	0.9220	-	12
Sepidan	0.9399	-	11
Arsanjan	0.9747	-	10
Bavanat	1	1.0609	3
Abadeh	0.9887	-	9
Fasa	1	1.0553	4
Kazerun	1	1.0485	6
Shiraz	1	5.9641	1

Table 15. Pairwise comparison matrix of criteria

	Natural disaster	Land cost	Distance	Topographic situation	Wind power	Population
Natural disaster	1	6	5	3	0.16	7
Land cost	0.16	1	2	0.2	0.14	4
Distance	0.2	0.5	1	0.16	0.125	2
Topographic situation	0.33	5	6	1	0.14	5
Wind power	6	7	8	7	1	7
Population	0.14	0.25	0.5	0.2	0.14	1

7.2 Validating by FTOPSIS model

In the first step of this method, the decision matrix for options with respect to each of the six criteria is formed, considering that the calculated quantitative values are not normalized (between 0 and 10); the normalized values of this matrix are shown in Table 17. For the population criterion in Izadkhast, for example, the triangular fuzzy number is (0.139,0.139,0.139).
In the next step, electronic questionnaires completed by five qualified experts are used to calculate the fuzzy weights of the criteria. For population criterion for example, the verbal variables assigned by experts are first converted to triangular fuzzy numbers with the help of Table 5; in this case, the five fuzzy numbers are (0.5,0.7,0.9), (0.7,0.9,1), (0.3,0.5,0.7), (0.7,0.9,1) ,(0.5,0.7,0.9). As a result, the fuzzy number related to final weight of population criterion is calculated as follows:

a_1= min{0.5,0.5,0.7,0.3,0.7}=0.3

a_2=average of {0.7,0.7,0.9,0.5,0.9}=0.74

a_3=max{0.9,0.9,1,0.7,1}=1

Table 16. Final weight of the cities after AHP analysis

City	Final weight	Rank
Izadkhast	0.1143	1
Estahban	0.0756	6
Safashahr	0.0977	2
Firuzabad	0.0688	8
Eghlid	0.0740	7
Neyriz	0.0680	9
Sepidan	0.0636	11
Arsanjan	0.0877	4
Bavanat	0.0932	3
Abadeh	0.0673	10
Fasa	0.0503	13
Kazerun	0.0598	12
Shiraz	0.0768	5

Table 17. Normalized decision matrix

	Positive criteria			Negative criteria		
City	Population	Wind power	Topographic situation	Distance	Land cost	Natural disaster
Izadkhast	0.139	1.6664	1.65	6.61	0.65	0.647
Estahban	0.33086	0.84	1.55	6.73	0.65	0.663
Safashahr	0.25126	1.2663	1.68	6.77	1.1	0.647
Firuzabad	0.598605	0.604	1.42	6.1	1.9	0.665
Eghlid	0.49094	0.7472	1.71	6.83	0.95	0.657
Neyriz	0.56875	0.5606	1.59	6.85	1.75	0.668
Sepidan	0.44699	0.6526	1.12	4.35	1.05	0.653
Arsanjan	0.20738	1.2623	1.32	5.17	0.7	0.596
Bavanat	0.24208	1.306	1.41	5.22	0.8	0.569
Abadeh	0.469875	0.6324	1.65	6.52	1	0.652
Fasa	1	0.2786	1.47	6.53	0.9	0.63
Kazerun	1.60396	0.4564	1.37	4.95	1.3	0.63
Shiraz	8.50339	0.264	1.17	4.4	4.5	0.65

In the next step, the decision matrix should be made scale-less using Eqs. (10) and (11). Then, according to Section 5.3, the weighted fuzzy decision matrix, ideal fuzzy solution, and anti-ideal fuzzy solution should be calculated. These values are presented in Table 19.

The distance from ideal fuzzy solution (FPIS) and anti-ideal fuzzy solution (FNIS) should then be calculated by Eq.(17). After that, the final step is to calculate the closeness coefficient (Eq.(20)), which is in fact the final weight. The results of these calculations are shown in Table 20. Cities that have a shorter distance from the ideal fuzzy solution and a longer distance from the anti-ideal fuzzy solution will have a higher ranking. Therefore, the city of Izadkhast is in first place because it has the shortest distance from the ideal fuzzy solution (2.6567) and the longest distance from the anti-ideal fuzzy solution (2.5831). Similarly, the city of Firouzabad is in last place because it has the longest distance from the ideal fuzzy solution (3.6105) and the shortest distance from the anti-ideal fuzzy solution (1.4324).

Table 18. Weights of criteria

Criteria	Triangle fuzzy number
Population	(0.3, 0.74, 1)
Wind power	(0.9, 1 , 1)
Topographic situation	(0.3, 0.7, 1)
Distance	(0, 0.26, 0.5)
Land cost	(0.3, 0.7, 1)
Natural disaster	(0.5, 0.86, 1)

Table 19. FPIS and FNIS

Criteria	FPIS	FNIS
Population	(1,1,1)	(0.005,0.005,0.005)
Wind power	(1,1,1)	(0.132,0.132,0.132)
Topographic situation	(1,1,1)	(0.196,0.196,0.196)
Distance	(0.5,0.5,0.5)	(0,0,0)
Land cost	(1,1,1)	(0.043,0.043,0.043)
Natural disaster	(1,1,1)	(0.426,0.426,0.426)

Table 20. Distances to FPIS and FNIS and closeness coefficient and final rank

City	Distance to FPIS	Distance to FNIS	CC	Rank
Izadkhast	2.6567	2.5831	0.492976917	1
Estahban	3.1330	2.0577	0.396422008	5
Safashahr	3.0439	2.0712	0.404912886	4
Firuzabad	3.6105	1.4324	0.284036302	13
Eghlid	3.2757	1.8587	0.362007487	6
Neyriz	3.5925	1.4686	0.29017445	12
Sepidan	3.4778	1.6290	0.318989132	9
Arsanjan	2.9062	2.2823	0.43987716	3
Bavanat	2.8837	2.2968	0.443357477	2
Abadeh	3.3652	1.7551	0.342770669	8
Fasa	3.5149	1.5968	0.312381858	11
Kazerun	3.4869	1.6178	0.3169279	10
Shiraz	3.4436	1.7826	0.341081896	7

Table 21. Results of the three ranking methods

City	Ranking with DEA	Ranking with AHP	Ranking with FTOPSIS
Izadkhast	2	1	1
Estahban	5	6	5
Safashahr	8	2	4
Firuzabad	13	8	13
Eghlid	7	7	6
Neyriz	12	9	12
Sepidan	11	11	9
Arsanjan	10	4	3
Bavanat	3	3	2
Abadeh	9	10	8
Fasa	4	13	11
Kazerun	6	12	10
Shiraz	1	5	7

Table 21 shows the results obtained from the two validity assessment methods in comparison to the results of the main method of the study. It is clear that the results of the three ranking methods are close to each other, which means that they can be relied upon and used with a higher degree of confidence. The reason behind Shiraz being in the top rank in the DEA method is its population criterion, because this criterion for Shiraz is much higher than other cities. The reason behind Shiraz being in seventh place in the FTOPSIS method is that in this method, wind power has been given a "very important" preferential value and Shiraz has a lower wind power compared with other cities. Safashahr has been ranked eighth in the DEA method and second in the AHP method because the population criterion and the distance from power grid criterion for this city are low and high respectively; so, in the DEA method, where population is an output criterion and distance is an input criterion, these value have caused it to be ranked in eighth place, but in the AHP method, where these criteria have a lower preferential value compared to other criteria, this city has been ranked second. The reason behind the improved ranking of Arsanjan in validity assessment is the low value of the natural disaster criterion for this city, because the two methods used for validity assessment have assigned a great deal of importance to this criterion. In the DEA model, Fasa has been ranked fourth because of its relatively high value for both the population and topographical conditions criteria. But in AHP and FTOPSIS, the wind power criterion is much more important; so, in these methods, Fasa has a much lower rank. The results of validity assessment also show that the differences in the rankings of Izadkhast, Bavanat, Eghlid, Sepidan, and Estahban by each of the three methods are very low. The reason behind this similar ranking is that values assigned to each criterion for these cities are consistent with the preferential values and verbal variables assigned in the AHP and FTOPSIS models. According to the results of the three ranking methods, the city of Izadkhast is the best option for the construction of wind farm, because it holds the top rank in validity assessment methods and second rank in the DEA method. Therefore, changes in the ranking of Izadkhast are very low, which shows the stability and reliability of its rank.

8. Conclusion

Environment-friendly benefits of wind power plants make them very desirable as an alternative source of energy. Hence, the determination of the optimum locations for the use of this resource is a vital decision. Generally, wind speed is used as a primary tool for determining the optimum locations for power plants. Therefore, in this approach, some local and social considerations are ignored. Some criteria such as geological and geographical considerations and the involved costs of facilities are examples of these misunderstandings. In this research, the DEA, AHP, and FTOPSIS approaches—which use a set of predefined indicators—were used to rank 13 different cities of the Fars province, namely Izadkhast, Estahban, Eghlid, Shiraz, Fasa, Safashahr, Bavanat, Abadeh, Arsanjan, Kazerun, Neyriz, Sepidan, and Firuzabad, in terms of the establishment of wind power station. The most important findings of this study can be summarized as follows:

- For ranking the cities, six important criteria—including three output criteria of wind conditions, topographical conditions, and population and three input criteria of distance from distribution grid, land price, and probability of natural disasters—were used for the DEA model.

- The probability of three types of natural disasters—flood, earthquake, and dust storm—was considered for this criterion as sub-criteria, because they impose the risk of damaging or even destroying wind turbines. Following the opinion of experts, weight coefficients of 0.25, 0.25, and 0.5 were considered for flood, earthquake, and dust storm respectively
- Bavanat and Neyriz were found to have the least (0.569) and the most (0.668) probability of natural disasters, respectively.
- Weibull distribution was used for the calculation of wind power density. It was finally specified that Izadkhast has the highest value of wind power among all the cities (with value of 166.64 W/m^2). Because wind power has been given a "very important" preferential value in two validation methods, Izadkhast was placed at the top of the 13 cities with AHP and FTOPSIS.
- After excluding places with trees, hills, mountains, and tall building, Safashahr was identified as the best city in terms of topographic situation with 171 km^2 of suitable land, while Shiraz was detected as the worst city with 117 km^2 of suitable land.
- The average of suitable distances to the city centre in a circle with 7.5 km radius for Neyriz was calculated to be 6.85 km; so, this city has most distance while Shiraz has least distance to distribution net.
- After executing the DEA model, the ranks of five cities were specified. But eight cities—Izadkhast, Estahban, Safashahr, Eghlid, Bavanat, Fasa, Kazerun, and Shiraz—attained full efficiency score; so for ranking these cities, the AP model was used.
- The final ranks of the cities by usage of DEA were 1- Shiraz, 2- Izadkhast, 3- Bavanat, 4- Fasa, 5- Estahban, 6- Kazerun, 7- Eghlid, 8- Safashahr, 9- Abadeh, 10- Arsanjan, 11- Sepidan, 12- Neyriz, and 13- Firuzabad.
- After ranking the cities with the two validation methods, Izadkhast was recommended for wind farm establishment.

References

[1] Esmaeili M., Kazemi A., Modelling of Harnessing Renewable Power Source with Evaluating of Economic Benefit, Congress of Wind Power (2012) 10-11

[2] Jabbari A., Shayeghi H., Esmaeilnejad B., Optimum Locating for Wind Turbines in Meshkinshahr City with Considering Technical and Economical Elements, Congress of Wind Power (2012) 10-11.

[3] Mostafaeipour A., Jadidi M., Mohammadi K., Sedaghat A., An Analysis of Wind Energy Potential and Economic Evaluation in Zahedan, Iran, Renewable and Sustainable Energy Reviews (2014)30:641-50.

[4] Azadeh A., Ghaderi S. F., Nasrollahi M. R., Location Optimization of Wind Plants in Iran by an Integrated Hierarchical Data Envelopment Analysis, Journal of Renewable Energy (2011) 36:1621-1631.

[5] http://www.suna.org.ir/fa/publishing/ books. [accessed 15.09.13]

[6] Azar A., Gholamrezaei D., Ranking Provinces of Iran with DEA Approach, Journal of Economic Studies of Iran (2007) 27:153-173.

[7] Mirjalili S. H., Mirdehghan S. A., Dehghan S., Evaluation and Determining of Efficiency in Industrial of Yazd Province with Using DEA, Journal of Studies and Economic Policies (2010) 54:95-122.

[8] Jovanovic B., Filipovic J., Bakie V., Prioritization of Manufacturing Sectors in Serbia for Energy Management Improvement-AHP Method, Energy and Converstion Management (2015) 98:225-235.

[9] Mohdevari S., Shahriar K., Esfahanipour A., Human Health and Safety Risks Management in Underground Coal Mines Using Fuzzy TOPSIS, Science of the Total Environment (2014) 448-449:85-99.

[10] Sang X., Liu X., Gin J., An Analytical Solution to Fuzzy TOPSIS and Its Application in Personnel Selection for Knowledge-Intensive Snterprise, Applied Soft Computing (2015) 30:190-204.

[11] Kelemenis A., Ergazakis K., Askounis D., Support Managers' Selection Using an Extension of Fuzzy TOPSIS, Expert System Applications (2011) 38:2774-2782.

[12] Mostafaeeipour A., Sedaghat A., Ghlishooyan M., Dinpashoh Y., Mirhosseini M., Sefid M., Pour-Rezaei M., Evaluation of Wind Energy Potential as a Power Generation Source for Electricity Production in Binalood, Iran, Renewable Energy (2013) 52:222-229

[13]Mohammadi K., Mostafaeipour A., Economic Feasibility of Developing Wind Turbine in Aligoodarz in Iran, Energy Conversation and Management (2013) 76: 645-653.

[14] Mostafaeipour A., Sedaghat A., Dehghan-miri A.A., Kalantar V., Wind Feasibility Study for City of Shahrbabak in Iran, Renewable and Sustainable Energy Reviews (2011) 15:2545-2556.

[15] Mohammadi K., Mostafaeipour A., Sabzpooshan M., Assessment of Solar and Wind Energy Potentials for Three free Economic and Industrial Zones of Iran, Journal of Energy (2014) 1-12.

[16]Azadeh A., Rahimi A., Moghaddam M., Location Optimization of Wind Power Generation_Transmission System under Uncertainty Using Hierarchical Fuzzy DEA: A Case Study, Renewable and Sustainable Energy Reviews (2014) 30:877-885.

[17]http://fa.wikipedia.org/wiki/%D8%A7%D8%B3%D8%AA%D8%A7%D9%86_%D9%81%D8%A7%D8%B1%D8%B3. [accessed 10.08.14].

[18] http://fa.wikipedia.org/wiki/FarsProvince. [accessed 20.09.14].

[19]http://www.ngdir.ir/geoportalinfo/PSubjectInfoDetail.asp?PID=869&index=16. [accessed 15.09.14].

[20]http://www.noojum.com/other/astronomy-tools/187-online-tools/6266-longitude-latitude.html. [accessed 05.03.15].

[21] Salimi J., Evaluation of Wind Power Potential for Powerhouse Establishment in Natanz Zone, Journal of Iranian Renewable Organization (2003) 115:25-33.

[22] Parvin N., Evaluation of Wind Energy in Qom Province, 4th International Congress of the Islamic World Geographers, (2010) 14-16.

[23]Grassi S., Chokani N., Abhari R. S., Large Scale Technical and Economical Assessment of Wind Energy Potential with a GIS Tool: A Case Study Iowa, Journal of Energy Policy (2012) 45:73-85.

[24] Kazemi M., Yazdankhah A., Evaluation of Effective Elements in Steady of Wind Net after Error Occurred, First Congress of Electric Powerhouses (2009) 18-19.

[25] Chen H. H., Kang H., Lee A., Strategic Selection of Suitable Projects for Hybrid Solar- Wind Power Generation Systems, (2010) 14:413-21.

[26] http://www.thewindpower.net/n-en/2012-1/ statistics_world_en.php. [accessed 20.08.13].

[27] SharifMoghaddam M., Wind Energy in Iran, Asian Journal on Energy and Environment (2009) 15:41-51.

[28]Mirhosseini M., Sharifi F., Sedaghat A., Assessing the Wind Energy Potential Location in Province of Semnan in Iran, Journal on Renewable and Sustainable Energy Reviews (2011) 15:449-459.

[29] Movahedi M. M., Hoseini S. M., Ranking of Different Area of Rail Way in Iran with Using DEA, Journal of Application Math (2010) 1(24):49-64.

[30] Farrel M.j., The Measurement of Productive Efficiency, Journal of The Royal Statistical Society (1957) 120:253-281.

[31] Charnes A., Cooper W. W., Rhodes E., Measuring the Efficiency of Decision Making Units, European Journal of Operational Research (1978) 2:429-444.

[32] Wanke P., Barros C., Two-Stage DEA, An Application to Major Brazilian Banks, Expert Systems with Applications (2014) 41:2337-2344.

[33] Sohn S.y., Kim y., DEA Based Multi-Period Evaluation System for Research in Academia, Expert Systems with Applications (2012) 39:8274-8278.

[34] Mitropoulos P., Mitropoulos L., Giannikos L., Combining DEA with Location Analysis for the Effective Consolidation of Services in the Health Sector (2013) 40:2241-50.

[35] Wu L., An Q., Ali S., Liang L., DEA Based Resource Allocation Considering Environmental Factors (2013) 58:1128-1137.

[36] Pourkazemi M. H., Ranking of Trade Banks of Iran, Journal of Studies and Economic Policies (2011)39-40.

[37] Mehregan M. R., Advanced Operation Studies, University Books Publication, First Publishment.

[38] Saaty T.L., The Analytic Hierarchy Process, NewYork, McGraw-Hill 1980.

[39] Beltran P. A., Gonzalez F. C., Ferrando J. P., An AHP (Analytic Hierarchy Process)/ANP (Analytic Network Process) Based Multi-Criteria Decision Approach for the Selection of Solar-Thermal Power Plant Investment Projects, Journal of Energy (2013) 68:1-17.

[40] Lai Y. J., Liu T. Y., Hwang C. L., TOPSIS for MODM, European Journal of Operational Research (1994) 76(3):486-500.

[41] Sengul U., Eren M., Eslamian S., Geder V., Fuzzy TOPSIS Method for Ranking Renewable Energy Supply System in Turkey, Renewable Energy (2013) 52:222-229.

[42] Ashtiani B., Haghighirad F., Makui A., Alimontazer G., Extension of Fuzzy TOPSIS Method Based on Interval-Valued Fuzzy Sets, Application Soft Computing (2009) 9:457-461.

[43] Zhou x., Lu m., Risk Evaluation of Dynamic Alliance Based on Fuzzy Analytic Network Process and Fuzzy TOPSIS, Journal of Science Management (2012) 5:230-240.

[44]http://www.shirazedc.co.ir/showpage.aspx?page_=form&order=show&lang=1&sub=o&pageId=4368codeV=1&tempname=amar. [accessed 15.02.13]

[45] Mathew S., Wind Energy Fundamentals, Resource Analysis and Economics. Electronically Available at http://www.springer.com/engineering/energy+technology/book/978-3-540-30905-5?changeheader.