3. Methodology

3.1 Fuzzy TOPSIS

Fuzzy TOPSIS can be based on triangular numbers (3 numbers) or trapezoidal numbers (4 numbers), but this study uses the triangular variant of the technique. Having the number of criteria (n) and the number of alternatives (m), after evaluating all alternatives with respect to all criteria, decision matrix is formed by Equation 1 (Ashtiani et al. 2009):

$$\tilde{D}=\begin{bmatrix}\tilde{x}_{11} & \cdots & \tilde{x}_{1n}\\ \vdots & \ddots & \vdots\\ \tilde{x}_{m1} & \cdots & \tilde{x}_{mn}\end{bmatrix} \quad (1)$$

X_{ij} is a triangular fuzzy number in the form of $X_{ij}=(a_{ij},b_{ij},c_{ij})$ reflecting the performance of alternative i $(i = 1,2, ..., m)$ in terms of criterion j $(j = 1,2, ..., m)$.

All criteria of this study are quantitative, so they only need to be normalized to a 0-10 scale. Since the assigned number should be triangular, all three parts of the number are considered to have the same value (Kelemenis et al. 2011).

Then, the weight reflecting the importance of each criterion in decision-making is defined as Equation 2 (Mahdevari et al. 2014).

$$\tilde{w} = [\tilde{w}_1,\tilde{w}_2,\ldots,\tilde{w}_n] \quad (2)$$

Since the numbers are of triangular fuzzy type, the weight of each component w_j is defined as $W_j=(w_{j1},w_{2j},w_{3j})$. For this purpose experts must be asked for inputs and the linguistic variables must be converted into fuzzy numbers based on classification of Table 2.

Table 2: Linguistic variables for expressing qualitative criteria and criteria weights and their equivalent fuzzy numbers (Ashtiani et al. 2009).

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, 0.5)	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, 1 , 1)	Very momentous	(9, 10, 10)	Very high

When x_{ij}'s are fuzzy, r_{ij}'s will be fuzzy as well. In this step, to avoid complex calculations, normalization is performed by linear scaling of values of criteria to a comparable scale. Since the fuzzy numbers are triangular, elements of normalized decision matrix for positive and negative criteria are calculated by equations 3 and 4 (Mahdevari et al. 2014).

$$\tilde{r}_{ij}=\left(\frac{a_{ij}}{c_j^*},\frac{b_{ij}}{c_j^*},\frac{c_{ij}}{c_j^*}\right) \quad (3)$$

$$\tilde{r}_{ij}=\left(\frac{a_j^-}{c_{ij}},\frac{a_j^-}{b_{ij}},\frac{a_j^-}{a_{ij}}\right) \quad (4)$$

In the above relationships, $c^*_j=max\ c_{ij}$ and $a^-_j=min\ a_{ij}$. With having the weights of all criteria, weighted fuzzy decision matrix is obtained by multiplying the importance weight of each criterion by the normalized fuzzy matrix using equation 5 (Zhou and Lu 2015)

$$\tilde{v}_{ij}=\tilde{r}_{ij}*\tilde{w}_j \quad (5)$$

In the above relationship, $\widetilde{w_j}$ is the importance weight of criterion c_j, which is determined using the experts' opinions. Thus, the weighted fuzzy decision matrix will be in the form of equation 6 (Kelemenis et al. 2011)

$$\tilde{v}=\begin{bmatrix} \tilde{v}_{11} & \cdots & \tilde{v}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{v}_{m1} & \cdots & \tilde{v}_{mn} \end{bmatrix} \tag{6}$$

Fuzzy ideal solution and Fuzzy anti-ideal solution are obtained by equations 7 and 8 respectively (Ashtiani et al. 2009).

$$A^{*}=\{\widetilde{v_1^*}, \widetilde{v_2^*}, \dots, \widetilde{v_n^*}\} \tag{7}$$

$$A^{-}=\{\widetilde{v_1^-}, \widetilde{v_2^-}, \dots, \widetilde{v_n^-}\} \tag{8}$$

Where $\tilde{v}_i^*$ and $\tilde{v}_i^-$ are the best and worst values of criterion *i* among the values obtained for all alternatives. In other words, $\tilde{v}_i^*$ is the highest value of all fuzzy numbers obtained for criterion *i*, while $\tilde{v}_i^-$ is the lowest value of all fuzzy numbers obtained for that criterion.
Then the distance of each alternative from the fuzzy ideal and anti-ideal solutions can be obtained, respectively, from Equation 9 and 10 (Engulf et al. 2015).

$$s_i^* = \sum_{j=1}^{n} d(\widetilde{v_{ij}}, \widetilde{v_j^*}), \qquad i=1,2,....,m \tag{9}$$

$$s_i^- = \sum_{j=1}^{n} d(\widetilde{v_{ij}}, \widetilde{v_j^-}), \qquad i=1,2,....,m \tag{10}$$

Closeness index can be calculated by equation 11 (Mahdevari et al. 2014).

$$c_i = \frac{s_i^-}{s_i^* + s_i^-} \tag{11}$$

In the last step of Fuzzy TOPSIS technique, alternatives must be ranked in the descending order of their closeness index, meaning that the ones with higher index will have a higher priority.

3.2 Criteria associated with location of wind-solar power plant

Criteria and sub-criteria considered in this study are listed in Table 3.

Table 3: Criteria and sub-criteria associated with location of renewable power plant

Criteria	Sub-criterion	Positive/ negative
Climate	Wind power density	Positive
	solar radiation energy	Positive
Geological conditions	the area of flat lands	Positive
	The area of lands without tree cover	Positive
	the ease of access to the site	Positive
	Average of distances between suitable places and power distribution grid	Negative
Economy	costs of land	Negative
	infrastructural costs	Negative
	costs of skilled labor	Negative
Natural disasters	flood	Negative
	earthquake	Negative
	dust storm	Negative
Social condition	population	Positive

3.3 Calculation of wind power

Wind speed is a random variable, so wind power density is typically obtained by Weibull distribution function, which has been proven accurate for this application (Mostafaeipour et al. 2014). This distribution is shown in equation 12 (Rezaei et al. 2017):

$$f(v) = (\frac{k}{c})(\frac{V}{c})^{k-1} e^{-(\frac{v}{c})^k} \tag{12}$$

Where *f(v)* is the probability density function and *V* is the wind speed. This relationship contains two constants, scale parameter (*c*) and shape parameter (*k*), which must calculated in advance (Murtaza-Ershad et al. 2016). These two constants can be obtained from equations 13 and 14 (Mohammadi et al. 2014; Eskin et al. 2008)

$$c = \frac{v}{\Gamma * (1 + \frac{1}{k})} \tag{13}$$

$$k = 0.83 v^{0.5} \tag{14}$$

In equation 12, *Γ* is the gamma function. Thus, to calculate *c* and *k*, the annual mean wind speed in each specific year must be obtained from the available data and then be substituted into equations 13 and 14. Finally, wind power is obtained from equation 15 (Mostafaeipour and Abarghooei, 2008):

$$\mathrm{P(v)} = \frac{1}{2} \rho A v^3 \tag{15}$$

Where ρ is the ambient air density (equation 16), which is given by (Ozlu and Dincer, 2015):

$$\rho = \frac{\bar{P}}{R_d \bar{T}} \tag{16}$$

In this relationship, $\bar{P}$ is the ambient air pressure in Pascal, $\bar{T}$ is the air temperature in Kelvin, and R_d is the gas constant for dry air *(=287 J/Kg.K)* (Murtaza-Ershad et al. 2016). After these calculations, the final step is to determine the wind power density required for rotation of turbine blade with area *A* using equation 17 (Rezaei et al. 2017)

$$\frac{P}{A} = \int_0^\infty \frac{1}{2} \rho v^3 f(v) dv = \frac{1}{2} \Gamma \rho c^3 (1 + \frac{3}{k}) \tag{17}$$

The values calculated for the studied cities are given in Table 4.

Table 4. Average of 10-years wind power density of the 7 cities.

City	Wind power density (KW/m^2)	Normalized values for FTOPSIS
Izadkhast	112.18	1.1218
Estahban	99.0	0.99
Safashahr	140.23	1.4023
Firuzabad	74.45	0.7445
Eghlid	146.30	1.463
Arsanjan	116.42	1.1642
Bavanat	132.50	1.325

3.4 Calculation of solar irradiance

So in an initial assessment, the Angstrom-Prescott equation shown in formula 18 (Li et al. 2012) is used to calculate solar irradiance, and then the areas not meeting any of the two above conditions are eliminated from the study.

$$H = H_0 * (a + b * (\frac{n}{N})) \tag{18}$$

In this equation, *H* is the average daily radiation reaching the earth's surface (MJ/m^2), H_0 is the average daily extraterrestrial irradiance, *n* is the actual sunshine hours, and *N* is the maximum possible sunshine hours in one day. The ratio of ground surface irradiance to extraterrestrial irradiance is called clearness index (Sang et al. 2015). H_0 can be obtained from equation 19 (Liu et al. 2015).

$$H_0 = \frac{24 \times I_{SO}}{\pi} \times [1 + 0.033 \cos(\frac{360d}{365})] \times [\cos \emptyset \cos \delta \sin \omega + \frac{\pi\omega}{180} \sin \emptyset \sin \varphi] \tag{19}$$

In the above equation, I_{so} is the solar constant and equals 1367 w/m^2 (Wan et al. 2008). $\emptyset$ is the latitude of the location. *d* denotes the number of days since January 1, which is equal to 1. δ is the sun declination angle, which varies between 23.5 degree north and 23.5 degree south in a yearly cycle and is obtained from Cooper's formula 20 (Surender-Reddy, 2016).

$$\delta = 23.45 \times \sin[\frac{360(284+d)}{365}] \quad (20)$$

ω is the sunset (or sunrise) hour angle, which represents the sun's position in the sky of each location relative to its Meridian, and equals 15 degrees per hour difference from solar noon (the hours before noon are negative and the hours past noon are positive). This parameter can be obtained from equation 21 (Wan et al. 2008).

$$\cos\omega = -\tan\emptyset \times \tan\delta \quad (21)$$

N is the maximum possible sunshine hours during the day, which is calculated by the following equation (Wan et al. 2008):

$$N=\frac{2\omega}{15} \quad (22)$$

The ratio $\frac{n}{N}$ represents the sky's cloudiness and provides information about the characteristics and conditions of the study area in this regard (Paulescu et al. 2016). Extraterrestrial irradiance (H_0) and maximum sunshine hours (N) are both function of latitude and calendar date.

In Prescott's equation, a and b are regression constants that depend on geographic and climatic parameters. Parameter a is defined as the fraction of the monthly average solar radiation ($\frac{H}{H_0}$) entering the atmosphere when there is a full cloud cover, and parameter b as the rate of change in $\frac{H}{H_0}$with respect to $\frac{n}{N}$ and latitude difference (Moeini et al. 2013). Since a great majority of stations in Fars province have the same climate as Shiraz, these two parameters are obtained using the reports of Renewable Energy Organization of Iran (SUNA) for the city of Shiraz, resulting in a=0.29 and b=0.49 (Moeini et al. 2013)

The average annual solar radiation energy calculated for the studied cities are presented in Table 5.

Table 5: Summary of average annual solar radiation energy values calculated by Angstrom-Prescott equation.

City	average annual solar radiation energy (MJ/m^2)	Normalized values for FTOPSIS
Izadkhast	6980	6.98
Estahban	7739	7.739
Safashahr	7452	7.452
Firuzabad	7307	7.307
Eghlid	7698	7.698
Arsanjan	7228	7.228
Bavanat	7429	7.429

3.5 Geological characteristics

For each city, evaluations must be performed for the area within the radius of 7.5 kilometers from the weather station of that city (Rezaei-Shouroki et al. 2017), so the criterion "usable area" is represented by the area of geologically suitable locations within this circle (in square kilometers). The results of this section are presented in Tables 6 and 7.

Table 6: Summary of results in relation to three positive sub-criteria geological condition (total area = 177 km^2).

City	Very hard and difficult to access areas (km^2)	Areas with tree cover (km^2)	Areas with mountain and hill (km^2)	Suitable and useful areas (km^2)	Normalized values for FTOPSIS
Izadkhast	42	18	32	85	8.5
Estahban	70	12	30	65	6.5
Safashahr	33	29	27	88	8.8
Firuzabad	52	35	28	62	6.2
Eghlid	42	23	21	91	9.1
Arsanjan	59	26	29	63	6.3
Bavanat	56	33	27	61	6.1

Table 7 also presents the information about the distance from distribution network in each of the studied areas as well as the normalized distances used in FTOPSIS.

Table 7: Distance to distribution net (negative criterion of geological condition)

City	Distance to distribution net (km)	Normalized values for FTOPSIS
Izadkhast	6.61	6.61
Estahban	6.73	6.73
Safashahr	6.77	6.77
Firuzabad	6.10	6.10
Eghlid	6.83	6.83
Arsanjan	5.17	5.17
Bavanat	5.22	5.22

3.6 Economic criteria

Economic feasibility is the primary prerequisite of every project. The values calculated for this criterion, which include the costs of land, infrastructure and skilled labor, are given in Table 8.

Table 8: Results in relation to economic criteria (combined cost of land, infrastructure, and skilled labor)

City	cost of land, infrastructure, and skilled labor (Rial)	Normalized values for FTOPSIS
Izadkhast	3,650,000	3.65
Estahban	3,850,000	3.85
Safashahr	4,100,000	4.10
Firuzabad	4,900,000	4.90
Eghlid	3,950,000	3.95
Arsanjan	3,700,000	3.70
Bavanat	3,800,000	3.80

3.7 Natural disasters

According to expert's opinion, weight coefficient of 0.25, 0.25, and 0.5 were considered for flood, earthquake and dust storm respectively. It is known that natural disasters such as floods and earthquakes follow a Poisson distribution, so this distribution can be used to calculate the probability of these two events with satisfactory precision. The probabilities of the three natural disasters are combined to determine the probability of at least one of these natural events over the 25 years (turbine lifetime). The results are presented in Table 9.

Table 9: Summary of results obtained for natural disaster criterion

City	earthquake	flood	dust storms	probability of natural disaster (at least one time in 25 years)	Normalized values for FTOPSIS
Izadkhast	0	0.867	0.86	0.647	0.647
Estahban	0	0.911	0.87	0.663	0.663
Safashahr	0	0.867	0.86	0.647	0.647
Firuzabad	0	0.941	0.86	0.665	0.665
Eghlid	0	0.867	0.88	0.657	0.657
Arsanjan	0	0.702	0.84	0.596	0.596
Bavanat	0	0.554	0.86	0.569	0.569

3.8 Population

Another criterion associated with location of plant is the population. Population of the under study cities are presented in table 10.

Table 10: Population of the studied cities (wikipedia.org).

City	Population	Normalized values for FTOPSIS
Izadkhast	48810	0.4881
Estahban	69173	0.69173
Safashahr	52002	0.52002
Firuzabad	119621	1.19621
Eghlid	100158	1.00158
Arsanjan	45872	0.45872
Bavanat	51289	0.51289

4. Analysis

After Analyzing data table 11 shows the final results. Any city that is closer to fuzzy ideal and farther from fuzzy anti-ideal achieves a higher priority. Among the studied cities, Eghlid is closest to the fuzzy ideal solution (d_{ideal}=1.8251) and is farthest from the fuzzy anti-ideal solution ($d_{anti-deal}$ =2.0073) and thus ranks first in terms of suitability for the project. The city least suitable for this purpose is Arsanjan, which is farthest from the fuzzy ideal solution (d_{ideal} =2.1748) and closest to the fuzzy anti-ideal solution ($d_{anti-deal}$=1.5382).

Table 11: Distances from fuzzy ideal and anti-ideal solutions and closeness index

City	Distances from fuzzy ideal solution	Distances from fuzzy anti-ideal solution	closeness index
Izadkhast	2.1327	1.6292	0.433070982
Estahban	1.9939	1.7735	0.470757783
Safashahr	2.0775	1.6609	0.444279311
Firuzabad	1.9861	1.8060	0.476256742
Eghlid	1.8251	2.0073	0.523776234
Arsanjan	2.1748	1.5382	0.414276266
Bavanat	2.0978	1.6290	0.437110489

5. Discussion

In this study, five methods of AHP, ELECTRE III, WSM, MAPPAC and DEA are used to assess the validity of results obtained from FTOPSIS model. Table 12 shows the comparison between these methods.

Table 12: Ranking of the cities after AHP analysis.

City	AHP	ELECTREE III	WSM	MAPPAC	DEA
	Rank	Rank	Rank	Rank	Rank
Izadkhast	6	4	6	6	4
Estahban	3	3	4	4	6
Safashahr	2	2	2	2	5
Firuzabad	4	7	7	7	2
Eghlid	1	1	1	1	1
Arsanjan	7	6	5	5	7
Bavanat	5	5	3	3	3

6. Conclusion

The results of this study are summarized as follows:

- Cities were rank according to five general criteria: climate, natural disasters, economic condition, social condition and geological condition, each with a number of sub-criteria. In total, the model used in this study consisted of 6 positive sub-criteria and 7 negative sub-criteria.
- After calculating the wind power and solar irradiance for all cities using, respectively, the Weibull distribution function and Angstrom-Prescott equation, Eghlid was found to have the best wind power, 146.30 KW/m^2, and Estahban was found to have the best solar irradiance, 7739 MJ/m^2, among the studied cities.
- After eliminating the geologically unsuitable areas, namely areas with tree cover, mountains and hills, and difficult accessibility, among the studied cities, Eghlid was found to have the greatest geologically suitable

land area (91 km^2) and Bavanat was found to have the smallest area with favorable geological conditions (61 km^2).

• Probability of natural disasters is another important site location criterion. Given the susceptibility of area to dust storms and magnitude of their effect on turbine blades, in these calculations, this event was a given a weight of 0.5 while both earthquake and flood were assigned with a weight of 0.25. After merging the probabilities of these three sub-criteria (natural events) based on the said weights, Bavanat with probability of 0.569 and Firuzabad with probability of 0.665 were found to have, respectively, the best and worst status among the studied cities in terms of susceptibility to unfavorable natural events.

• After running the model, ranks of the 7 cities in terms of suitability as the site of solar-energy hybrid plant was determined. The final ranking obtained in this study is: 1-Eghlid, 2- Firuzabad, 3- Estahban, 4-Safashahr, 5- Bavanat, 6- Izadkhast and 7-Arsanjan, indicating that Eghlid is the best option for combined exploitation of wind and solar energy, which as mentioned, leads to reduced maintenance, operation, and infrastructural costs, greater operation efficiency, and better reliability.

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