A SPATIAL PLANNING SUPPORT SYSTEM FOR WIND FARM CONSTRUCTION WITH MACRO AND MICRO PERSPECTIVES

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ABSTRACT:

Wind energy is well-known Renewable energy that contributes to countries achieving their sustainable development goals, so governments have planned to increase electricity generation from wind energy in recent years. Selecting suitable places for installing wind farms is one of the most challenging parts of wind energy projects because of the necessity of identifying various parameters, which is considered a site selection problem and needs spatial planning to solve. Furthermore, in constructing a wind farm, finding the optimum placement of wind turbines, known as the wind farm layout optimization (WFLO) problem, is crucial for obtaining maximum total power capacity while minimizing the number of turbines installed. In this research, the analysis is divided into two macro and micro levels to find an efficient and comprehensive approach. In the first level, after removing the restricted area, the MCDM method is used to find the most suitable sites, considering economic, social, and environmental criteria. After selecting one of the most suitable areas located in the middle of Alborz province, the GA algorithm as a meta-heuristic method is employed to solve the WFLO problem at the micro level. The essential criterion in this level is the wake effect among turbines which is simulated according to the Jensen model. As a test case, the selected area was subdivided into 144 cells that, after micro siting, 28 V47-660-45 turbines were placed, which could have a total power of 8732.283 kW capacity.

1. INTRODUCTION

Rising electricity consumption and fossil fuel prices, along with concerns about increasing carbon dioxide in the atmosphere that contributes to global warming, have amplified the worth of renewable energy production in recent years (Rahman et al., 2021). Among renewable energy sources, offshore and onshore wind energy is considered one of the most reliable options for meeting the growing need for electricity (Lacal-Arántegui, 2019; Perveen et al., 2014). However, renewable energy project developers should consider all their environmental impacts on ecology and society that cause a negative attitude toward renewable energy development (Rahman et al., 2022). Wind energy could have some detrimental effects on flora and fauna, particularly on protected areas and NIMBYism (not in my backyard) that come from the shadow and noises emitted by the wind farm (Buchmayr et al., 2022; Schöll and Nopp-Mayr, 2021). Moreover, wind turbines should be located where enough wind is available, and this area should guarantee the wind farm's security and efficiency during its operational lifetime(Asadi and Pourhossein, 2021).

So, finding a practical approach to diminish the deleterious impacts on the environment while producing energy on a sustainable path is vital. Site selection of renewable energy is a complicated decision-making problem that needs some spatial analysis to minimize these problems and get maximum output from that selected site (Shao et al., 2020; Villacreses et al., 2022; Wu et al., 2021; Zhao et al., 2022). The advent of the Geographic Information System (GIS), considered a spatial decision support system (SDSS) tool, has made the site selection process more accurate and helped researchers solve this complex issue.
rejection.

1.1 Literature Review

Many research studies have been conducted on determining the feasible locations of offshore and onshore wind farms. The combination of Geographic Information System (GIS) with different types of multi-criteria decision-making (MCDM) methods (TOPSIS, ELECTRE, VIKORE, AHP, etc.) has recently had the main role in finding a suitable place to construct the wind farm(Ayodele et al., 2018; Genç et al., 2021; Gil-García et al., 2022; Messaoudi et al., 2019; Villacreses et al., 2017). On top of that AHP method is one of the popular approaches among scientists (Table 1).

Field of research	References
Wind Energy	Höfer et al. (2016)
Bio Energy	Bharti et al. (2021)
Solar Energy	Albraheem and Alabdulkarim (2021)
Thermal Energy	Meng et al. (2021)
Hybrid	Effat and El-Zeiny (2022)

Table 1. Application of AHP method in previous studies.

Xu et al. (2020) combined the GIS with interval Analytic Hierarchy Process (IAHP) and stochastic VIKOR methods to study the site selection of wind farms in the Wafangdian region, China considering the economy, society, topography, and ecological environment parameters. The author compared the result of the research with the actual locations of the existing wind farms and found that this approach is much more effective than others and can be utilized for siting other sorts of renewable energy.

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Moradi et al. (2020) applied GIS and Analytical Hierarchy Process (AHP) methods to evaluate suitable wind farm locations in Alborz province. The results show that the southwest of this province is the appropriate place for constructing a wind farm, and the sensitivity analysis is used to indicate the reliability of these results.

Cunden et al. (2020) identified the appropriate place for wind farms by integrating GIS with AHP and Weighted Linear Combination (WLC) based on a given set of exclusion and restriction criteria in Mauritius. According to the results, although there were ten sites with the highest potential for wind farm placement, the author selected two sites for wind farm installation just because of the higher mean wind speed at 60 m, in which 23 turbines were put without any layout optimization. However, the optimal layout of wind farm turbines on highly suitable sites was not considered, which may show other alternatives have more priority.

Tercan (2021) presented a GIS-based MCDM integrated approach for onshore wind farms' location selection in Balıkesir, Turkey. Best Worst Method (BMW) method is employed to calculate the criteria weights, and the result indicates that 10.58% of the study zone is highly suitable for wind farm construction.

Zahedi et al. (2022)applied the multi-criteria decision support system and GIS to identify the capacity of western Iran to harness maximum wind power. They considered four technical, Environmental, Geographical, and Economic criteria. They found that 26% of Iran's western region is suitable for constructing wind farms in which 7267 turbines arranged in this area can generate a maximum of 1897 MW of wind power.

The majority of such studies focus on only finding a suitable area to construct an efficient wind farm or just working on wind farm layout optimization; however, the novelty of this study is considering both macro and micro siting simultaneously to evaluate the area's potential. Although the feasibility study for finding an efficient site is valuable, the wind farm layout optimization is vital in increasing wind turbines' ability and power capacity that should not be waived.

2. OVERVIEW OF WIND POWER DEVELOPMENT IN IRAN

Iran is considered a developing country that relies on its natural gas and oil to provide energy. Figure 1 shows the amount of generated electricity in Iran since 2010, and it is evident that the share of renewable energy is minuscule compared with fossil fuels. While fossil fuels produce 94% of Iran's electricity, renewables and nuclear power comprise 3.5% and 2.3% of electricity generation, respectively (Slocum and Gessel, 2022).

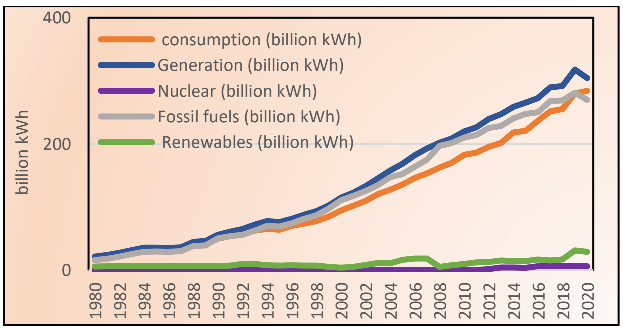

Figure 1. Energy generation and consumption in Iran.

Iran ranked 30th in the world for wind energy produced and has a small percentage of the global wind power capacity (837 GW). Iran's onshore wind has a technical resource potential of more than 140000 MW, and the wind power capacity in this country is just about 317 MW (Table 2). With this high wind potential, Iran could provide at least two-thirds of the nation's current electricity use in this way.

Names	capacity (MW)	Province	City	Date
Manjil	92.2	Gilan	Manjil	2008
Ben Ali	1.98	Azarbayjan Sharghi	Tbariz	2009
Binalood	28.38	Khorasan Razavi	Binalod	2010
Behin	1.5	Khorasan Razavi	Khaf	2013
Mapna	55	Ghazvin	Kahak	2015
Dizbad	4.1	Khorasan Razavi	Neyshabour	2015
Atrin	2.5	Khorasan Razavi	Khaf	2016
Mahabad	61.2	Ghazvin	SiaahPoush	2017
Mapna	50	Azerbaijan Sharghi	Aghkand	2018
Mapna	20	sistan and baluchestan	Mil Nader	2021
Total Installed Capacity (MW): 317.16				

Table 2. Wind farms in Iran (SATBA).

2.1 Study area

Alborz province is located at the hill of the Alborz mountains and 30 Km west of Tehran (capital of Iran), with a total area of 5833 Km^2. This province comprises six countries, Karaj, Savojbolagh, Nazarabad, Fardis, Eshtehard, and Taleqan. The difference in elevation between the lowest point, 1063 m, and the highest point, 4101 m above sea level, is about 3038, which is the root of the high wind speed in some parts of this province.

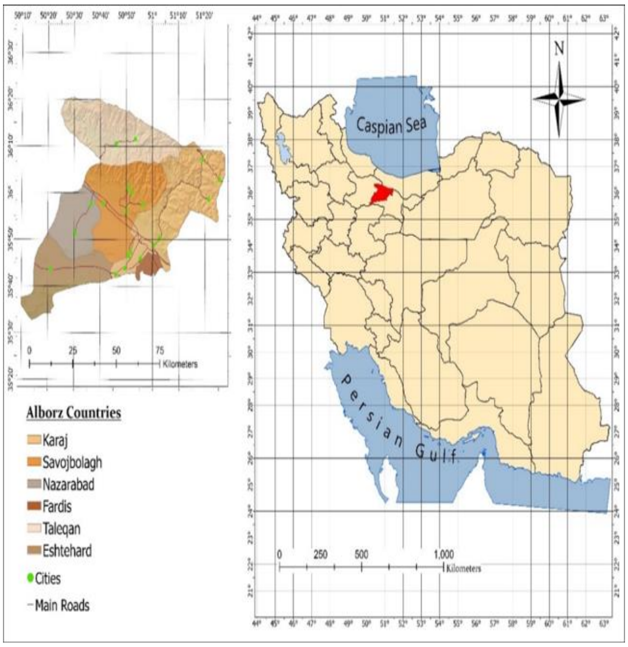

Figure 1. Location of Alborz province.

According to the last national census in 2016, the population of Alborz province was 2,712,400, the fourth most populated province in Iran, with a 2.4% annual increase. In recent decades, due to the increasing industrial zones and construction of numerous factories, especially in the Eshtehard centuries, besides the population growth, we have witnessed Unbalanced development. The amount of energy consumed in this province is approximately 2.013 % of total energy generation in Iran, with about 6 TWh In 6 different categories, and has an annual growth of 7 to 8% (Moradi et al., 2020). So, this province requires more energy sources to meet the residents' needs in various sectors.

3. METHODOLOGY

In this research, the objective is focused on developing a method for assessing potential locations for wind farm installation in two stages macro siting and micro siting (figure 3). The macro-siting stage breaks down into removing the unsuitable place from our study area and finding the optimal locations for developing wind farms. Firstly, based on relevant parameters for Iran, the study area is divided into feasible and none feasible regions. After subtracting unsuitable areas, the MCDM method is combined with the GIS to spatially investigate the environmentally, geographically, and structurally possible areas considering the technical, socio-economic, and environmental assessment criteria. Finally, the ultimate map presents the suitable places for constructing wind farms.

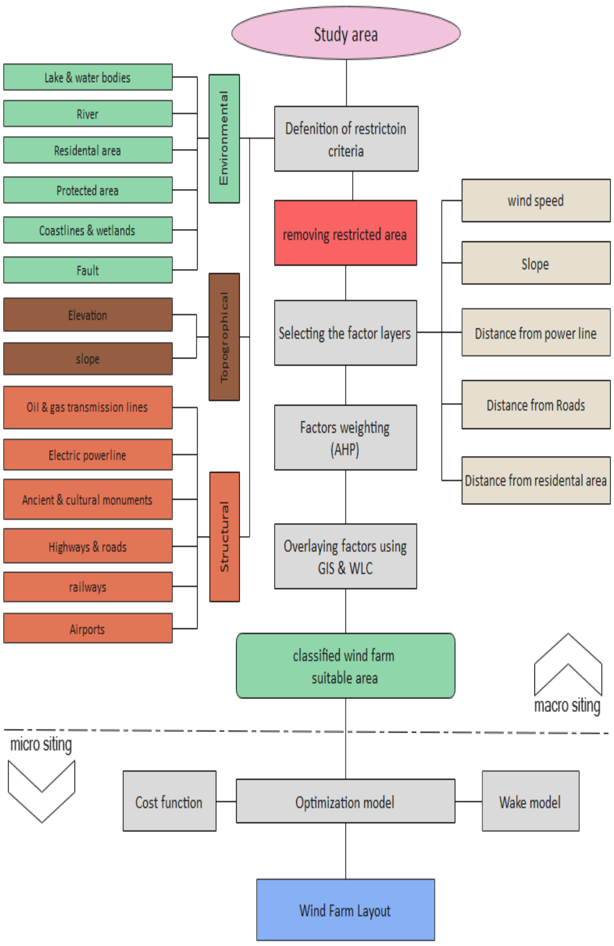

Figure 2. Methodology of the study.

In the micro-siting stage, one of the most suitable areas in the previous step was evaluated as a candidate region for finding an optimal layout. Every specific area could have a variety of wind farm layouts which depend on that location's geographical and environmental features and cause different costs and power output. The main aim of this stage is to choose a wind farm layout that harnesses maximum energy from that area's wind resource with the minimum cost of wind turbines installation. The various grid-based Wind farm layout optimization (WFLO) techniques have been used in recent years that the study area is divided into 10-by-10 cells(Khanali et al., 2018; Patel et al., 2017), but in this study, as a result of our analyses in the first stage, the optimization could develop in a realistic land space with irregular boundaries. After the wind turbine extracts energy from the wind, the wind power is reduced downstream, and turbulence is made behind the turbine, which results from the changes in wind speed caused by the impact of the turbines on each other. This phenomenon is named as wake effect. In this research, The Jensens analytical wake model which is based on conserving momentum in the downstream direction, is used to find the actual power extracted from each turbine. The GA algorithm is implemented as an optimization method to determine the optimal placement of wind turbines considering the cost and the total power output.

3.1. Restricted area

The constraint area should be removed from the study to mitigate the harmful effect of the wind farm on the environment and people. This process comprises three environmental, structural, and topographical categories and 11 parameters that identify suitable and unsuitable areas (table 3).

This method uses the Boolean logic approach to specify the suitable location according to defined criteria. This logical math tool considers a binary condition for data and denotes 1 and 0 to the true and false variables, respectively. The study area is classified into two separate classes, 1 belongs to the site with a probability of construction wind farm and 0 is the area without any chance for wind farm siting. figure.4 shows the final restrictive area.

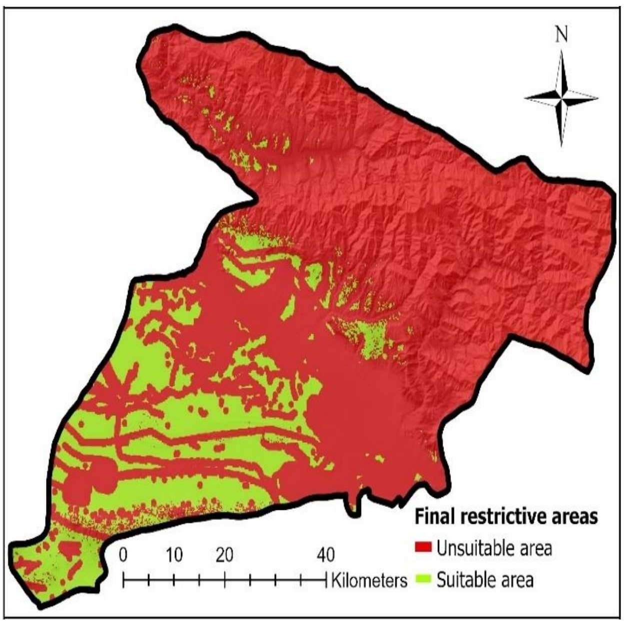

Figure 3. Exclusion area.

Data	Buffer Zones	References
Lake & water bodies	<1000	(Satkin et al., 2014)
River	<500	(Noorollahi et al., 2016)
Residential Area	Cities <2000 Village <500	(Noorollahi et al., 2016; Satkin et al., 2014)
Environmental protected area	<2000	(Moradi et al., 2020)
Coastlines & wetlands	<500	(Satkin et al., 2014)
Faults	<500	(Yousefi et al., 2022)
railways	<300	(Noorollahi et al., 2016)
Highways & roads	<500	(Yousefi et al., 2022)
Oil and gas transmission lines	<500	(Moradi et al., 2020)
Airports	<2500	(Yousefi et al., 2022)
Electric powerline	<250	(Zahedi et al., 2022)
Ancient and cultural monuments	<700	(Satkin et al., 2014)
Elevation	>2000	(Yousefi et al., 2022)
slope	>15%	(Satkin et al., 2014)

Table 3. Exclusion parameters.

3.2. AHP

MCDM methods are tools that help researchers to make the best decision in intricate decision-making problems. The analytical hierarchy process technique considers a strong MCDM tool initially introduced by Thomas Saaty (Saaty, 1990) in 1980. Since then, many researchers have used this method to tackle intricate decision problems in their analyses.

AHP method helps us to have the relative weight of each criterion concerning the importance of the rest criteria; besides, it has this feature to examine the accuracy and consistency of our evaluation. The essential part of This method is breaking down the multiple criteria problem into a hierarchy of decision trees containing four levels of program goal, criteria, sub-criteria, and choices (Bertolini et al., 2006; Bowen, 1990). The AHP method compares the criteria two by two, and for this compression, they are given points ranging from one to nine (table 4).

After defining the decision problems, a (n×n) pairwise comparison matrix should be prepared, which n is the number of criteria. Then consistent ratio (CR) should be used to examine the consistency of the pairwise comparison matrix.

In this method, the coherence ratio should be under 0.1; if it exceeds 0.1, the judgment Is inconsistent, and decision-makers should re-examine their choice in the pairwise compression (Saaty, 1990). The value of the consistent ratio depends on the consistency index (CI) and random index (RI) that depends on the number of criteria offered in table 4 (Equation 1).

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{1}$$

Scale	Numerical Rating	Reciprocal
Equal importance	1	1
Equal to moderate importance	2	1/2
Moderate importance	3	1/3
Moderate to strong importance	4	1/4
Strong importance	5	1/5
Vital to very strong importance	6	1/6
Very strong importance	7	1/7
Very to extremely strong importance	8	1/8
Extreme importance	9	1/9

Table 4. Pairwise comparison scales in AHP (Kunasekaran and Kannan, 2014).

The consistency index (CI) that shows the incompatibility of pairwise comparison can be calculated as the following equation:

$$\mathrm{CI} = \frac{\lambda_{\max} - \mathrm{n}}{\mathrm{n} - 1} \tag{2}$$

where n is a number of factors and $\lambda_{\max}$ is the Eigenvalue of the pairwise comparison matrix.

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49

Table 5. Random Index values according to saaty and Tran.

3.3. Wake model and turbine parameters

Wind farm layout optimization (WFLO) aims to find the optimal placement of wind turbines to increase power production and decrease installation costs and other trouble factors. A wake zone is produced by rotating the turbine blade, negatively influencing other downstream turbines' ability (Patel et al., 2017). Optimizing layout configuration led to minimizing this wake effect and maximizing the power extracted from wind turbines.

The total power of a wind farm is directly related to wind conditions. In this approach, we consider single wind speed and direction to optimize the layout of the wind farm.

For this study, wind turbine V47-660-45, a production of Vestas and also currently is manufactured in Iran (Saba Energy Company), is selected. The power curve of turbine V47-660-45 is shown in figure 5. The turbine starts producing power at a wind speed of 4 m/s and reaches the maximum produced power of 660 kW at a wind speed of 15 m/s. At 25 m/s, the turbine stops working in order to prevent turbine damage. The technical features of this turbine are presented in Table 6.

Parameters	Value
Rated power	660.0 kW
Cut-in wind speed	4.0 m/s
Rated wind speed	15.0 m/s
Cut-out wind speed	25.0 m/s
Rotor diameter (m)	47.0 m
Swept area	1,735.0 m²
Hub height	45

Table 6. Technical characteristics of V47-660-45 wind turbine.

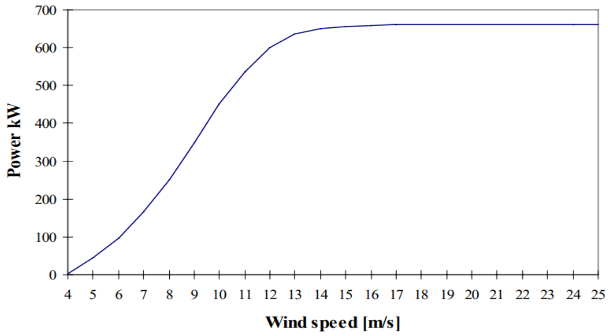

Figure 5. Power curve of V47-660-45 wind turbine.

The electric output power curve of V47-660-45 wind turbine generator (WTG) can be modelled as a following function (El-Shimy, 2010) :

$$p_i(KW) = \begin{cases} 0 & u_i \le 4 \\ -1.059u_i^2 + 82.5u_i - 342.22 & 4 \le u_i \le 15 \\ 660 & 15 \le u_i \le 25 \end{cases} \quad (3)$$

To obtain the power output of every turbine, it is essential to find the velocity deficit at each turbine. The present study uses the Riso approach, developed by Jenson in 1983, for the wake modeling of the wind farm to describe wind behavior in the wake region (figure 6).

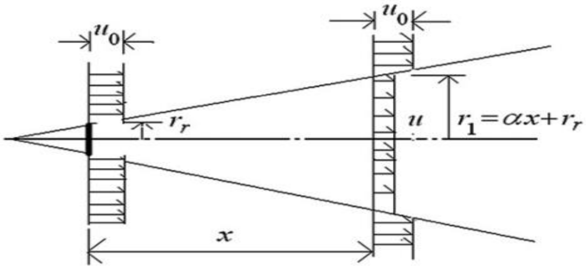

Figure 6. Schematic diagram of Jensen's wake model (Grady et al., 2005).

Assuming the conservation of momentum in the wake, the wind velocity of a downstream turbine which affected by a single wake is as follows (Mosetti et al., 1994):

$$u = u_0\left[1 - \frac{2a}{\left(1+\alpha\left(\frac{x}{r_1}\right)\right)^2}\right] \quad (4)$$

where, u is the downstream velocity, u_0 is the free flow velocity, α is the entrainment constant, a is the axial induction factor , x is a distance from the upstream turbine to downstream turbine following the wind direction, and r_1 is the downstream rotor radius that shown by equation (5) (Grady et al., 2005).

$$r_1 = r_r\sqrt{\frac{1-a}{1-2\,a}} \quad (5)$$

where a is the axial induction factor, and r_r is the rotor radius. And the entrainment constant α could be computed by:

$$\alpha = \frac{0.5}{\ln\left(\frac{z}{z_0}\right)} \quad (6)$$

where z_0 is the surface roughness, and z is the hub height of the wind turbine. In this selected region we faced with flat terrain and surface roughness can be considered as a constant number of z_0=0.3.

The axial induction factor can be calculated by using the turbine thrust coefficient CT, which is considered a constant of value 0.88 according this selected turbine across the whole wind speed range, by following relationship (Grady et al., 2005):

$$(1-2a) = \sqrt{1-c_T} \quad (7)$$

In a wind farm the turbine can be under many wakes, assuming to the kinetic energy deficit is equal to the sum of the energy deficits, the velocity of downstream turbine can be expressed by: (Patel et al., 2017).

$$u_i = u_0\left[1 - \sqrt{\sum_{k=1}^{N}\left(1-\frac{u_k}{u_0}\right)^2}\right] \quad (8)$$

3.4. Genetic Algorithm

GA algorithm is one of the meta-heuristic search algorithms proposed by John Holland which is based on the procedure of evolution in nature. The procedure of this algorithm contains three steps (1) choosing the population, (2) using operators (crossover, mutation, selection), and (3) evaluating the chromosomes (Liu et al., 2021).

Mutation and crossover are two operations in GA that create a new generation. The mutation operator makes new chromosomes by randomly changing the previous chromosomes, and the crossover operator combines the chromosomes of two parents to produce new offspring. Then according to the fitness value, the selection operator chooses the best of these parents and their offspring to become a new generation (Dhunny et al., 2020) . The algorithm continues to produce a new generation to find the best solution (final position) with the highest fitness value. The main parameters of GA are Population size, crossover rate, and mutation rate, which must be defined carefully because of their significant impact on the final solution (Khanali et al., 2018).

4. IMPLEMENTATION AND RESULT

4.1 Macro siting

After removing the unsuitable area from the study area, the suitability map should be provided for the rest of the study area. In the present case study, AHP criteria include wind speed, distance from the power line, the slope of the terrain, distance from roads, and distance from residents' areas. These criteria are used to form 5 × 5 pair-comparison matrixes and compared with each other, and the weighting factors were assigned to each data layer according to its relative impotence. These pairwise comparison matrixes were created by the average opinion of experts in economic and renewable energy (professors and researchers). Table 5 shows the final weight of the AHP criteria, and the CR value, which is lower than 0.1 for pairwise comparison.

Criteria	Weight [%]
Wind Speed (WS)	42.2
Distance from power lines (DP)	29.7
Distance from highways and roads (DR)	15.4
Distance from urban areas (DU)	7.8
Slope of terrain (ST)	4.9
CR=0.04	

Table 7. The relative importance of criteria.

All these data sources were introduced in ArcGIS and reclassified into ten categories according to their value and all five maps were converted to a 188m cell size raster. The weight provided by AHP incorporated in their related maps then these maps were combined to produce the Final Cell Value (FCV) and the final map (equation 9).

$$\text{FCV}= 42.2*\text{WS}+29.7*\text{DP}+15.4*\text{DR}+7.8*\text{DU}+4.9*\text{S} \quad (9)$$

The final map is a raster that each cell assigned to the appropriate weight based on the criteria and presents the location where the installation of wind farms is more suitable (figure 7).
According to the suitability map, one of the best suitable areas, which is located in the middle of the province (50°45'37"E, 35°57'48" N) with the area of 5089536 m^2, is chosen for wind farm construction (figure 7). In this region, according to the wind speed and wind direction data in the nearest synoptic station for the last five years at 3 h intervals, the average wind speed is 9 m/s, and the dominant wind direction is toward the south.

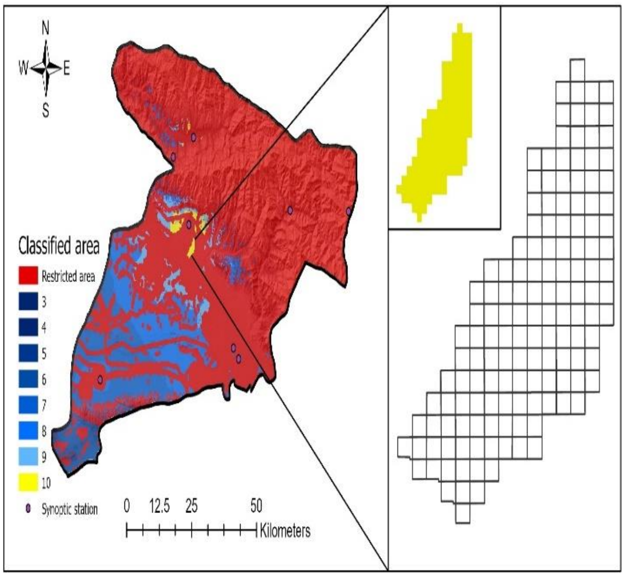

Figure 7. Suitability map and the selected area.

4.2 Micro siting

The selected construction area is divided into square, equal-sized cells, and each cell can contain only one wind turbine placed in the center of each cell (figure 7). The cells were indexed from 1 to 144, The width of the cells is $4 \times D = 188\text{m}$ (D is the diameter of selected turbines) to keep the minimum distance between turbines (Aggarwal et al., 2021). The two-dimensional cartesian coordinate system (x_i, y_i), is allocated to grid. To each cell on the grid there is a related binary variable ω_i for $i = 1, \ldots, N$

$$\omega_i = \begin{cases} 1, & \text{if turbin i exist at location i} \\ 0, & \text{if turbin i does not exist at location i} \end{cases}$$

and the variables are collected in the vector matrix. Every chromosomal string is an individual, which illustrates the layout of the given wind farm. The layout of the wind farm, including the location of the turbines, can be shown:

$$l = \begin{bmatrix} x_1 & x_2 & \cdots, x_i \\ y_1 & y_2 & \cdots, y_i \end{bmatrix}$$

where (x_i, y_i) is the location of ith wind turbine.
In this research, the binary string GA was used in MATLAB to find the optimal layout of the wind farm. After inserting data in the algorithm, the objective function should be defined as minimizing the cost and maximizing the annual energy production. For calculating the cost, the equation used in Mosetti et al. is applied in this study (Mosetti et al., 1994). The installation cost of the wind farm directly depends on the number of installed wind turbines:

$$\text{cost} = N\left(\frac{2}{3} + \frac{1}{3}e^{-0.00174N^2}\right) \quad (10)$$

where N is the number of turbines that are installed in the wind farm. The following objective function should be optimized:

$$\text{objective} = \frac{\text{cost} \downarrow}{P_{\text{total}} \uparrow} \; \frac{N\left(\frac{2}{3} + \frac{1}{3}e^{-0.00174N^2}\right)}{\sum_{i=1}^{i=N} p_i} \quad (11)$$

A random individual was created for the initial population, we set the population size to be 500 and the new generation was produced using crossover and mutation functions. This paper uses the single point crossover, and the crossover and mutation rate are considered 0.9 and 0.1, respectively. The wind farm layout evolved after 400 generations. Figure 8 shows the optimal wind farm layout.

Fitness value	Total power	Cost	Number of turbines
0.00241	8732.283 kw	21.0522	28

Table 8. Optimization results.

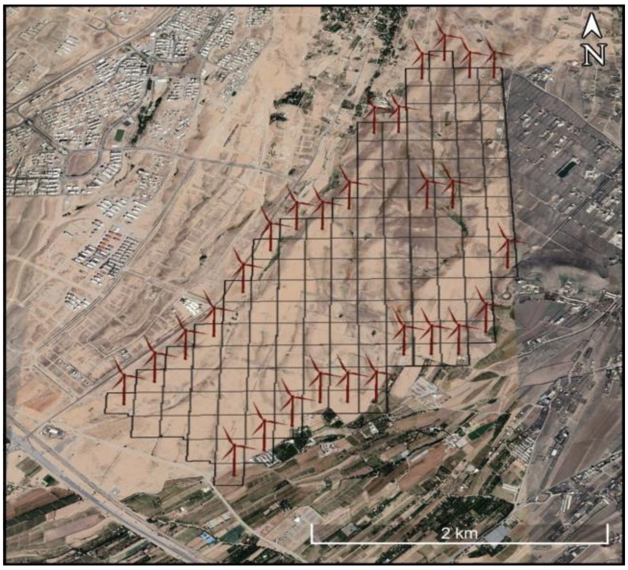

Figure 8. Final wind farm layout.

5. CONCLUSION

Iran needs access to great renewable energy recourses to move toward sustainable development. Alborz province is one of the country's most populated provinces, and electricity consumption is increasing rapidly due to the development of towns in this province. The purpose of this study is to present a model for constructing a wind farm in this province. Solving the site selection problem and providing a method to optimize the wind farm layout are the subjects that have been worked on separately in various research. However, one of the goals of this study is to provide a comprehensive approach to not only finding the best place for constructing a wind farm but also evaluating the potential of a suitable region considering the power output and cost. In this paper, after selecting one of the best suitable regions, the windfarm layout in that place was optimized, and according to the selected wind turbine, the wind power capacity of that selected area is 8732.283 KW. Without a doubt, the additional parameters could help achieve a more accurate solution, for example, considering complex terrain and several wind speeds with different wind directions in optimization.

REFERENCES

Aggarwal, S.K., Saini, L.M., Sood, V., 2021: Large Wind Farm Layout Optimization Using Nature Inspired Meta-Heuristic Algorithms. *IETE Journal of Research*, 1-18. 10.1080/03772063.2021.1905082.

Albraheem, L., Alabdulkarim, L., 2021: Geospatial Analysis of Solar Energy in Riyadh Using a GIS-AHP-Based Technique. *ISPRS International Journal of Geo-Information* 10, 291. doi.org/10.3390/ijgi10050291.

Asadi, M., Pourhossein, K., 2021: Wind farm site selection considering turbulence intensity. *Energy* 236, 121480. doi.org/10.1016/j.energy.2021.121480.

Ayodele, T.R., Ogunjuyigbe, A.S.O., Odigie, O., Munda, J.L., 2018: A multi-criteria GIS-based model for wind farm site selection using interval type-2 fuzzy analytic hierarchy process: The case study of Nigeria. *Applied Energy* 228, 1853-1869. doi.org/10.1016/j.apenergy.2018.07.051.

Bertolini, M., Braglia, M., Carmignani, G., 2006: Application of the AHP methodology in making a proposal for a public work contract: International Journal of Project Management 24, 422-430. doi.org/10.1016/j.ijproman.2006.01.005.

Bharti, A., Paritosh, K., Mandla, V.R., Chawade, A., Vivekanand, V., 2021: GIS Application for the Estimation of Bioenergy Potential from Agriculture Residues: An Overview. *Energies* 14, 898. doi.org/10.3390/en14040898.

Bowen, W.M., 1990: Subjective judgements and data envelopment analysis in site selection. *Computers, Environment and Urban Systems* 14, 133-144. doi.org/10.1016/0198-9715(90)90018-O.

Buchmayr, A., Verhofstadt, E., Van Ootegem, L., Thomassen, G., Taelman, S.E., Dewulf, J., 2022: Exploring the global and local social sustainability of wind energy technologies: An application of a social impact assessment framework. *Applied Energy* 312, 118808. doi.org/10.1016/j.apenergy.2022.118808.

Cunden, T.S.M., Doorga, J., Lollchund, M.R., Rughooputh, S.D.D.V., 2020: Multi-level constraints wind farms siting for a complex terrain in a tropical region using MCDM approach coupled with GIS. *Energy* 211, 118533. doi.org/10.1016/j.energy.2020.118533.

Dhunny, A., Timmons, D., Allam, Z., Lollchund, M., Cunden, T., 2020: An economic assessment of near-shore wind farm development using a weather research forecast-based genetic algorithm model. *Energy* 201, 117541. doi.org/10.1016/j.energy.2020.117541

Effat, H.A., El-Zeiny, A.M., 2022: Geospatial modeling for selection of optimum sites for hybrid solar-wind energy in Assiut Governorate, Egypt. *The Egyptian Journal of Remote Sensing and Space Science* 25, 627-637. doi.org/10.1016/j.ejrs.2022.03.005.

El-Shimy, M., 2010: Optimal site matching of wind turbine generator: Case study of the Gulf of Suez region in Egypt. *Renewable Energy* 35, 1870-1878. doi.org/10.1016/j.renene.2009.12.013.

Genç, M.S., Karipoğlu, F., Koca, K., Azgın, Ş.T., 2021: Suitable site selection for offshore wind farms in Turkey's seas: GIS-MCDM based approach. *Earth Science Informatics* 14, 1213-1225. doi.org/10.1007/s12145-021-00632-3

Gil-García, I.C., Ramos-Escudero, A., García-Cascales, M.S., Dagher, H., Molina-García, A., 2022: Fuzzy GIS-based MCDM solution for the optimal offshore wind site selection: The Gulf of Maine case. *Renewable Energy* 183, 130-147. doi.org/10.1016/j.renene.2021.10.058.

Grady, S., Hussaini, M., Abdullah, M.M., 2005: Placement of wind turbines using genetic algorithms. *Renewable energy* 30, 259-270. doi.org/10.1016/j.renene.2004.05.007

Höfer, T., Sunak, Y., Siddique, H., Madlener, R., 2016: Wind farm siting using a spatial Analytic Hierarchy Process approach: A case study of the Städteregion Aachen. *Applied Energy* 163, 222-243. doi.org/10.1016/j.apenergy.2015.10.138.

Khanali, M., Ahmadzadegan, S., Omid, M., Keyhani Nasab, F., Chau, K.W., 2018: Optimizing layout of wind farm turbines using genetic algorithms in Tehran province, Iran. *International Journal of Energy and Environmental Engineering* 9, 399-411. doi.org/10.1007/s40095-018-0280-x.

Lacal-Arántegui, R., 2019: Globalization in the wind energy industry: contribution and economic impact of European companies. *Renewable Energy* 134, 612-628. doi.org/10.1016/j.renene.2018.10.087.

Liu, Z., Fan, S., Wang, Y., Peng, J., 2021: Genetic-algorithm-based layout optimization of an offshore wind farm under real seabed terrain encountering an engineering cost model. *Energy Conversion and Management* 245, 114610. doi.org/10.1016/j.enconman.2021.114610.

Meng, F., Liang, X., Xiao, C., Wang, G., 2021: Geothermal resource potential assessment utilizing GIS - based multi criteria decision analysis method. *Geothermics* 89, 101969. doi.org/10.1016/j.geothermics.2020.101969.

Messaoudi, D., Settou, N., Negrou, B., Rahmouni, S., Settou, B., Mayou, I., 2019: Site selection methodology for the windpowered hydrogen refueling station based on AHP-GIS in Adrar, Algeria. *Energy Procedia* 162, 67-76. doi.org/10.1016/j.egypro.2019.04.008.

Moradi, S., Yousefi, H., Noorollahi, Y., Rosso, D., 2020: Multi-criteria decision support system for wind farm site selection and sensitivity analysis: Case study of Alborz Province, Iran. *Energy Strategy Reviews* 29, 100478. doi.org/10.1016/j.esr.2020.100478.

Mosetti, G., Poloni, C., Diviacco, B., 1994: Optimization of wind turbine positioning in large windfarms by means of a genetic algorithm. *Journal of Wind Engineering and Industrial Aerodynamics* 51, 105-116. doi.org/10.1016/0167-6105(94)90080-9.

Noorollahi, Y., Yousefi, H., Mohammadi, M., 2016: Multi-criteria decision support system for wind farm site selection using GIS. *Sustainable Energy Technologies and Assessments* 13, 38-50. doi.org/10.1016/j.seta.2015.11.007.

Patel, J., Savsani, V., Patel, V., Patel, R., 2017: Layout optimization of a wind farm to maximize the power output using enhanced teaching learning-based optimization technique. *Journal of Cleaner Production* 158, 81-94. doi.org/10.1016/j.jclepro.2017.04.132.

Perveen, R., Kishor, N., Mohanty, S.R., 2014: Off-shore wind farm development: Present status and challenges. *Renewable and Sustainable Energy Reviews* 29, 780-792. doi.org/10.1016/j.rser.2013.08.108.

Rahman, A., Aziz, T., Masood, N.-A., Deeba, S.R., 2021: A time of use tariff scheme for demand side management of residential energy consumers in Bangladesh. *Energy Reports* 7, 3189-3198. doi.org/10.1016/j.egyr.2021.05.042.

Rahman, A., Farrok, O., Haque, M.M., 2022: Environmental impact of renewable energy source based electrical power plants: Solar, wind, hydroelectric, biomass, geothermal, tidal, ocean, and osmotic. *Renewable and Sustainable Energy Reviews* 161, 112279. doi.org/10.1016/j.rser.2022.112279.

Saaty, T.L., 1990. How to make a decision: The analytic hierarchy process. *European Journal of Operational Research* 48, 9-26. doi.org/10.1016/0377-2217(90)90057-I.

Satkin, M., Noorollahi, Y., Abbaspour, M., Yousefi, H., 2014: Multi criteria site selection model for wind-compressed air energy storage power plants in Iran. *Renewable and Sustainable Energy Reviews* 32, 579-590. doi.org/10.1016/j.rser.2014.01.054.

Schöll, E.M., Nopp-Mayr, U., 2021: Impact of wind power plants on mammalian and avian wildlife species in shrub- and woodlands. *Biological Conservation* 256, 109037. doi.org/10.1016/j.biocon.2021.109037.

Shao, M., Han, Z., Sun, J., Xiao, C., Zhang, S., Zhao, Y., 2020: A review of multi-criteria decision-making applications for renewable energy site selection. *Renewable Energy* 157, 377-403. doi.org/10.1016/j.renene.2020.04.137.

Slocum, A.H., Gessel, D.J., 2022: Evolving from a hydrocarbon-based to a sustainable economy: Starting with a case study for Iran. *Renewable and Sustainable Energy Reviews* 154, 111750. doi.org/10.1016/j.rser.2021.111750.

Tercan, E., 2021: Land suitability assessment for wind farms through best-worst method and GIS in Balıkesir province of Turkey. *Sustainable Energy Technologies and Assessments* 47, 101491. doi.org/10.1016/j.seta.2021.101491.

Villacreses, G., Gaona, G., Martínez-Gómez, J., Jijón, D.J., 2017: Wind farms suitability location using geographical information system (GIS), based on multi-criteria decision making (MCDM) methods: The case of continental Ecuador. *Renewable Energy* 109, 275-286. doi.org/10.1016/j.renene.2017.03.041.

Villacreses, G., Martínez-Gómez, J., Jijón, D., Cordovez, M., 2022: Geolocation of photovoltaic farms using Geographic Information Systems (GIS) with Multiple-criteria decision-making (MCDM) methods: Case of the Ecuadorian energy regulation. *Energy Reports* 8, 3526-3548. doi.org/10.1016/j.egyr.2022.02.152.

Wu, Y., He, F., Zhou, J., Wu, C., Liu, F., Tao, Y., Xu, C., 2021: Optimal site selection for distributed wind power coupled hydrogen storage project using a geographical information system based multi-criteria decision-making approach: A case in China. *Journal of Cleaner Production* 299, 126905. doi.org/10.1016/j.jclepro.2021.126905.

Xu, Y., Li, Y., Zheng, L., Cui, L., Li, S., Li, W., Cai, Y., 2020: Site selection of wind farms using GIS and multi-criteria decision-making method in Wafangdian, China. *Energy* 207, 118222. doi.org/10.1016/j.energy.2020.118222.

Yousefi, H., Motlagh, S.G., Montazeri, M., 2022: Multi-Criteria Decision-Making System for Wind Farm Site-Selection Using Geographic Information System (GIS): Case Study of Semnan Province, Iran. *Sustainability* 14, 7640. doi.org/10.3390/su14137640.

Zahedi, R., Ghorbani, M., Daneshgar, S., Gitifar, S., Qezelbigloo, S., 2022: Potential measurement of Iran's western regional wind energy using GIS. *Journal of Cleaner Production* 330, 129883. doi.org/10.1016/j.jclepro.2021.129883.

Zhao, B., Wang, H., Huang, Z., Sun, Q., 2022: Location mapping for constructing biomass power plant using multi-criteria decision-making method. *Sustainable Energy Technologies and Assessments* 49, 101707. doi.org/10.1016/j.seta.2021.101707.